OPTIMIZING THE. USE OF BREAKER SWITCHED CAPACITORS IN CEB SYSTEM

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Science

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Abstract

Ceylon Electricity Board (CEB) as many other utilities uses breaker switched capacitor banks for voltage support and reactive power compensation in grid substations. At present it has a 320Mvar installed capacity and 70Mvar more to be come in next few years. The main intentions of the use of capacitor banks is to give voltage support at the substation level, reduction of losses in power transformers and transmission lines, and to release the capacity constraints in transformers and lines.

CEB uses power factor regulation for switching these capacitor banks. The general view of the system control center (SCC) who operates the network is that this concept does not allow economical utilization of capacitor banks and sometimes they need to manually switch on them overriding the auto controller and vise versa. Underutilizing an economical reactive power source is a factor to consider. Therefore, the objective of this research is to study the technical feasibility of connecting maximum available capacitor banks in each sub station and by doing so, to propose a better switching policy than the existing one.

The research was planned as a case study, selecting a typical grid sub station in CEB and then, the results are expected to be extrapolated to a general concept, to suit the whole CEB network. First, actual substation data was collected, logged and analyzed. The possibilities of connecting more capacitor banks, under such real time system characteristics were studied in a computer simulation model. PSCAD is the simulation software used for the network simulations. The impacts due to additional banks on the system conditions, technical constraints, non violation of general standards and economics were studied using the results from the simulations. The results were compared with actual data measurement by forcing the simulated conditions for the maximum utilization, in the real system.

The analysis revealed that the present switching concept does not fully fit for CEB network. The possibilities of further utilization of already installed capacitor banks, was identified. Instead of present switching criteria, reactive power based control and voltage based control schemes were evaluated. Although the present criterion has a comparatively high utilization factor, it also seems that banks are not utilized at mostly required periods. As per the observations, reactive power controlled capacitor bank switching criteria is more useful compared to loss reduction in the system. When comparing the voltage control based switching, the switching pattern is similar to the pattern with reactive power control based switching in the day time. -During night time it gets closure to the requirement that SCC actually needs. However, complex algorithms are necessary to coordinate the two control loops, AVR and capacitor bank controller when-using such voltage control schemes. When two independent controls try to control same parameter, it leads to an unnecessary switching or simply, hunting the tap changer and capacitor banks.

Finally, as the conclusion of the research, multi functional switching scheme based on voltage and reactive power was proposed for the switching policy of the capacitor banks in the CEB network.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

D.D.U. Dompege
22nd July, 2009

UOM Verified Signature

We endorse the declaration by the candidate.

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Acknowledgement

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May be I could not have made it without your valuable support.

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Chapter 1

1. Introduction

1.1 Background

The nature of all electrical loads connected to power system is such that they are inherently inductive which consume reactive power and therefore the system has to generate reactive energy. Although the reactive power does not produce any usable output, each network operator has to live with it. Therefore power utilities around the globe have to invest on required reactive energy which in turn does not give compensation. Not only the generators have to produce this ineffective energy, the same shall be transmitted to the end user as well. The ultimate result of these is to introduce losses, capacity constraints in transmission and distribution networks and voltage drops. That is why most of the power utilities around the world are trying to generate its reactive power requirements as close as possible to the load centres. In general, many utilities describe this as the concept of reactive power compensation in the technical vocabulary.

Apart from generating reactive power from the costly generators, compensation can be done with variety of sources. Using static var compensators, synchronous condensers, breaker switched capacitor banks are common among these. Breaker switched or fixed capacitor banks, especially those at distribution level are still most effective whereas the cost is concerned. They are comparatively economical and installation is also easy. Retrofitting and later additions according to match load characteristics are comparatively flexible.

The application of capacitor banks and its controlling philosophy is different from location to location. For an end consumer it is used as a power factor corrector that helps to reduce his demand and avoid penalties from the energy supplier. For a distribution company, the capacitors installed at intermediate locations on distribution line reduce line losses hence increases line capacities and improve the bus voltage. For a transmission company, the intention is not only to reduce loses or increase line capacities but also to give voltage support which is an inherent system problem under heavily loaded conditions and to further differ investment costs on improving lines and substation capacities. At generation buses, capacitor banks also can be used for voltage support though it is rare. Depending on the location and requirement, the controlling philosophy of the capacitor banks will differ. Generally, as mentioned earlier, the distribution capacitor banks are controlled for local requirements. In many cases the control consists of switches that are opened and closed in a seasonal basis or some other local requirement

Ceylon Electricity Board, also adopting to this general practice of using breaker switched capacitor banks, at present has an installed capacity of about 320Mvar of Breaker switched Capacitor (BSC) banks located at various substations in the system. BSCs' of further 70Mvar is to be added by year 2010 at different new locations. Almost all the capacitor banks in CEB network are connected to the 33kV load bus in the relevant grid except Pannipitiya in which capacitors are connected to the 33kV tertiary winding of the 220 / 132 / 33 kV inter bus transformer. In all locations, the control philosophy of the switching of the BSC units is based on the power factor regulation at 33kV transformer incoming feeder.

The capacitor banks installed at Grid sub station level in CEB are controlled according to the power factor regulation. This philosophy of switching the capacitor banks in grid substations does not either ease the distribution feeder capacity or reduce the feeder losses. If those were expected then the capacitors could have been closer to the loads. However, lagging Var injection or in other words leading Var consumption at 33kV bus level improves the voltage stability and releases the power transformers at the substation. If the utility expects latter two cases, the switching of the capacitor banks shall be based on reactive power or voltage. In case of voltage, the banks should be switched considering the voltage measurements at the point of interconnection. If release the capacity constraint or minimize losses are concerned, then the capacitors shall fully utilized to minimize drawing var from remote generation. If the utility controls them in indirect way like power factor, then it should check whether the requirements are best met with or the available resources are fully utilized [1].

When analyzing the load profile, the data shows that the system load has an early morning peak, a mid daytime peak and a night time peak. Power factor during morning and night peak gets improved since the rise of load during those periods is mainly lighting loads. The daytime load is mainly commercial and industrial therefore the power factor badly decreases. Voltage at day time mainly decreases due to reactive power and at night peak, due to IZ drop further to reactive power. Voltage improves in mid night till early morning but considerable reactive base load exists. Power factor improves after around 17.00hrs leaving capacitor banks gradually switching off. Frequent occasions of manual re-closing of banks shut off by the capacitor controllers are also observed and utilization sometimes drops to 50% even before the night peak starts.

CEB's switching criteria of those capacitor banks has not been evaluated in the past. The system has grown up and whether the present switching criteria is economical or not for CEB, is in question. CEB neither has performed such a study nor they have checked the possibilities of maximizing the use of their capacitor banks. It is worth to discuss several factors in this case. When controlled with power factor regulation, there are situations where some of the capacitor banks on the distribution system are kept unused, while having an acute problem of heavy reactive power requirement in transmission system. This happens mostly when power across the company's transmission system does not coincide with load conditions in locations where the capacitor banks are fixed. In some situations, the power factor may be within acceptable limits but the voltages are below the nominal or onload tap changer is forced on higher taps to take care of the voltage. The substation level capacitor bank can directly serve to give voltage support or var support, without depending on power factor regulation which is an indirect measure of voltage or var requirement.

Addition of reactive power at substation level has to be done without violating the system regulations. The voltage rise due to reactive power injection has to be considered. Such a voltages rise at the bus bar at which the capacitors are connected should not violate its' continuous maximum rating. The On-load tap changer (OLTC) current switching capacities have to be considered during negative var transferring conditions. Impacts on voltage distortion and harmonic resonance conditions have to be monitored and they should not beyond the specified limits.

1.2 Objectives

Taking all these into Consideration, the main objective of the research study is to look in to the possibilities of exploiting the maximum utilization of BSC banks already installed in the system without violating the permitted regulations and other technical limitations. In this regard following points will be studied in this study.

- To check the applicability of present switching criteria
- To check the possibility of connecting maximum capacitor banks installed without violating technical constraints

- To check the possibility of optimizing the present switching parameters, if present switching criteria is acceptable.
- To design and propose a suitable switching criteria for the capacitors by means of network simulation and practical implementation.

1.3 Scope of work

- Evaluation of extent of present utilization of capacitor banks by précised data collection using data loggers and using the daily data sheets by selecting a typical substation.
- Studying the technical constraints of,

    a. Voltage rise at 33kV bus bar due to addition of capacitor banks
    b. Effects of resonance when adding capacitor banks to bus bars with load harmonics
    c. Effects to voltage distortion caused by load harmonics, when adding more capacitor banks
    d. Capability of On Load Tap Changer to handle switching current during back feeding the excess leading reactive power to the system through power transformers

  by network modelling and simulating under the relevant operating conditions.

- Considering above technical constraints, identify the possibilities of maximum utilization of the capacitor banks by maintaining them in switched "ON" condition as much as possible during the periods when transmission system needs reactive power.

Chapter 2

2. Capacitor Banks in Substations

2.1 Shunt Capacitors

Use of capacitor banks in utility substations as a source of reactive power is not new to electricity transmission and distribution. They are comparatively inexpensive, easy and quick to install, and can be deployed at any location. Therefore, this is one of the most economical way of generating the reactive power requirement and maintaining the voltage stability in power systems in comparison to the other similar devices such as static var compensators, STATCOM devices etc.

Capacitor Banks consist of individual capacitor units where such a unit is a combination of shunt or series set of capacitor elements. Depending on the bank size, those units are again connected in series or parallel to give the required size. In medium and high voltage levels, sizing of the capacitors in parallel combinations in banks generally has to consider the discharge energy through a shorted parallel capacitor in the same group.

These capacitors banks are fixed or switched type according to a local requirement. The switched type capacitor banks give a poor regulation due to step wise connections. Typical applications of capacitor banks at different locations are shown in figure 1.1

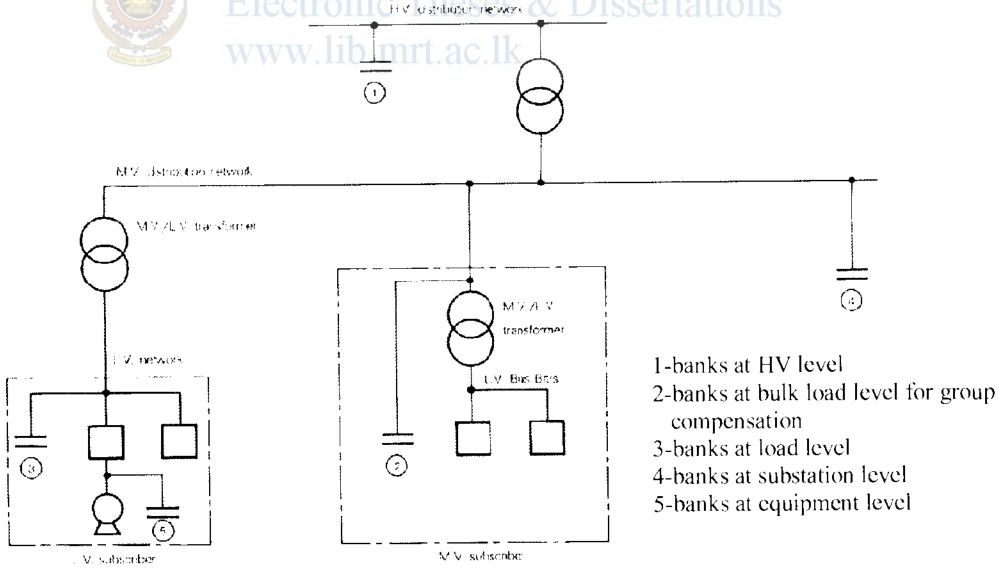


Figure 2.1 : Typical arrangement of Capacitor banks in a utility systems

2.2 Different types of Capacitor banks

Different types of capacitor banks are available in the present market. Metal enclosed type, pad mounted type, stack-rack banks and pole tip mounted types are the most common type in utility applications. Metal enclosed type banks specifically made for indoor installations. Pad mounted capacitor banks are also enclosed in a metal enclosure and commonly used for areas where accessible to public.

Normally, metal enclosed and pad mounted units come with factory assembled and tested hence the installation is very easy. Those banks significantly reduce unnecessary human interference such as trespassing and tampering. They do not need a fence around it. However their initial cost is high compared to other types and only available up to a certain voltage level.

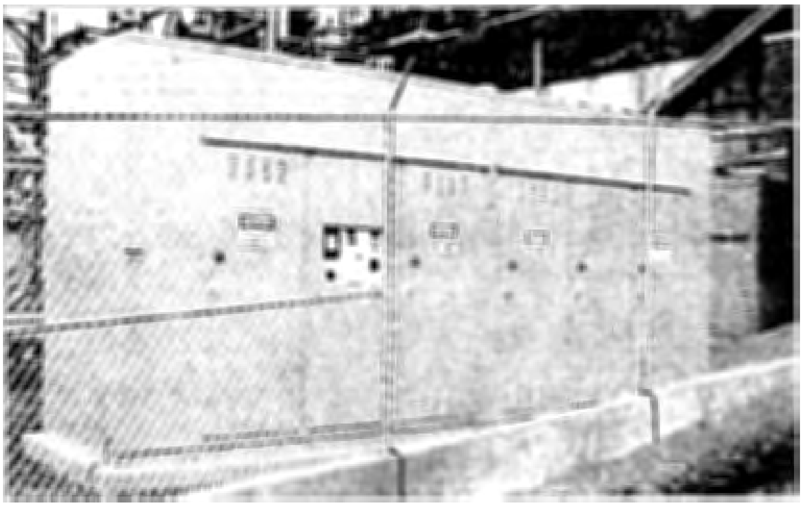


***Figure 2.2**: Typical pad mounted Capacitor bank*

Stack rack capacitor banks are commonly used in the utility sub stations. The initial cost of these is comparatively low and all components are visible. The components are easily replaceable and also easily expandable.

***Figure 2.3**: Typical stacked rack Capacitor bank*

The pole tip mounted banks are commonly used in distribution networks for improving the voltage profile in distribution lines. Those are available as smaller banks and eliminate the need for space. The maintenance and component replacement is little difficult.

Figure 2.4: *Typical pole tip mounted Capacitor bank*

2.3 Controlling philosophy

The switching of the breaker switched capacitor banks in utility substations depends on the local requirements of each utility. Basic need for such a control is to regulate the bus voltage, reduce the losses in lines and transformers and to avoid system constraints. Depending on those, the controlling parameter may be different, and may be one of such as voltage, Var, time, temperature or power factor. Some of these paramcters are directly represent the system parameters but some, for example power factor can be used as an indirect measurement for var, losses etc,.

2.3.1. Temperature control

This is not a true indicator of the system status and an indirect measure only. The control effectiveness depends on how well the load characteristics are known. Not useful in cases where those characteristics change often. Tempcrature control does not require any current sensors.

2.3.2. Time control

Some what better parameter for controlling and has to be based on load characteristics. Ever changing characteristics of the system load profiles does not allow the optimal controlling when time based control is used. Time control does not require any current sensors. Both time and temperature controlling need only simple and inexpensive controllers.

2.3.3. Current control

Current control is not an efficient control because it responds to total line current, and assumptions must be made about the load power factor. Current controls require current sensors.

2.3.4. Power factor control

The power factor is an indirect measure of the var load or the line or transformer losses of the system and always depends on the real power at the time of measurement. For same power factor, the actual amount of var load depends or changes according to the real power. These measurements require both current and voltage sensors. Generally, power factor regulation or control is advisable for bulk consumer loads, to avoid low load power factors which are penalized by the utility companies. Power factor improvement by capacitor banks in the substation does not reduce the distribution line loses and neither eliminates distribution line constraints. It will release the transformer capacities, reduces transmission line losses and improve the voltage profile. However power factor is an indirect measure for all these. Therefore, power factor controlled capacitor banks may not be fully utilized in most of the time unless the setting parameters are carefully assessed.

We have noticed occasions where the capacitor banks kept unconnected due to power factor being within limits while the loads consume reactive power than minimum switchable steps. Specially, during low voltage profiles, since the power factor does not consider bus voltage, the capacitors may be kept unconnected if power factor is within the limits. This means that as a result of the switched capacitors they will reduce transmission line losses and improves the bus voltage, but power factor is not a measure of the need for the above. So, for a utility substation, power factor correction is not the best control criteria for switching.

The above will be explained using system data in a later chapter.

2.3.5. Var control

Var control is the natural means to control capacitors because the latter adds a fixed amount of leading Var to the system regardless of other conditions, and loss reduction depends only on reactive current. Since reactive current at any point along a feeder is affected by downstream capacitor banks, this kind of control is susceptible to interaction with downstream banks. In a system like CEB, there are no switchable capacitor banks along the distribution feeder so that this problem will not arise. How ever, in multiple capacitor feeders, the furthest downstream banks should go on-line first and off-line last. Var controls require current sensors and typically costly.

2.3.6. Voltage control

Voltage control is used to regulate voltage profiles on the bus on which the capacitors are connected to. However, while doing this it may not consider the reduction of system losses since lagging or leading low power factors always increase the currents through its components. Voltage control requires no current sensors.

Considering above parameters for switching the capacitor banks, we can define two concepts of control philosophies. First is single variable switching that considers only one measuring parameter. Second concept is multi variable and Boolean switching. In the latter case multiple parameters are measured and the decision for switching is done depending on the optimal situation considering both parameters. The fact we have to consider is the cost of the controllers.

2.4 CEB's Present Configuration

Ceylon Electricity Board has installed number of breaker switched capacitor banks in various Grid substations in the system. All of such capacitor banks are installed at the 33kV level and there are no capacitor banks at the transmission level. The reason for this is due to lower costs at low voltage levels than at higher voltage levels. The selection of locations has been done considering the system planning studies done by CEB and considering the voltage, MW and Mvar profiles at different locations in the system.

Generally, the banks are equipped with the inrush limiting reactors as well as detuning reactors in most cases. However there are banks without those reactors as well. The banks with detuning reactor are called as the filter banks because they are meant for eliminating the switching inrush, reduce resonance effects and to filter 5th harmonics in the system loads. The other banks are sometimes having inrush limiting reactors and sometimes there are no such rectors.

In the present system, the typical step size of each bank is 5Mvar. This may slightly changes with the presence of the reactor. The Total capacity is changing from 10Mvar to 30Mvar. In Pannipitiya, the bank size is 100 Mvar and therefore 4 x 5 and 4 x 20 banks are available. In Athurugiriya 2 x 10 Mvar banks are available. The ***Appendix 1(a)*** gives the details of capacitor banks available in the CEB system.

CEB's general concept in fixing the capacitor banks is such that it uses symmetrical banks for each bus section in the 33kV bus sections. Each bus section has an individual controller to switch the particular bank. This arrangement has been changed in some of the substations later due to new additions of transformers. ***Appendix 1(b)*** shows the arrangement of capacitor banks in Panaduara grid substation. ***Appendix 1(c)*** shows the CEB transmission network with the connected capacitor banks. The figure 2.5 shows one 5Mvar stacked rack type capacitor bank at Panadura GSS.

Figure 2.5: *5Mvar stacked rack type capacitor bank – Panadura Grid sub station*

For switching the capacitor banks, each bus section has an individual controller. This works as an independent controller when the bus section is open and if the bus section is in ON position, the set of controllers are arranged to work one as a master and the other as a slave. In independent operation, the controller switches the banks assigned to it, typically two. First is always the filter bank and compensator bank later. In the master slave mode, the master will control all the banks if the communication between the controllers is established. If not each controller becomes independent. In master slave mode, the banks assigned to slave are identified by the master and those units are switched once the master's own banks are switched ON.

The switching criteria used in CEB are the power factor regulation. The controller evaluates the power factor of the 33kV transformer incomer feeder using voltage and current analogue signals and switches the first filter bank when the power factor is below a certain specified limit. Generally, this limit is 0.9800. The next banks are switched on as per the same condition considering the calculated power factor. Since there are two types of controllers in CEB system switching off schemes is different. One type of controller switches off the banks when the power factor becomes leading 0.98. The other type does not use power factor for switching off. It calculates the reactive power calculated with power factor and the real power at the time of measurement and reactive power with the set power factor and real power at the time of measurement. If the ((1+hysterisis)* difference) is greater than minimum step of the banks, then a bank is switched off. Therefore in this kind of controllers, the switching off is depends on a reactive power limit.

During all this period, the automatic voltage regulator of the transformer stays reacting independently to adjust the LV side bus voltage. There is no coordination between the cap bank controller and voltage regulator.

Chapter 3

3. Problems Due to Capacitor banks in Substations

Although the capacitor banks are used by many of the utilities in their substations for local requirements such as var control, power factor control, or voltage control, the presence of same creates considerable operational difficulties in the network. However those difficulties are not reasons for any utility to refrain from using them because their application gives more benefits than those difficulties. Although, a complete removal of them from the network is difficult, there are ways to minimize them. The cost involved in minimizing them can be justified with the savings.

Switching transients (voltage & current), harmonic resonance and increasing voltage distortion at the point they are connected, are the most important factors to be discussed [2]. Switching of the capacitor banks into and out of the system creates heavy switching transients. The inherent quality of energy storing in the capacitors and inductors is the main reason causing the oscillation in both voltage and currents in the system.

The other problems are created by the harmonics in the system loads. The harmonic currents containing multiple frequency current components force the RLC networks to resonate at certain frequencies creating unusual high currents through its components.

Voltage distortion is an impact going together with the resonance. The high currents drawn at resonance create heavily distorted voltage at all levels in the system. Even for very insignificant harmonic current levels, the resulting distortion in the system is very high. Distorted system voltages create severe mal functionalities causing adverse effects and therefore, are not acceptable by the standards and regulations.

3.1 Switching inrush

Switching of capacitors in power networks that consists of capacitive, inductive and resistive components creates oscillator transients in the system. In such cases, the redistribution of energy associated with circuit components take place to meet new system conditions. Since such redistribution of energy in inductors and capacitors does not happen instantaneously, this will lead to oscillatory transients until the situation damps to the steady condition.

Capacitors switching transients are experienced during single bank switching (energization inrush), back to back switching and during switching off. The transients are also caused during the faults in other feeders while capacitors are in service in the substations (out rush transients).

The presence of such transients were studied during the simulations of the models developed using PSCAD. With the theoretical calculation for single bank switching condition as given below, acceptance of developed model for such a transient study can be justified.

The figure 3.1 below shows a simplified model of a single bank capacitor switching where it represents an equivalent voltage source and reactance. By considering the typical circuit notations, the above simplified circuit was analyzed as follows [3].

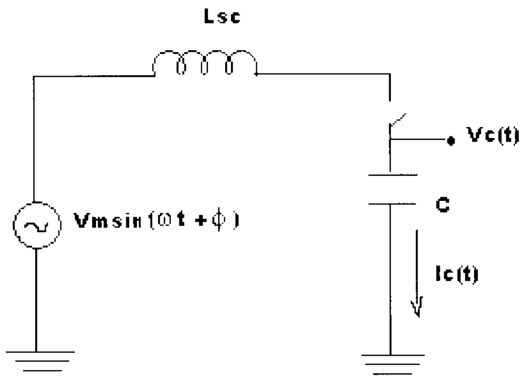


Figure: 3.1 Model for a single bank switching

Assuming that Xsc is much less than Xc, the steady state voltage across C can be approximated to $V_m \sin(\omega t+\Phi)$. But capacitor voltage can not be changed instantaneously therefore there must be a transient oscillation term to adjust the initial condition voltage across C. This voltage across C is given as

$$V_c(t) = V_m \operatorname{Sin}(\omega t+\Phi) - (V_m \operatorname{Sin}\Phi) \operatorname{Cos} \omega_o t$$

The associated current will be

$$I_c(t) = \omega C V_m \operatorname{Cos}(\omega t+\Phi) + (V_m \operatorname{Sin}\Phi)\sqrt{(C/L_{sc})} \operatorname{Sin} \omega_o t \quad \text{where } 1/\sqrt{(L_{sc}C)} = \omega_o$$

It can be shown that the maximum value of inrush current for switching at voltage maximum can be approximated to

$$I_{rated} (X_c/X_{sc})^{\wedge 0.5}$$

Where I_{rated} is the rated rms current of capacitor, X_{sc} is the short circuit reactance at the point of application of capacitor

With these approximations, for the selected substation having,

- Xsc = 5.1ohm (equivalent source impedance)
- Inrush reactor of 0.003H (≈ 0.9425Ω)
- Two transformers in parallel (≈.05pu)
- Single capacitor bank of 14. 6μF (≈ 218.02Ω),

the per unit representation will calculates the maximum rms switching current at point of maximum voltage can be high as eight times.

The figure 3.2 and 3.3 shows the simulation results for same conditions with no load connected and gives same results as calculations.

The sub station selected for the case study was modelled with PSCAD gives the following transient results for current and voltages for single bank switching. This was simulated under no load conditions and for breaker closing at a voltage peak point. The peak switching currents peak steady current ratio is around 10.

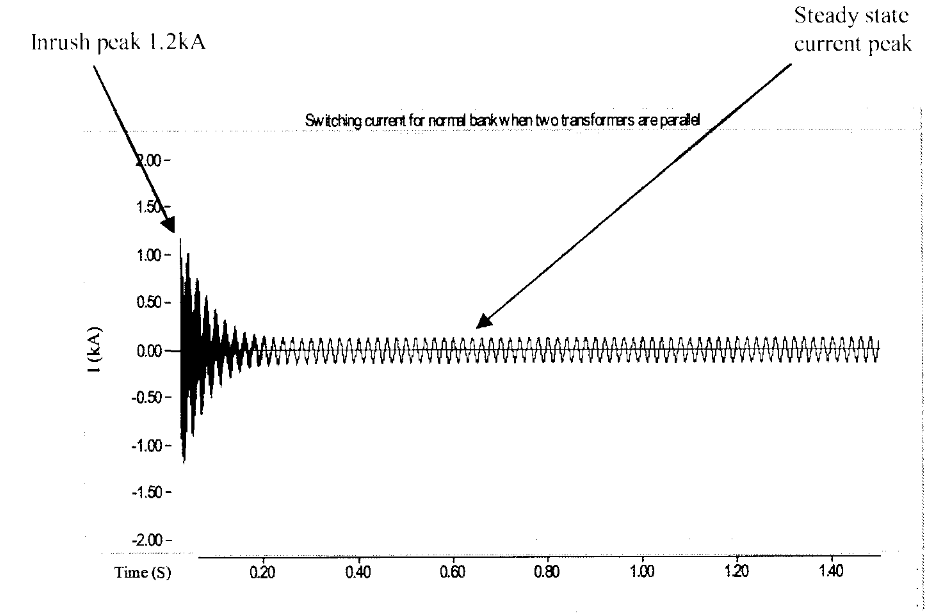


Figure: 3.2 Inrush current in normal bank switching - Panadura GSS Simulation results

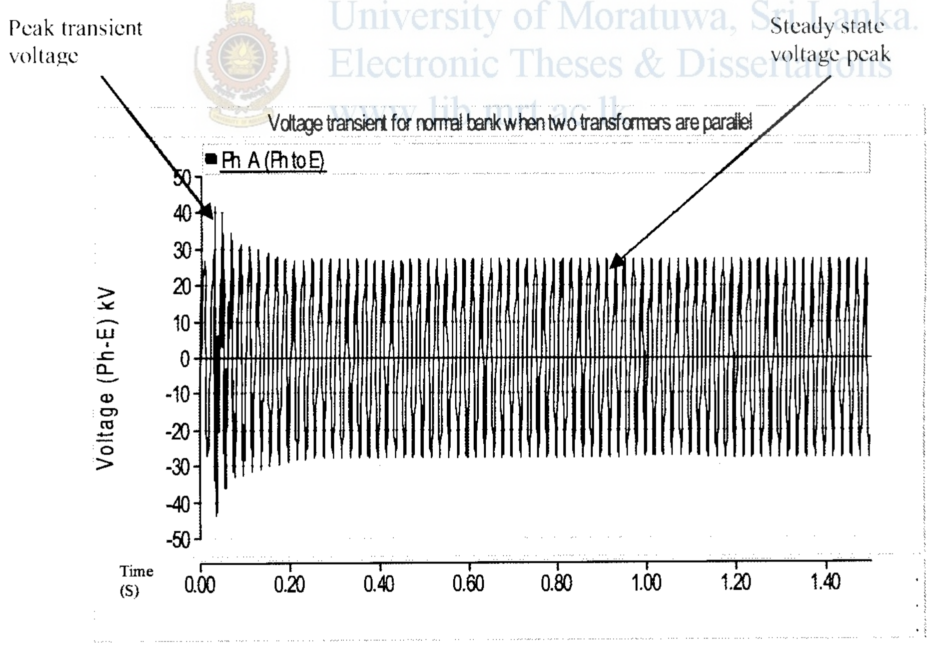


Figure: 3.3 Voltage transient -Normal bank switching - Panadura GSS Simulation results

The figure 3.3 shows the voltage transient during the same single bank switching instance and we can see that it goes about to two times the steady state voltage peak.

In general, the degree of the transient may rise even up to 2.0p.u in voltage and 10p.u. in the current [4]. The frequencies of these transients are in the order of 200 to 800Hz. The extent of the transient depends on the fault level of the location of the capacitor, system impedance, capacitance of the capacitor etc. These conditions are clearly visible in the selected substation.

Interestingly, the switching of the filter bank with a comparatively large reactor reduces these impacts. The figures 3.4 & 3.5 show the switching transients of filter bank switching.

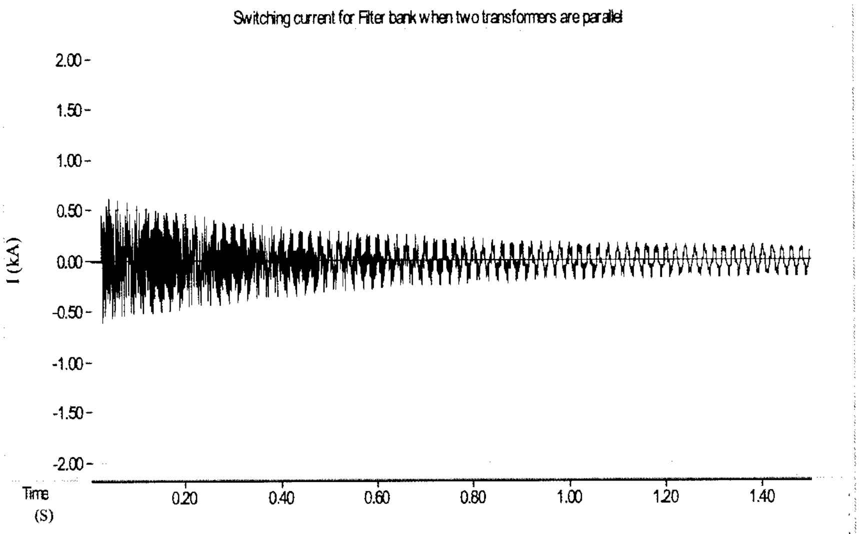


Figure: 3.4 *Inrush current in filter bank switching - Panadura GSS -Simulation results*

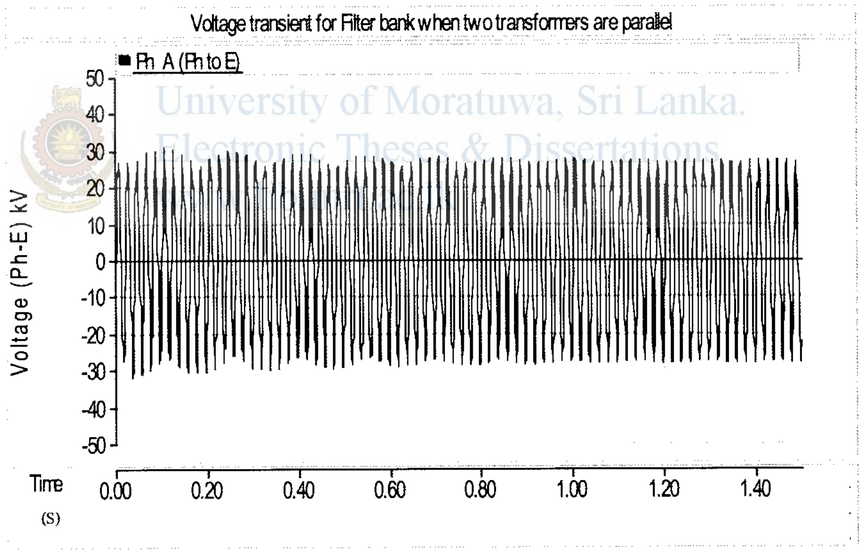


Figure: 3.5 *Voltage transient in filter bank switching - Panadura GSS -Simulation results*

The above figures indicate that the rise in voltage and current are considerably reduced due to the large inductor. This again raises a question to think about the suitability of the inrush reactor in the normal bank. However CEB has a practice to first switch the filter banks so that the impacts are less.

Back to back switching is the incident where a capacitor bank is energized with already energized capacitor bank. The above mentioned problem of high valued high frequency inrush current and over voltages is made more severe by the presence of already energized parallel banks. The similar conditions are modelled and simulated in the PSCAD model and results are shown in figures 3.6 and 3.7

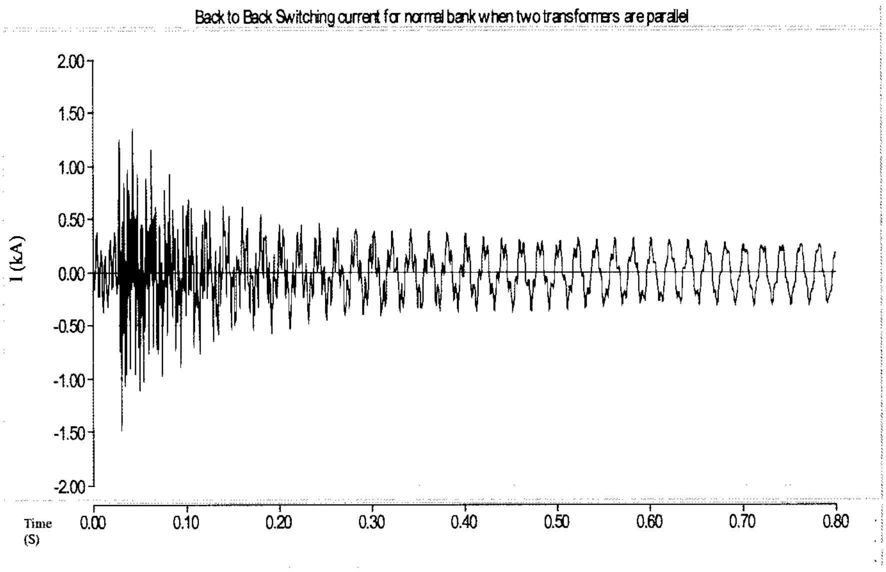


Figure: 3.6 *Inrush current in back to back switching - Panadura GSS -Simulation results*

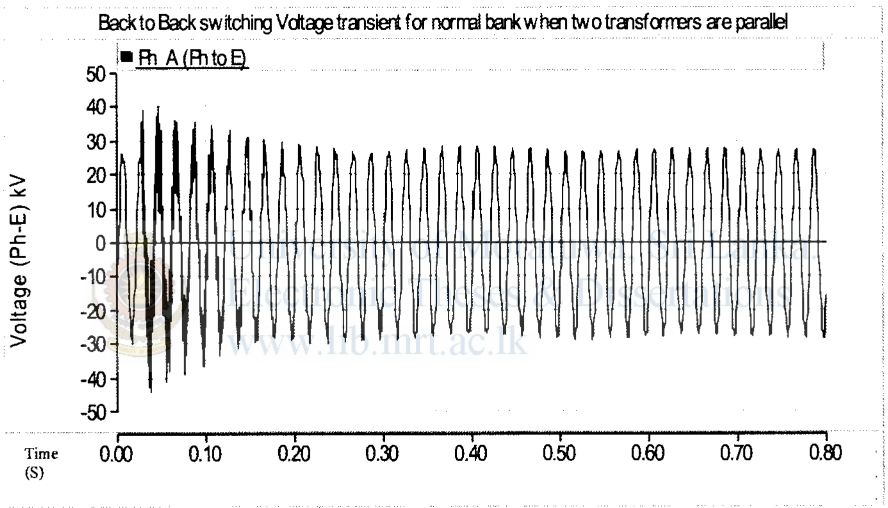


Figure: 3.7 *Voltage transients in back to back switching - Panadura GSS -Simulation results*

All these transients with high amplitudes and frequencies adversely affect the life of the breakers and capacitors. The short time rating of breaker as well as the capacitor must be sufficient to withstand this high frequency inrush current which may last for several a.c. cycle. High frequency current flow in capacitor causes considerable thermal overloading in the capacitors. Also, an examination of the voltage equation will show that, in the extreme case of voltage maximum switching, the instantaneous voltage of the capacitor may reach a maximum of 2xVm in the first few a.c cycles. This will lead to severe strain on the capacitor dielectric leading to a loss of life of the capacitor.

The switching transients also can interfere in the others parts of the network and may cause insulation damages, equipment damages, mal tripping of protection relays, metering errors, tripping of equipment etc.

The switching off transients, specially the voltages across the breaker tips also harmful to the breakers and capacitors. The PSCAD model was run to see theses effects as well and the figure 3.8 indicates how the voltage between breaker tips behaves during the capacitor switching off.

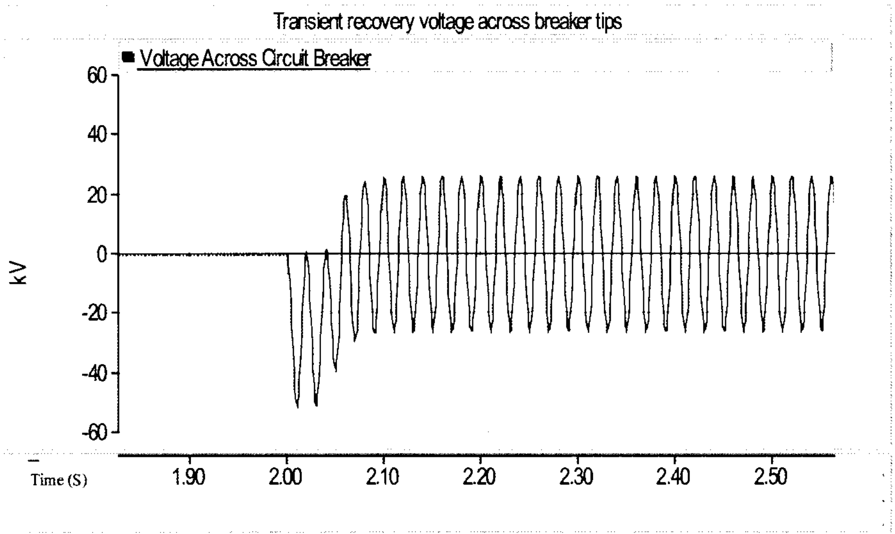


Figure: 3.8 *Voltage transients across CB during bank opening - Panadura GSS -Simulation results*

High frequency transients occur during the switching causes problems for circuit breakers. Specially, SF6 circuit breakers have considerable impact due to this. Then, during capacitive switching, high voltage possible up to 2.0p.u may appear between the pole tips of the circuit breaker. This may cause restrike if the breaker cannot bare such a high transient recovery voltage.

All these effects in transients suggest that the regular or frequent switching of capacitor banks is a problem to the network. In CEB system, in some of the banks, inrush limiting reactors are fixed but in some cases it is not available. Therefore, it is better if the network can be operated with minimum switching operations of the capacitor banks.

3.2 Harmonic resonance

Presence of non-linear load that takes non-sinusoidal current from a sinusoidal supply voltage creates multiple frequency current components in the system loads. Hence, the power network currents can contain harmonics if there are nonlinear loads. Loads like saturated transformers and machines, welding units, arc furnaces, rectifier and inverter units, battery charging equipment, thyristor controlled power converters and motor control equipment, static VAR compensators etc. are nonlinear and introduce harmonic currents into the distribution network and elsewhere.

These harmonic currents flowing in the line impedance produces harmonic voltages along with the fundamental frequency voltage at all points in the system. The effects due to tooth ripple in generation & machines, variation in air gap reluctance in a synchronous machine, non-sinusoidal flux distribution in a generator, magnetizing inrush of transformers etc. also create harmonic voltages in the system [5] [6].

Irrespective to the reasons for them to be present, when they are close or equal to the order of the resonant frequency of the network, then large harmonic currents may be circulated between the supply and the capacitor equipment. These currents as same as switching transients will do the same adverse effects to the equipment. The figure 3.9 shows a typical frequency scan plot obtained by the PSCAD model run for two different cap bank transformer configurations in Panadura substation.

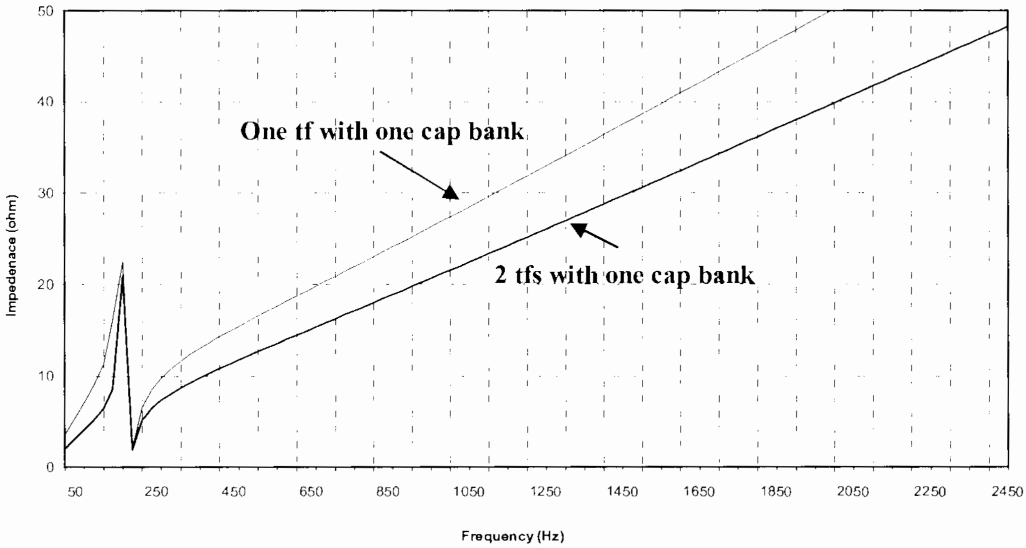


Figure: 3.9 *Frequency scan obtained from PSCAD model for panadura GSS*

The figure clearly shows two distinct frequencies where one shows very high impedance and the other like short circuit. Most system loads have harmonics closer to those frequencies.

3.3 Voltage distortion

The other severe problem due to these harmonics is the voltage distortion at the point where the capacitors are connected. As in figure 3.9 at the frequencies at which high impedances are formed, very smaller harmonic current can introduce a high harmonic voltage. The result is such that it distorts the system voltage at the point of capacitor connection.

Voltage distortion beyond critical limits will create un necessary mal funtions in the system. Where the capacitors are concerned, the high voltage harmonics over stress the insulation of capacitors and may cause even blowing them. To avoid such occurrences when installing capacitor banks in sub stations, the utility has to invest on the detuning reactors as well. The selection of those reactors should be done following a study of the real system.

The figure 3.10 shows an example for measured distortion levels at Panadura GSS for station maximum load with all banks are in ON position, under worst harmonic level content of the substation (For around 16% THD). The initial high distortion is due to voltage source time constant in the simulation and no need to consider.

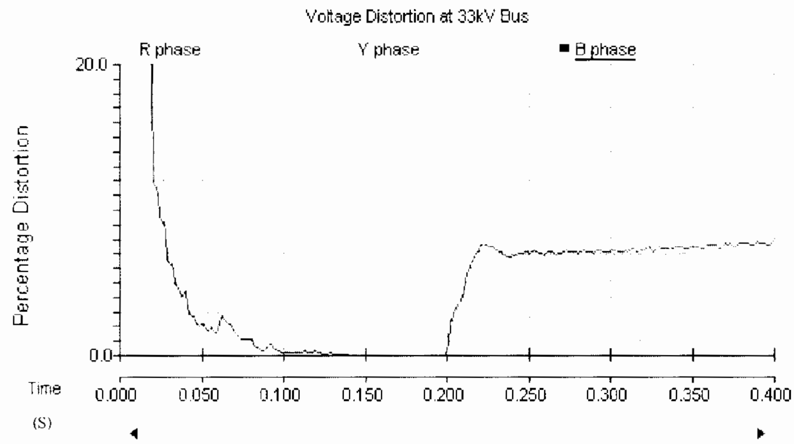


Figure: 3.10 *Voltage distortion at 16% I_{THD} at maximum average load and with all banks in ON position*

Chapter 4

4. Case Study for Panaduara Substation

A detailed study on the real system behaviour is an important necessity, not only in deciding a policy to switch the capacitor banks in a system but also to evaluate and existing such criteria. However, studying the total system is practically impossible in a live system. There are lots of operational difficulties for precise data collection and measurements in an operating system. How ever, a case study is a sufficient and satisfactory solution for a research like this. Such a sample study has to be selected to represent the total system as a whole. On the other hand, the duration during which the data collection and measurements is done, shall cover a substantial duration to represent the actual system variations. The general practice of such a study is to have one week duration.

Considering the data available in the system control centre of CEB, and taking the fact of locating amidst balanced domestic and industrial load area, Panadura grid substation was selected as a pilot station and the research was based on the findings for the selected sub station. Factors like convenience in fixing equipment, flexibilities in supervision etc, made the selection further easy. The load curves both real and reactive, were compared with the system behaviour and found satisfactorily matching and representing the system as a whole.

4.1 Substation details

Sub station capacity	– 2 x 31.5 transformers
Incoming feeders	– Connected to Pannipitiya Matugama lines as a T connection / Double circuit connection
No of feeders	– 6
No of capacitor banks	– 4 x 5 Mvar
Maximum average night peak	– 46MW +27Mvar
Minimum average load	– 19MW +12Mvar

4.2 Measurements & Collection of sub station data

Two on line data loggers were used for recording data, one at 33kV voltage level and other at 132kV level. Following inputs were connected and recorded, firstly for 8 days cycle without connecting the capacitor banks. The recorded data is as per the format given in ***Appendix 2(a)***.

33kV side measurements
- MW and Mvar
- 33kV bus voltage
- Power factor at 33kV incomer –Transformer 1
- Tap position of on load tap changer – transformer 1
- Load side harmonics

132 kV side measurements
- MW & Mvar
- Power Factor at 132kV bus bar
- 132kV bus voltage

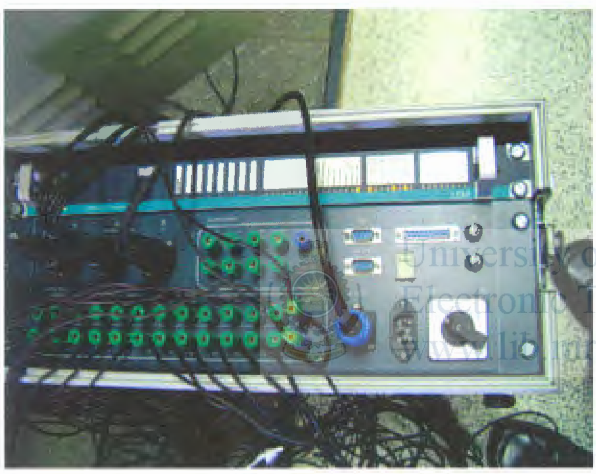
Measured data was fed and simulated to a model of the substation developed with PSCAD which is the simulation software used for the network simulations. Following the results of these simulations, the same measurements were done with all four capacitor banks forcibly connected to the system.

4.3 Measuring devices and data loggers

The following standard data logging equipment with their sensing equipment were used in measuring and recording the data.

- LEM Qwave Primium - power quality Analizer
- Ellite 4 – Pholyphase power meter

Figure 4.1 and 4.2 shows the equipment and their sensing devices used for the data logging and recording.



4.1 (a) Ben analyzer connected for 33kV measurements

4.1 (b) Analyzer connected for 132kV measurements

4.1 (c) Sensing equipment

Figure: 4.1 *Data recording equipment*

Figure: 4.2 Sensing equipment (Contd)

4.4 Behaviour of the power factor in the system

The figures 4.3(a) and 4.3(b) show the pattern of the power factor in the substation load. It shows a regular daily pattern with two peaks. One peak can be observed around 6.00hrs in the morning, during the morning load peak. The second peak is during the night peak time.

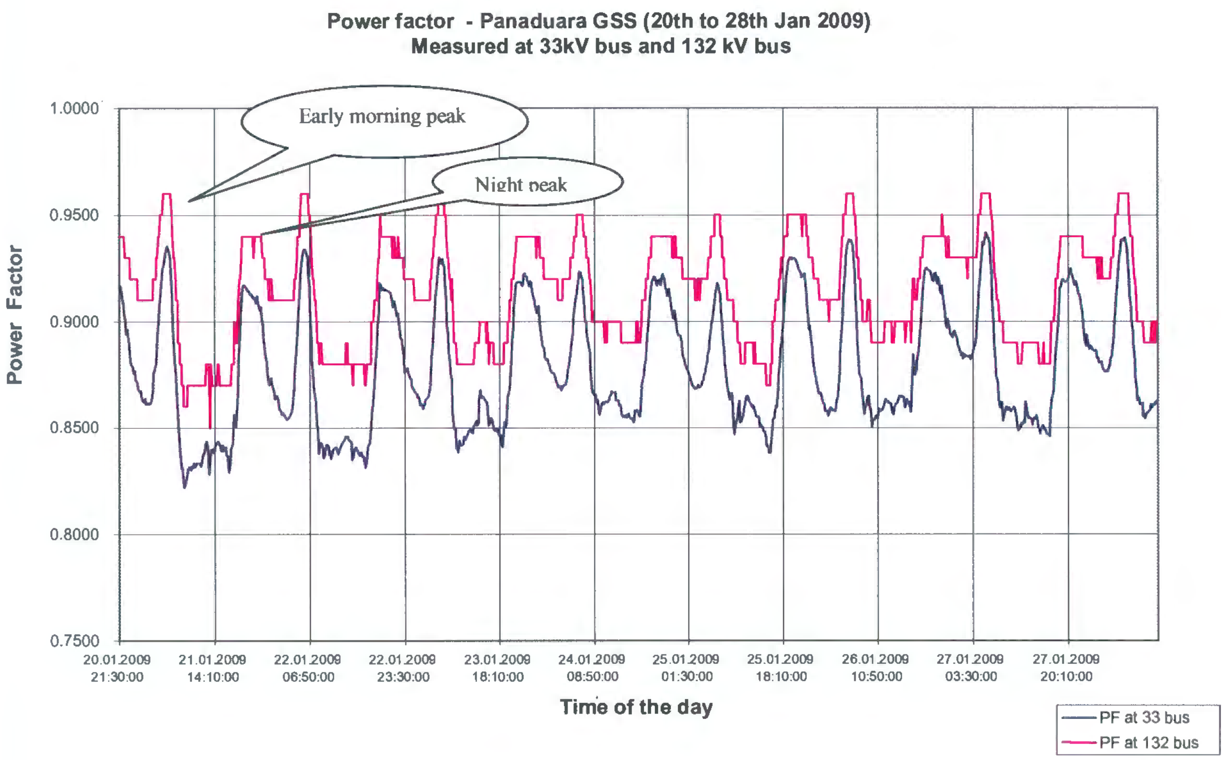


Figure: 4.3(a) Pattern of the power factor measured at 33kv & 132kV levels over total measurement period

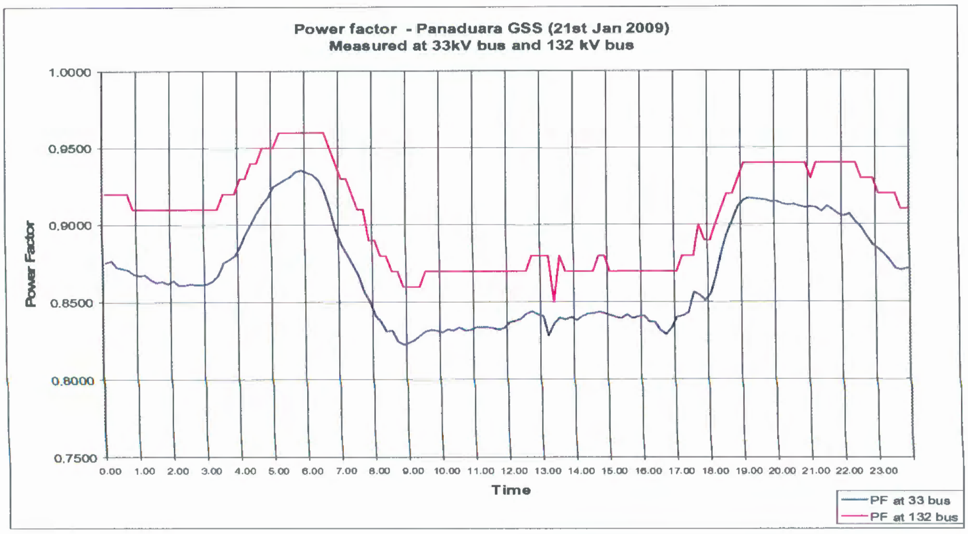


Figure: 4.3(b) Pattern of the power factor measured at 33kv & 132kV levels on 21st January 2009

The power factor improves during these two time slots because the load rises are mainly due to lighting loads. This can be further clarified by observing the real and reactive power consumptions. Obviously, during these periods, there must be a voltage drop due to rise in loads. The figures 4.4(a) and 4.4(b) shows this clearly. We cannot see such a drop in 33kV voltage level because of the AVR which regulates the secondary side voltage.

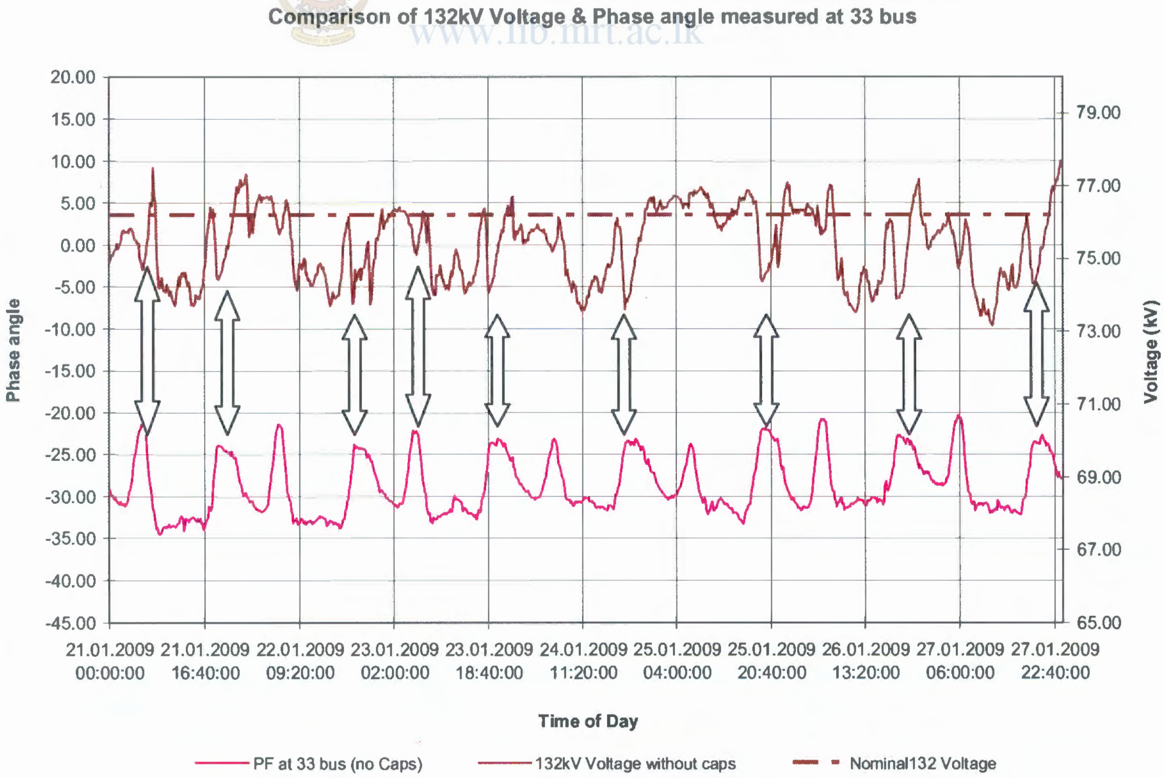


Figure: 4.4(a) Comparison of 132kV voltage and power factor over total measurement period

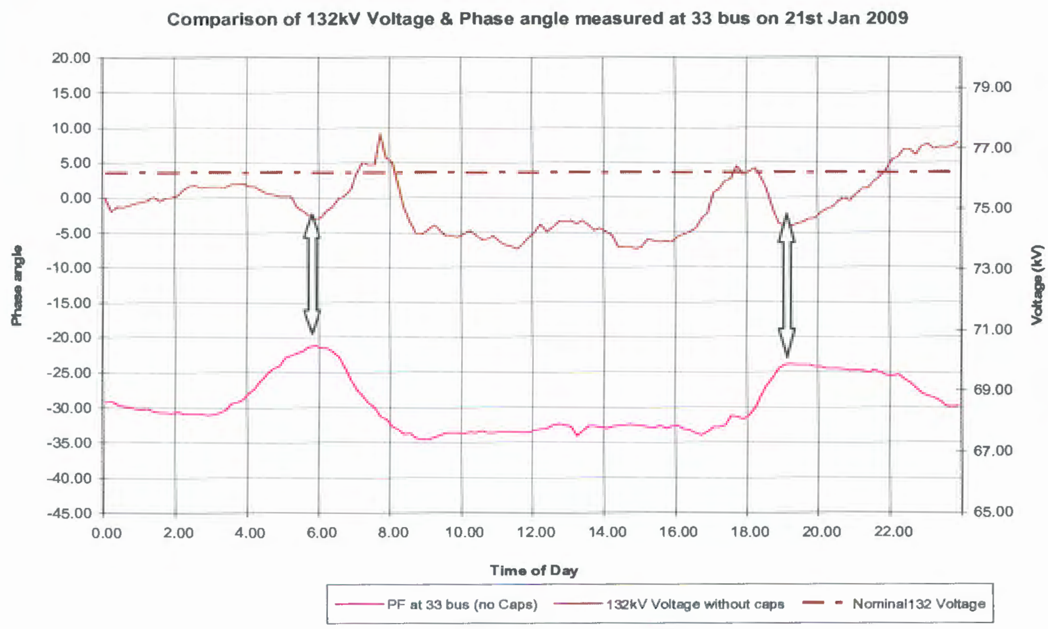


Figure: 4.4(b) *Comparison of 132kV voltage and power factor on 21st January 2009*

As the figures 4.4(a) & 4.4(b) suggest, the voltage drops during day time is mainly due to heavy reactive load and due to lighting load during night and morning. For a switching criteria based on power factor, contradictorily power factor goes high during night and morning peaks causing tendency to switch off the capacitors but bus voltage goes down. Due to this, we may deliberately ignore a possibility of improving bus voltage due to gradual disconnecting capacitor banks during night peak or delay in picking up the banks in the morning. In other words, either it is possible to keep some capacitor banks for extended time or some banks can be connected bit earlier.

During day time the both real and reactive loads are high so that voltage drops again due to this. The low power factor initiates to switch on the capacitors. As the figure 4.3,4.4 and 4.5 reveal, power factor stabilizes during day time and show a flat profile. This means that the real and reactive loads have similar slopes during up and down. The point that has to consider is that if the first come banks correct the power factor then the others will not come even if there is a possibility of compensating more reactive power.

Not only that but there is another important feature in the power factor, real and reactive load cureves. During mid night, there is another region where the power factor becomes worse and reactive power remains some what constant while real power still dropping down. There is a possibility of over compensating during such a period.

We can see this very clealy in figures 4.6 (a to h) since the graphs are exagerated on daily basis. The flat regions of the power factor are clearly seen in these figures. Power factor during these flat areas are apprximately close but the real and reactive power loads show large variation. Due to these considerations, the switching of capcitor banks based on power factor is not the best criteria for a sub station in CEB system.

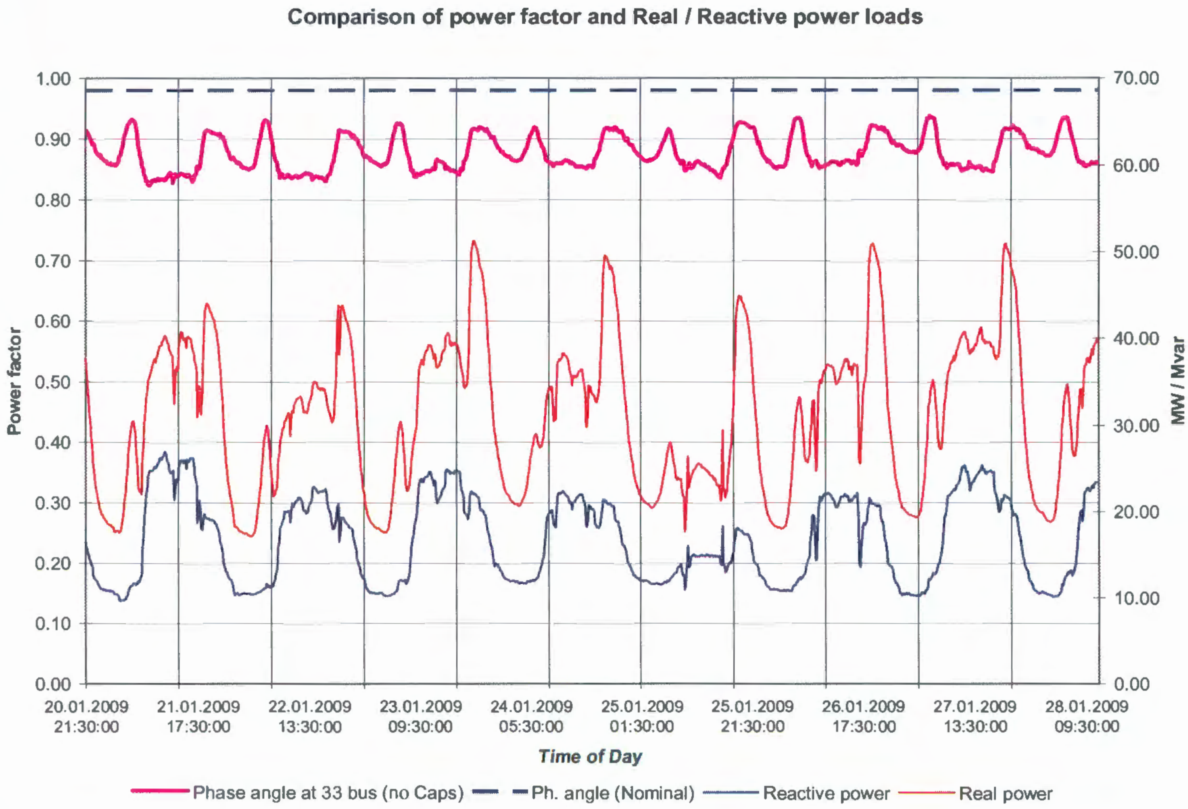


Figure: 4.5 Comparison of real and reactive power with power factor

4.5 Switching pattern of capacitor banks in the Substation

The behaviour of the capacitor banks in the substation with the present switching criteria was observed. The capacitor controller installed at Panadura grid sub station behaves as follows [7].

Controller - POCOS reactive power controller

Type - RPC-A-064-111-S000 M

Switching ON criteria;

If measured power factor < 0.98

Switching OFF criteria;

If $Q_{komp} > Q_{set} * (1 + Hysteresis/100)$

Where Q_{komp} = Difference in reactive power calculated from the actual cos ϕ value and set cos ϕ value

Hysteresis = A setting value defined by user (set value 10%)

Q_{set} = Lowest switchable power

Although the controller at this sub station switch on the banks based on power factor, it does not switch off the banks based on the same principle. Therefore, this kind of controllers installed in CEB system is not purely power factor based control. But in ABB and ASEA capacitor controllers used in some of the other substations, the switching off criteria is also based on leading power factor. The switching off criteria based on reactive power avoids the hunting of capacitor bank switching and considerably improves the utilization of capacitor banks.

The switching pattern of the capacitor banks for the measuring period based on above criteria is shown in figures 4.6 and 4.7. The figures 4.6 (a) to (g) show the switching pattern in master slave mode (bus coupler closed) while the figures 4.7 (a) to (g) show the same with bus coupler off position (Independent mode).

By observing the switching patterns, the following factors are noticed.

- There is a distinct difference in switching pattern under two operating conditions (at bus coupler ON and OFF)

- In the independent mode, two capacitor banks (one for each transformer) are in ON state through out the day. In the master slave mode, most of the time three capacitors are in ON position.

- In master slave mode, since three banks are ON in the mid night time, i.e. approximately after the night peak time and up to around 6.00 hrs morning, the sub station operates at a high leading power factor.

- In the real situation, during the period with lightly loaded lines especially in mid night, the line capacitances dominate and Ferranti effects causes high voltages at load ends. Addition of capacitors during such a period at substation makes the situation worst. Due to this, the control centre sometimes instructs to switch off the capacitor banks manually. Under such circumstances, due to operational difficulties, the operators switch off the controllers and hence all the banks are switched off. When operating a transmission network, this kind of leading reactive power compensation is also necessary. Although this is an un-economical situation as far as the sub station is considered, it is unavoidable. The situations like this once again prove that the power factor regulation is not the best switching criteria for CEB sub stations.

- Daily switching pattern shows that even at times where all four banks can be switched on, there are occasions where the controller switches only three banks especially during daytime. This may be due to the flat profile of the power factor during such periods. Both real and reactive power increases in the same proportion keeping the power factor unchanged. The controller does not consider reactive power increase if there is no decrease in power factor below limits.

- When the banks are switched off at nights manually to avoid voltage rises and again put into auto mode in the next morning, then the switching pattern disrupts and become even more uneconomical.

- The table 4.1 below shows a segment of data record that shows certain time slots in which only 3 banks are connected but still the other bank also can be connected.

Date & Time	Station Load		1 bank ON		2banks ON		3Banks ON		4 Banks ON	
	MW	Mvar	Unserved Var/TF	P.F after banks	Unserved Var/TF	P.F after banks	Unserved Var/TF	P.F after banks	Unserved Var/TF	P.F after banks
22.01.2009 09:00:00	29.78	19.18	7.09	-0.9029	4.59	-0.9556	2.0908	-0.9903	-0.41	0.9996
22.01.2009 09:10:00	30.43	20.00	7.50	-0.8970	5.00	-0.9500	2.4981	-0.9868	0.00	1.0000
22.01.2009 09:20:00	30.53	19.94	7.47	-0.8982	4.97	-0.9508	2.4725	-0.9871	-0.03	1.0000
22.01.2009 09:30:00	30.71	19.89	7.45	-0.8998	4.95	-0.9518	2.4461	-0.9875	-0.05	1.0000
22.01.2009 09:40:00	31.21	20.00	7.50	-0.9013	5.00	-0.9523	2.4981	-0.9874	0.00	1.0000
22.01.2009 09:50:00	31.34	20.07	7.53	-0.9012	5.03	-0.9521	2.5343	-0.9872	0.03	-1.0000
22.01.2009 10:00:00	30.88	19.84	7.42	-0.9013	4.92	-0.9528	2.4188	-0.9879	-0.08	1.0000
22.01.2009 10:10:00	28.69	18.73	6.86	-0.9021	4.36	-0.9567	1.8643	-0.9917	-0.84	0.9990

3 Banks ON and still 2.53 Mvar /transformer, drawn from source. Therefore if other bank is energized all var requirement can be fed.

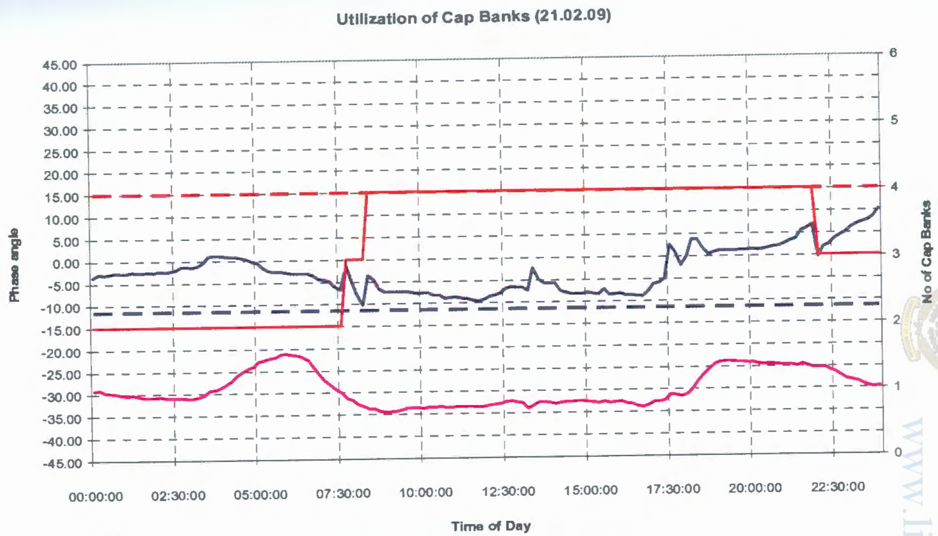
Situation if 4th bank is connected

Table: 4.1 *Extract from the data measurement*

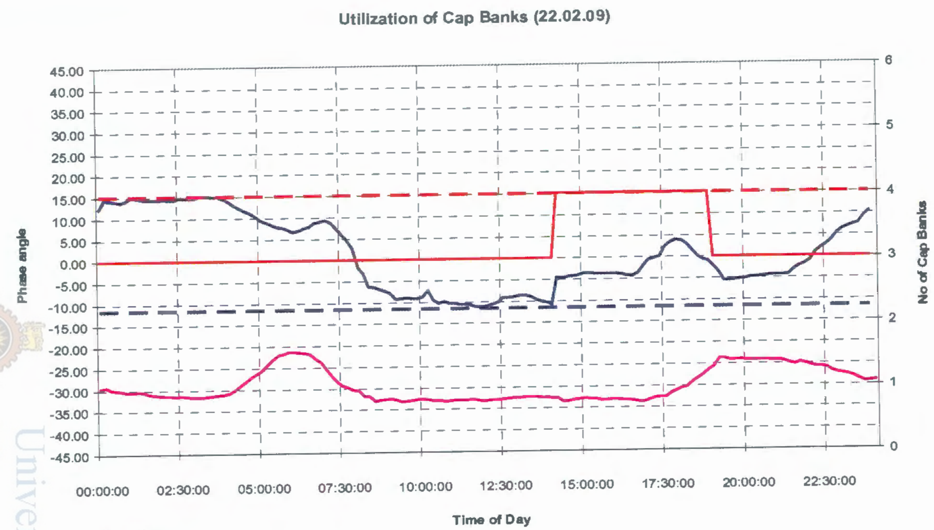
The figure 4.6, shows that there are occasions where the fourth capacitor bank does not automatically operates under power factor regulation control. However, independent mode operation seems to be more economical than master slave mode under same switching control in day time but during night time it may be not. However, the feeder loads are not identical so that the bus coupler has to be kept closed all the time. Therefore, most of the time the capacitor bank controllers are in master slave mode and utilization is not optimized.

4.6 Uncompensated reactive power

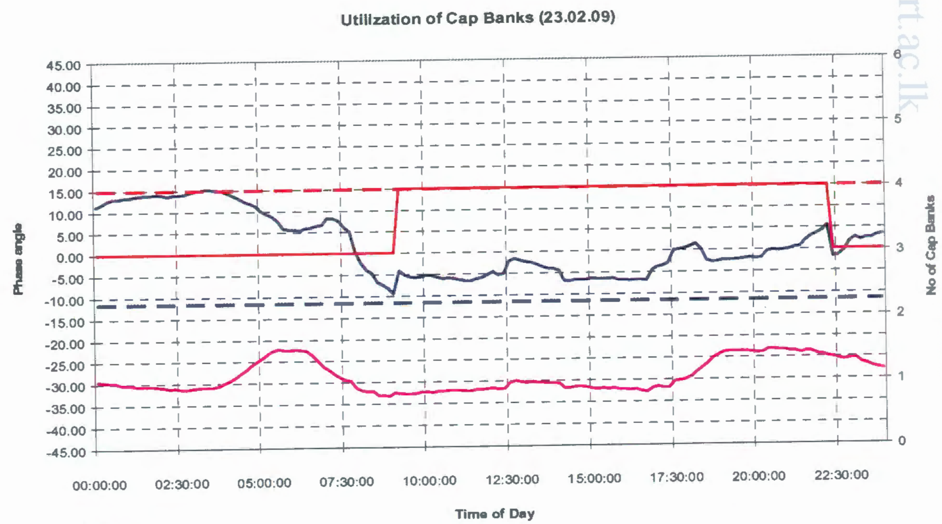
The best operational criterion for the substation is to operate its loads close as possible to unity power factor as far as the losses are concerned. The data measured and recorded shows that there are occasions where reactive loads could be further compensated by the capacitor banks while they are not fully utilized, to minimize line and transformer losses. The breaker switched capacitors operates in steps and hence they give poor regulation. Low power factors whether lagging or leading gives same effects as far as losses are concerned. However, under the conditions where transmission network needs reactive power, operate with leading power factor can be considered.



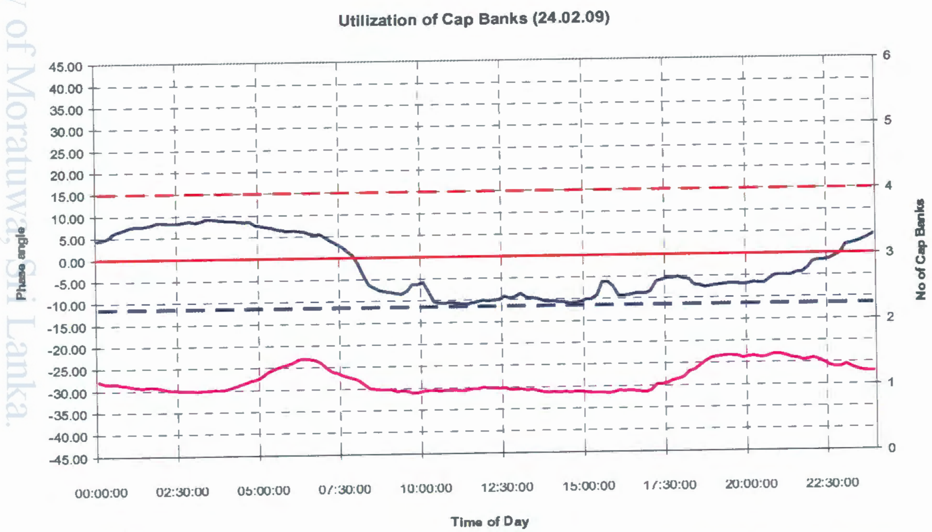
4.6(a)



4.6(b)



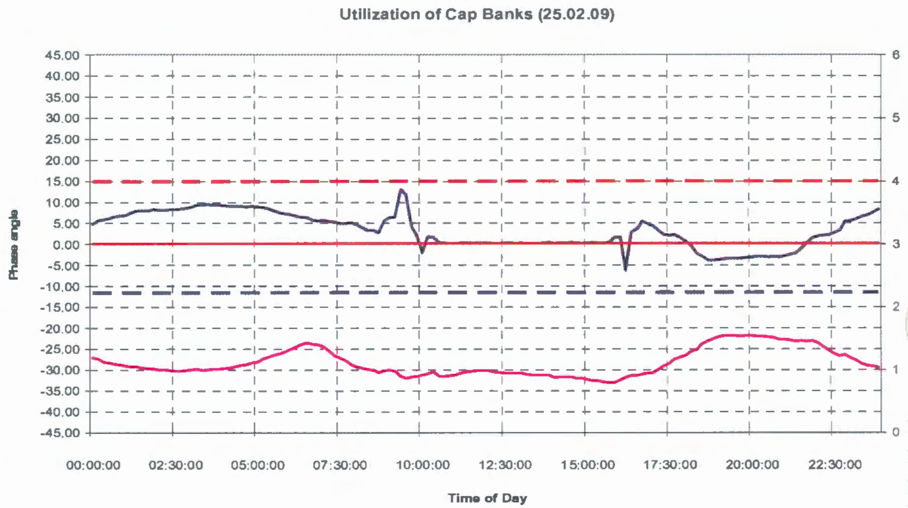
4.6(c)



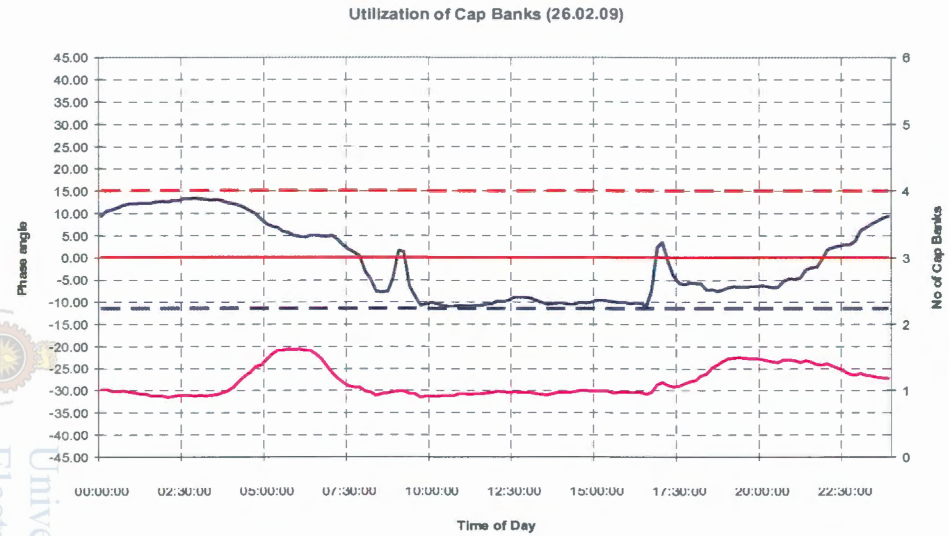
4.6(d)

Phase Angle at 33 bus (no Caps)
Ph. angle (Nominal)
No of Max Cap Banks
Phase Angle with Cap Banks (calculated)
No of Cap Banks

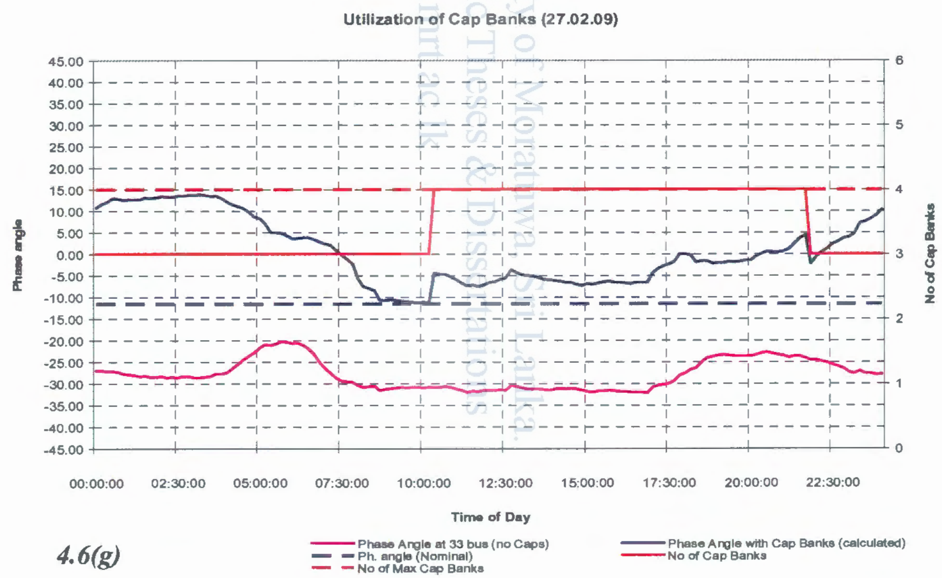
Figure: 4.6(a to d) *Utilization of cap banks under master slave mode*



4.6(e)

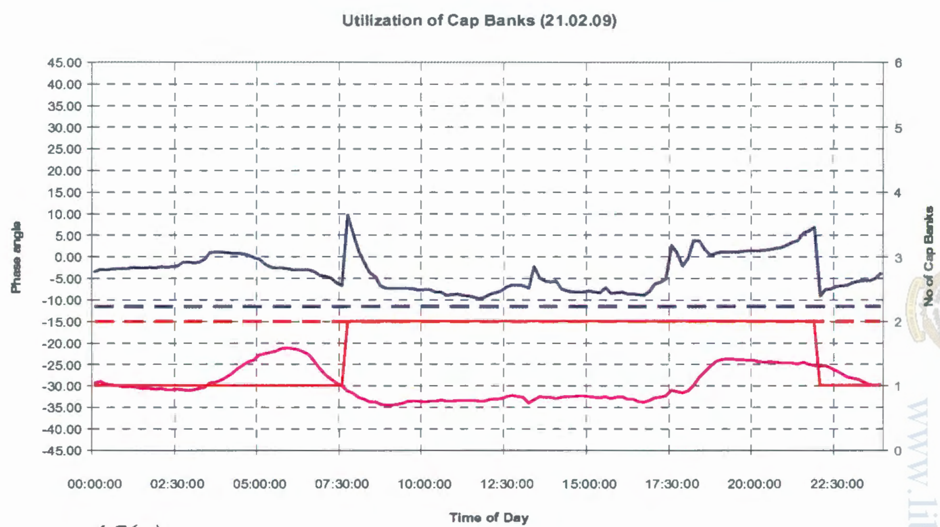


4.6(f)

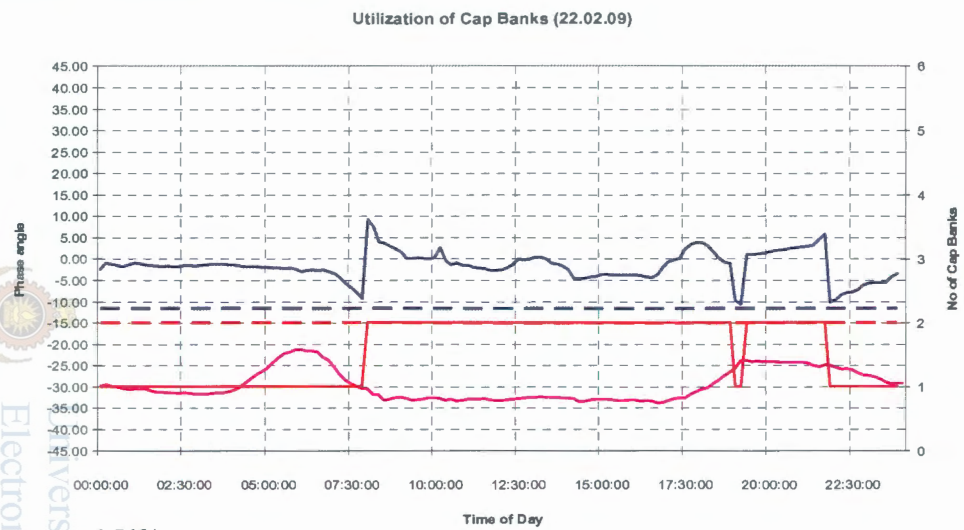


4.6(g)

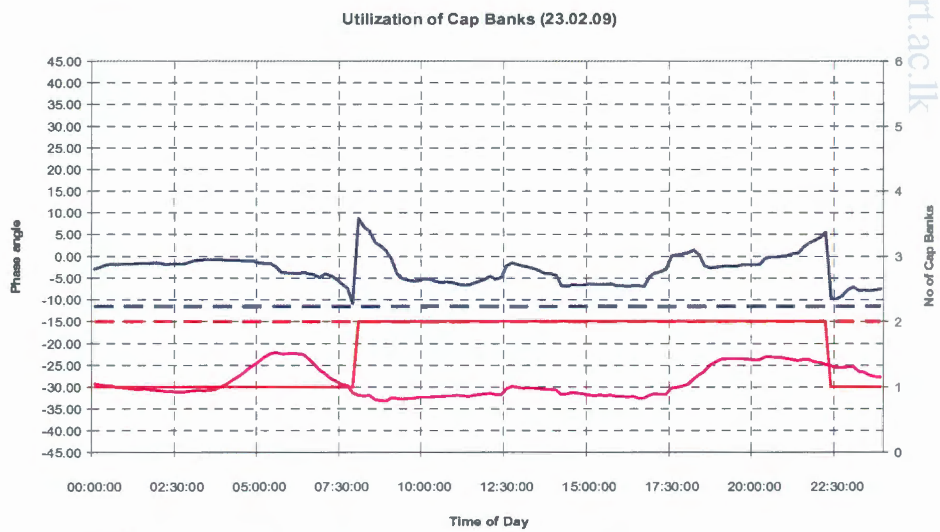
***Figure: 4.6 (e to g)** Utilization of cap banks under master slave mode*



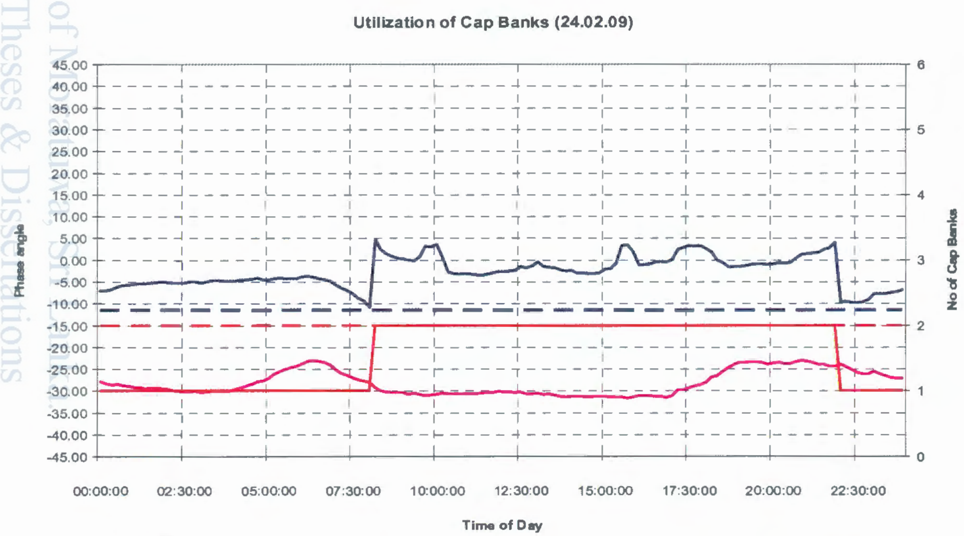
4.7(a)



4.7(b)

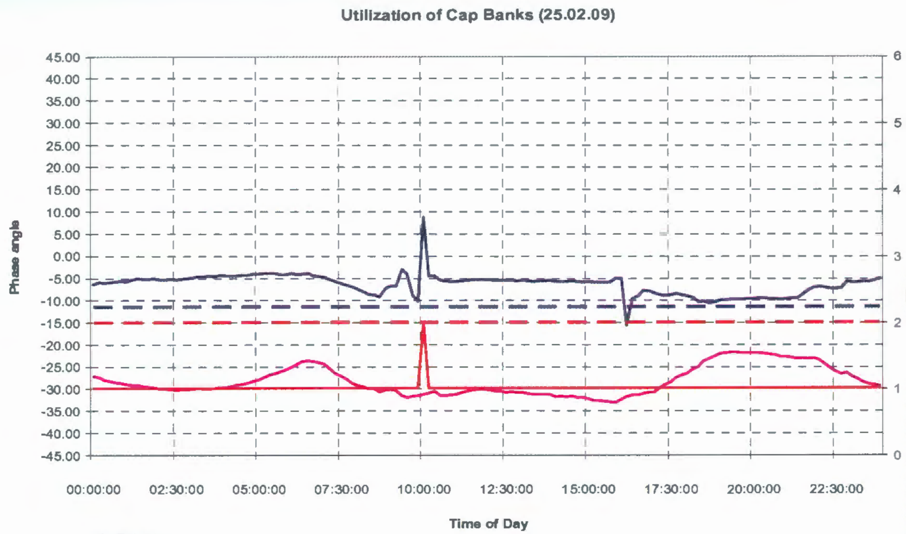


4.7(c)

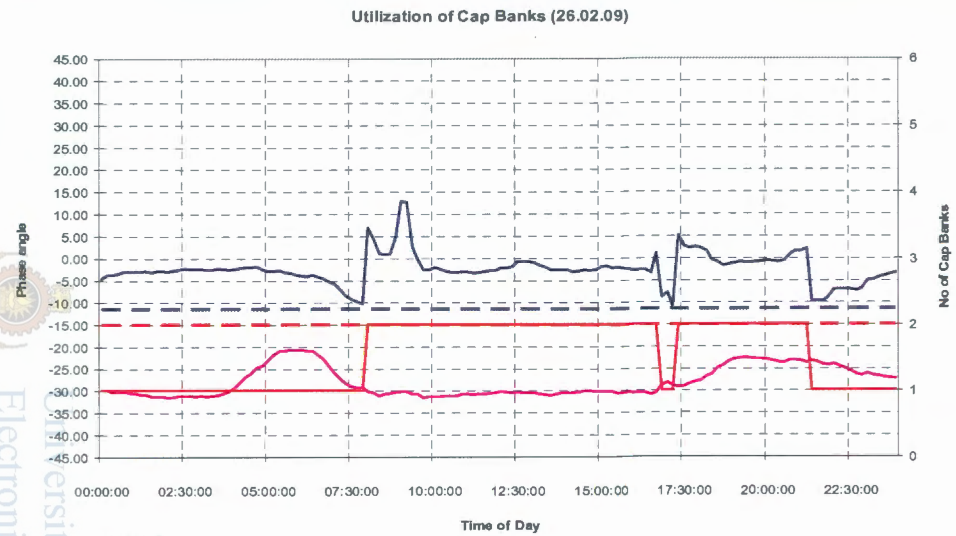


4.7(d)

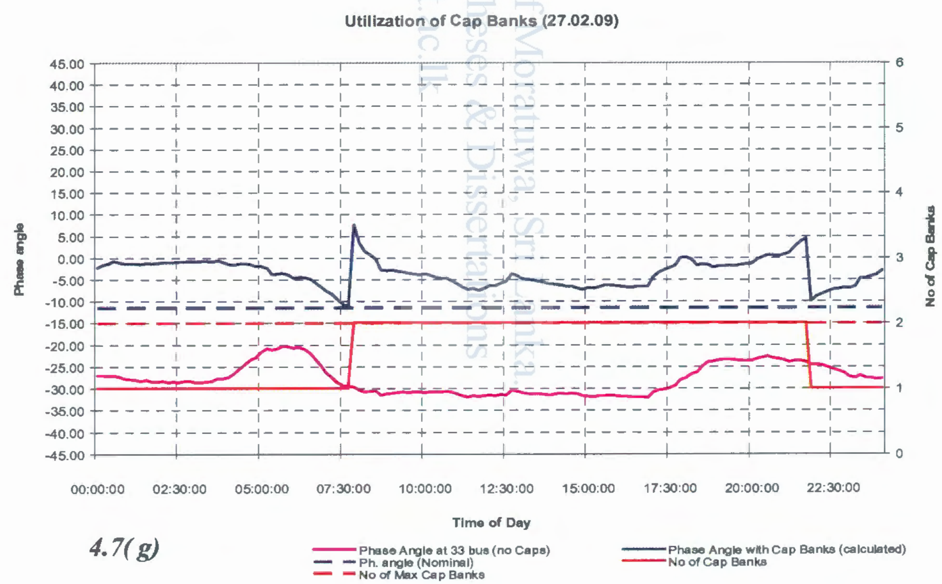
Figure: ***4.7 (a to d)*** *Utilization of cap banks under independent mode*



4.7(e)



4.7(f)



4.7(g)

Figure: 4.7 (e to g) Utilization of cap banks under independent mode

The figures 4.8 (a) to (g) shows the reactive power drawn from the system or fed into the system after capacitor banks are connected to the system under present switching criteria. The reactive power drawn from the system at the time, in which capacitors are not fully utilized, is the important matter to be discussed.

In the graphs the negative reactive power means it back feeds reactive power to the network and positive means it draws reactive power from the system.

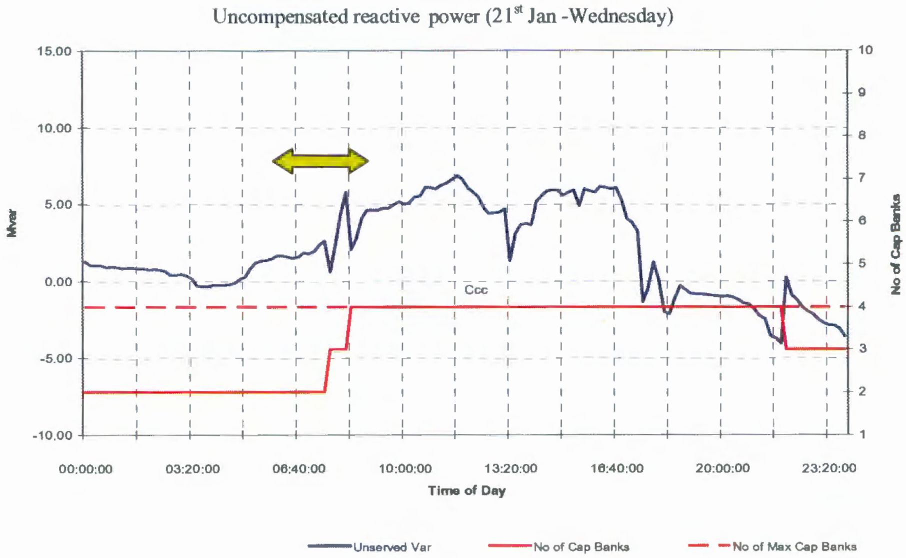


Figure: 4.8 (a) Reactive power flow under present switching criteria in master slave mode 21.01.09

The yellow arrow shows the area where capacitors are under utilized while the load substaintially drawing reactive power from the system.

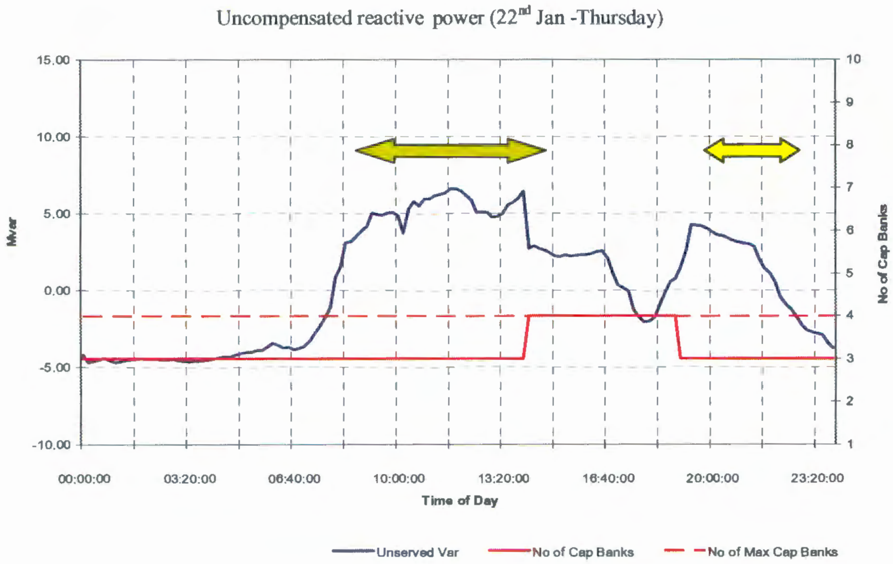


Figure: 4.8 (b) Reactive power flow under present switching criteria in master slave mode 22.01.09

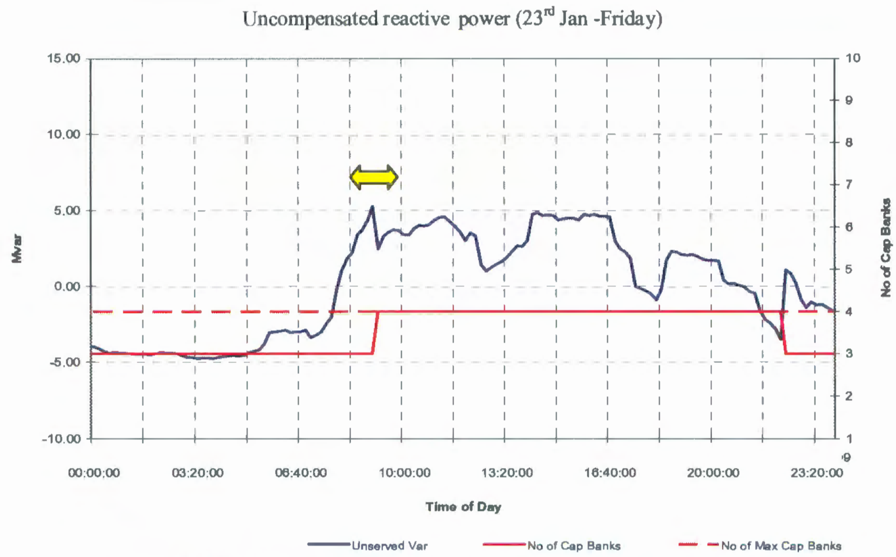


Figure: 4.8 (c) *Reactive power flow under present switching criteria in master slave mode 23.01.09*

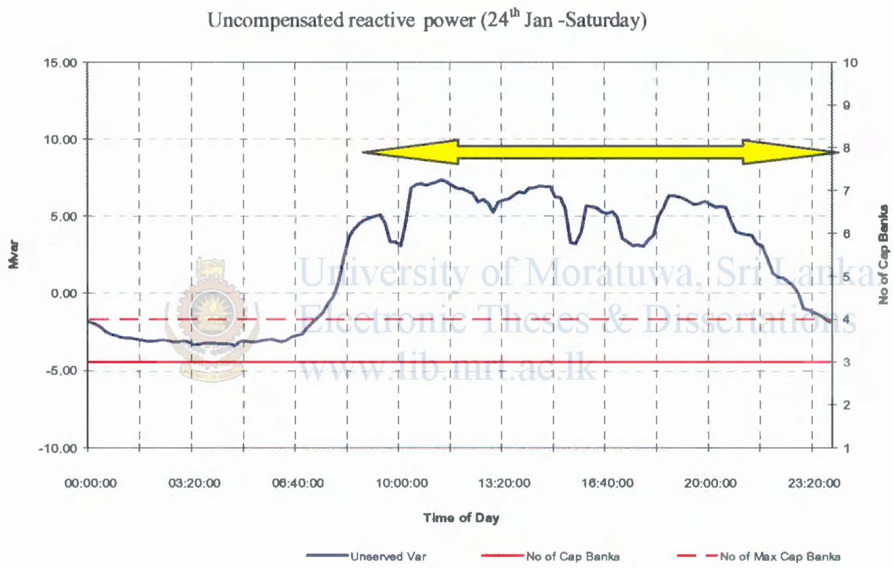


Figure: 4.8 (d) *Reactive power flow under present switching criteria in master slave mode 24.01.09*

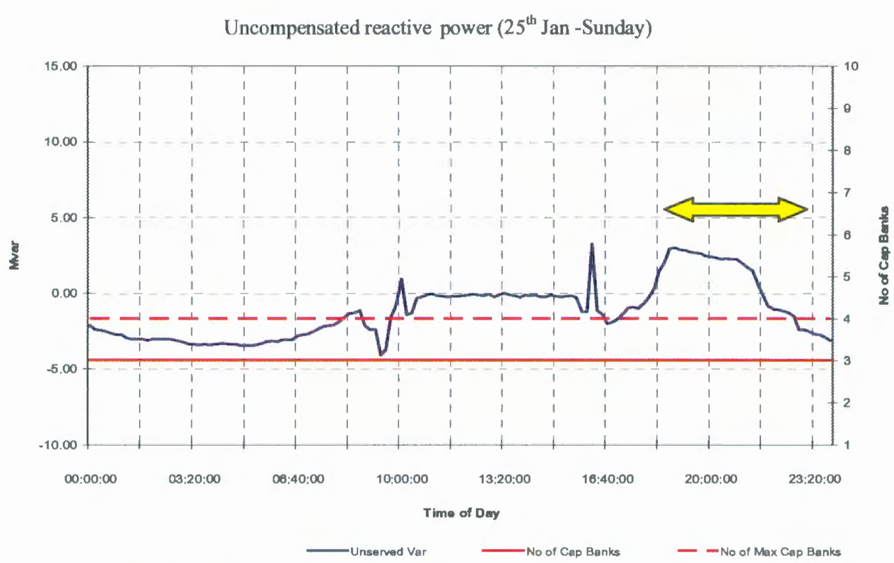


Figure: 4.8 (e) *Reactive power flow under present switching criteria in master slave mode 25.01.09*

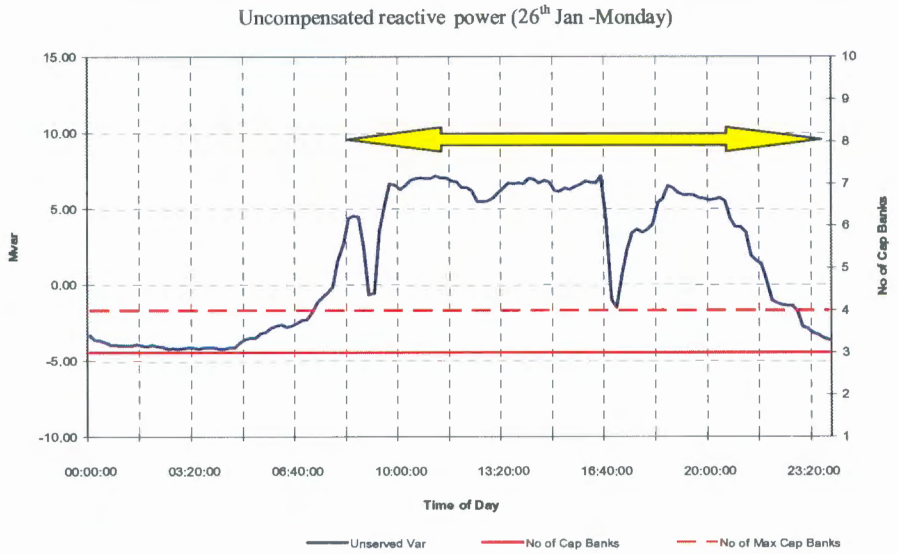


***Figure: 4.8 (f)** Reactive power flow under present switching criteria in master slave mode 26.01 2009*

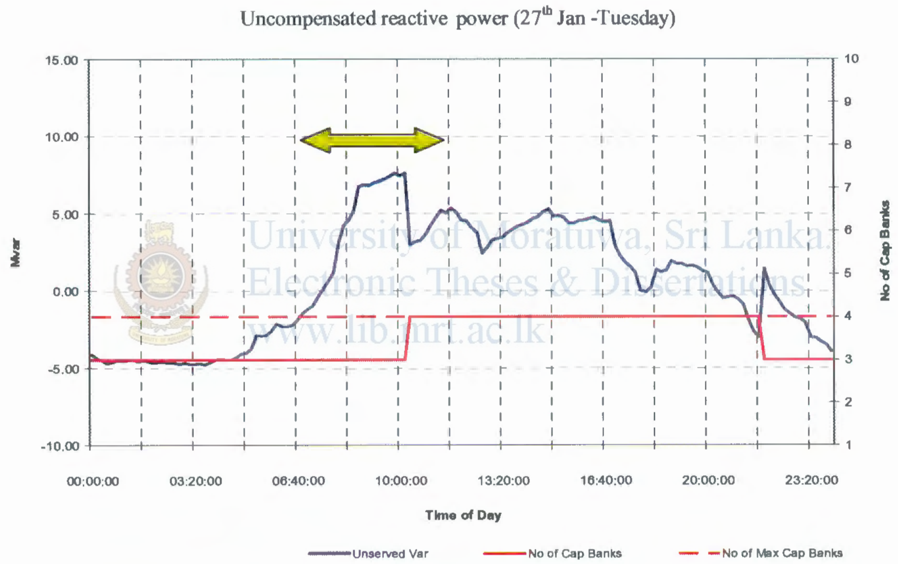


***Figure: 4.8 (g)** Reactive power flow under present switching criteria in master slave mode 27.01.09*

The figure 4.8(b) shows that the 4th bank has not connected even till 14.00 hrs and could have been in ON position more hours during the evening, in the particular day. Figure 4.8 (c) suggests, the fourth capacitor banks could be connected more early in the day.

All other figures 4.8(d), 4.8(e), 4.8(f), and 4.8(g) shows that there are possibilities of switching more capacitor banks early, maintain the already connected ones furthermore, or switch the fourth bank that has not come during the day.

4.7 Behaviour of transformer Tap position

The function of the on load tap changer (OLTC) is to adjust the LV bus voltage to its nominal value. When the load is high, the bus voltage is low due to IZ drop and tap changer raises its tap to high position to adjust the terminal voltage.

The voltage rise obtained by raising one tap position up, is 1.5 % of the voltage at the point of measuring. This is as per the specifications of the OLTC. At 33kV voltage this rise is about 0.495 kV. The approximated percentage voltage rise given by switching one 5Mvar capacitor bank is given as (kvar / kva) * X_t Where kvar = addition of reactive load, kva = transformer rating and X_t = transformer reactance in % [8]. When two transformers are in parallel, this value becomes 0.79% and the voltage rise is 0.260kV at 33kV.

As these figures suggests, the effect of rise in one tap step is same as adding two 5Mvar capacitor banks when two transformers are paralleled or one 5Mvar banks when one transformer is connected. Tap changer adjusts the voltage by adjusting the transformer ratio but capacitor banks by reducing the reactive power through the transformers and tranmission lines. Further it reduces the currents and hence the losses and release the euipment capacities. Therefore, the reactions of capacitor controller and AVR has to be optimally utilized.

The Table 4.2 gives an extract from a output file showing simulation results for LV and HV voltage, MW and Mvar at LV side and transformer HV side peak currents under different tap positions with no capacitor banks and with four capacitor banks. (simulation results for conditions at 20.30 hrs on 24.01.09) If the condition starts from point **(A)** in tablee 4.2, It stabilizes at point (B) under tap changer control and ends at point (C) when capacitors are switched on by a voltage control scheme.

From (A) to (B), the results shows 3% voltage rise, 6% real power increase, 6 % reactive power increase and 5% current increase. From (A) to (C), there is a voltage increase of 3%, real power increase of 6% but the current and reactive power reduces by 7% and 74% respectively. This shows the effectiveness of both control loops when operates independently.

Multiple Run Output File No cap banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9250000000	74.78120511	33.50227824	-23.51500332	47.12524546	20.50556929	.1714195128
2	.9400000000	74.79557315	32.98062952	-23.51500149	45.66920959	19.87200561	.1660712497————(B)
3	.9550000000	74.80926471	32.47476970	-23.51500464	44.27907683	19.26711830	.1609690167
4	.9700000000	74.82232163	31.98400256	-23.51500323	42.95096263	18.68921707	.1560980129 ————(A)
5	.9850000000	74.83478258	31.50767152	-23.51499635	41.68126197	18.13673328	.1514445311

Multiple Run Output File 3 cap banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9250000000	75.17429356	34.45411052	-6.171918169	49.83944434	5.389319552	.1621685425
2	.9400000000	75.17643599	33.91244808	-6.172074955	48.28522601	5.221766022	.1570913437
3	.9550000000	75.17849488	33.38725110	-6.171084037	46.80027560	5.060076609	.1522262048
4	.9700000000	75.18038156	32.87809638	-6.170808773	45.38412407	4.906991965	.1476188801————(C)
5	.9850000000	75.18219740	32.38406964	-6.171620046	44.03061954	4.760750879	.1431963655

Table: 4.2 *Output file from PSCAD simulation showing differences in measurements*

Figures 4.9 (a), (b) and (c) shows the observations on the behaviour of the tap position in the absence of the capacitors. The number of capacitor banks that could be connected if the controller was in auto mode, is also indicated in the figures. The figures reveal that there is the possibility of operating the sub station at lower tap positions if the capacitor banks connected under the present criteria. The ***Appendix 2(b)*** illustrates the effects clearly.

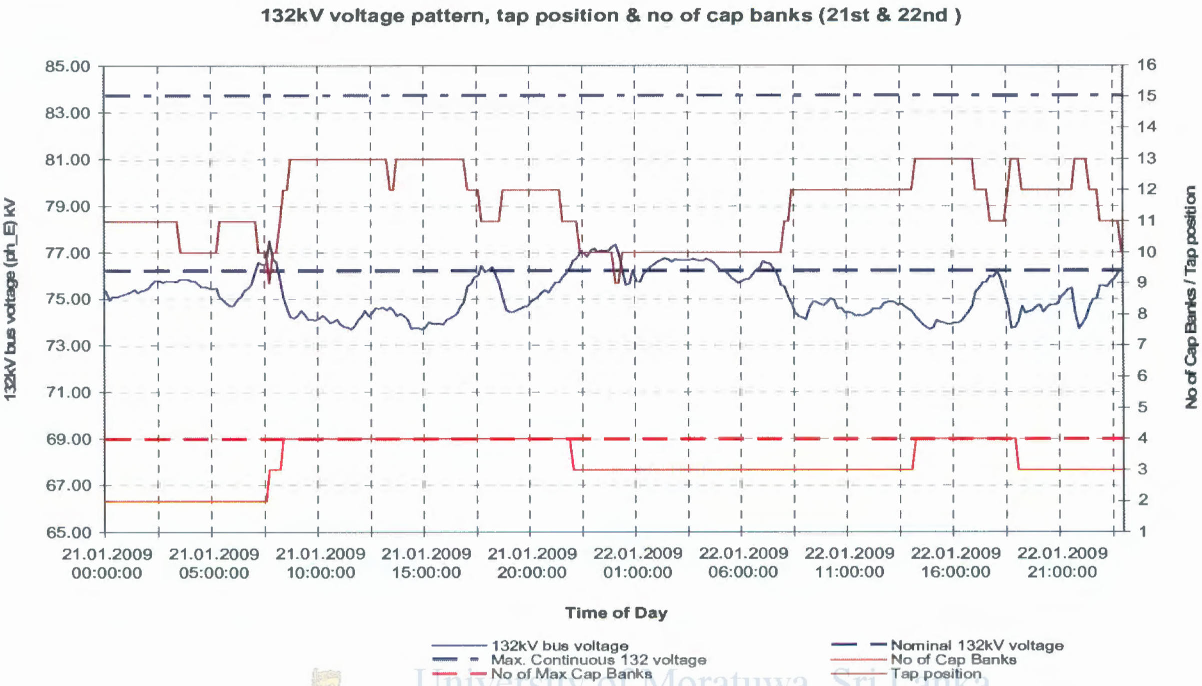


Figure: 4.9 (a) *Pattern of tap position with no capacitor banks 21st & 22nd*

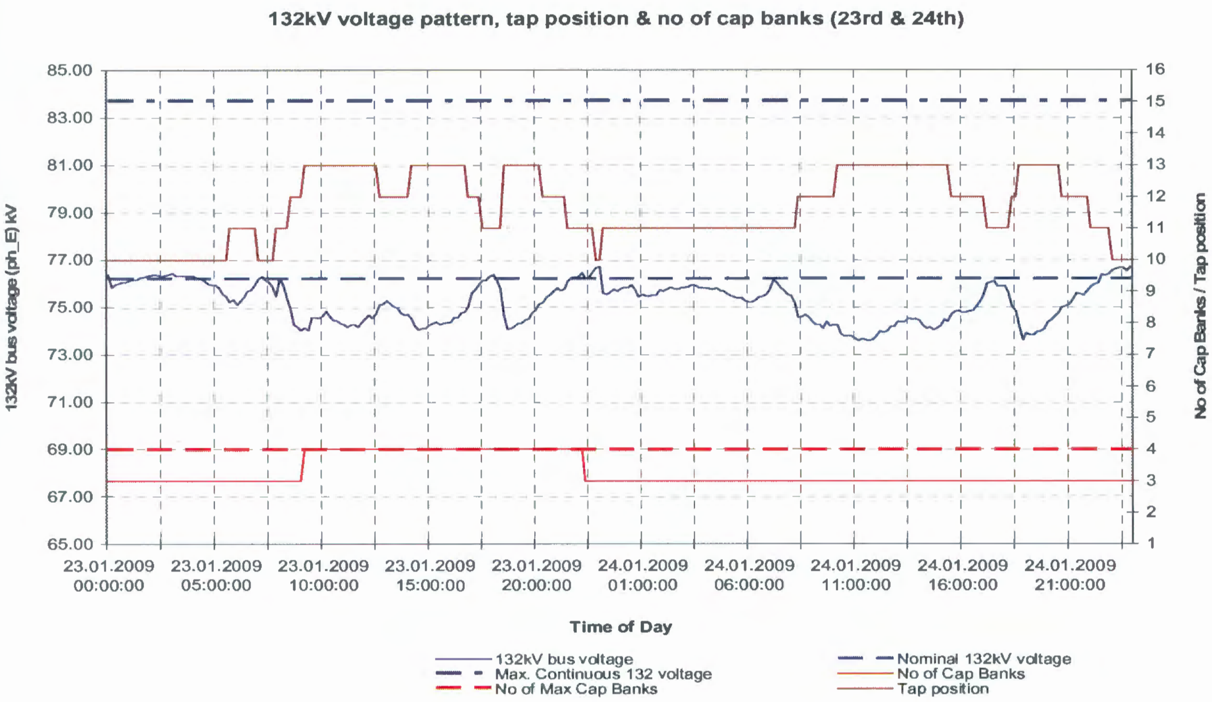


Figure: 4.9 (b) *Pattern of tap position with no capacitor banks 23rd & 24th*

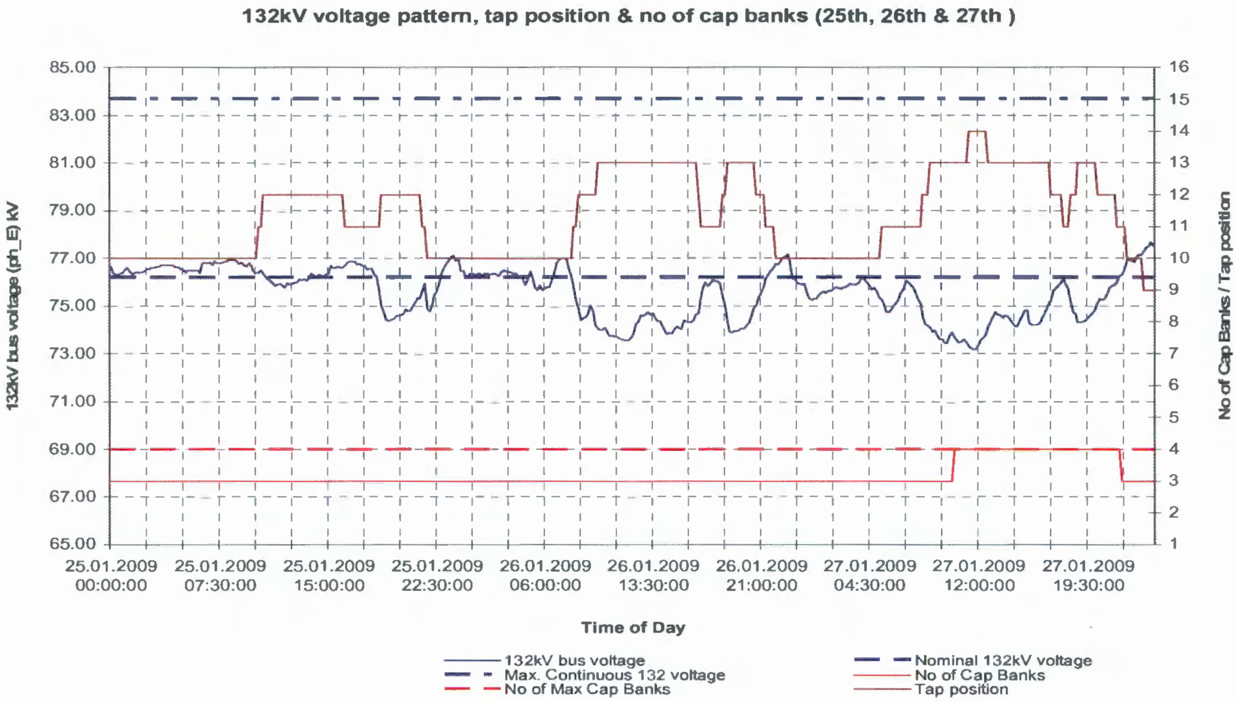


Figure: 4.9 (c) *Pattern of tap position with no capacitor banks 25th to 27th*

Appendix 2(b) compares the difference between the patterns of the tap position while having no capacitor banks and the same with the maximum number of capacitor banks. Since the voltage boost up by adding capacitors at 33kV side, the raise of transformer tap can be minimized.

4.8 Summary of the system study

By summarizing the results from the case study, it seems that the present switching criteria especially when the bus section breaker is in ON position dose not neither maximize nor optimize the use of installed capacitor banks in the selected substation.

Therefore, it is worth to consider different switching criteria that utilize the capacitor banks, than the existing utilization. However, under such circumstances, the effects to the system voltage, avoiding extreme over compensation that introduces losses due to leading power factor and other technical constraints have to be considered.

Chapter 5

5. System modelling, simulations and data analysis

Exploring the possibilities of maximizing the use of capacitor banks in an existing substation has to be done in several steps. As discussed in the previous chapter, the first is to collect and record the system data and analyze them. Then by considering those results, simulation of the system under various operating scenarios and different capacitor bank combinations can be done. This needs a suitably developed computer simulation model. Using such a simulation various effects on the system due to switched capacitor banks can be studied. Followings are the areas that have to be studied as mentioned above.

- Maximum voltage rise due addition of capacitor banks at the bus bar in which they are connected
- The capability of transformer OLTC and AVR to handle those voltage variations by changing tap position, when necessary.
- The capability of OLTC to handle the current through it without exceeding it's current switching capacity during back feeding reactive power into the system
- The effect of resonance when adding more capacitor banks under various load conditions and system harmonic levels
- Effects on voltage distortion caused by load harmonics at 33kV bus, when adding more capacitor banks
- Cost analysis considering the reduction of losses due to power factor improvement, release of system component capacities etc. and many others.

5.1 System modelling and simulation

One of the main aspects of the research is to model the substation for analyzing various system conditions by simulation. Suitable computer aided simulation software with transient as well as steady state analyzing capabilities was needed for this purpose. Therefore, PSCAD which is a tool used by many power system Engineers, was used for modelling and simulations. PSCAD is a graphical user interface working along with an electromagnetic transient analysis program called EMTDC and a widely used software by power system engineers for power system studies [9]. Power system Computer Aided Design abbreviated as PSCAD schematically construct a circuit, run a simulation, analyze the results and manage the data in a completely integrated graphical environment. PSCAD is mainly for transient analysis but also equipped with all modules for the steady state analysis as well.

The difficulty faced in using PSCAD was that it is not free software and needs a license for use. However, a free student version with limited nodes is available. Also a trail version is available for limited time frame. The basic trials were done for simplest blocks with the free student version and later the complete model was developed with the trial version.

5.2 The Basics in Substation model

Main substation components such as power transformers, grounding zigzag transformers, circuit breakers, substation load, capacitor banks, tap changers, etc., are included in the model. Most of the components are available with the master library in the PSCAD. Some has to be approximated to the available modules in the main library.

The transformers are selected as two winding transformers with the tap changer on HV side of the transformers. The real transformer was approximated to the simplest form and percentage impedance was considered as an inductance only. The magnetization circuit was approximated with typical values.

The grounding zigzag transformer is represented with a typical star delta transformer with delta winding unconnected to a load. This representation is sufficiently valid for this kind of analysis [10]. The developed module for the transformer is as given in figure 5.1

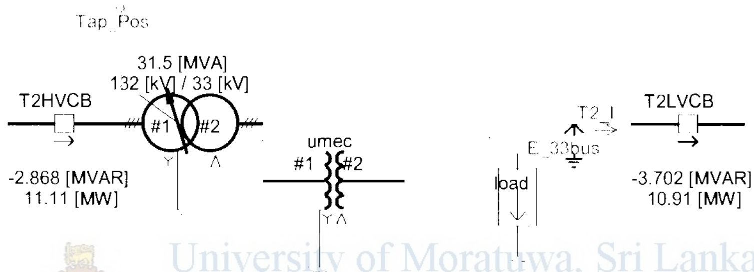
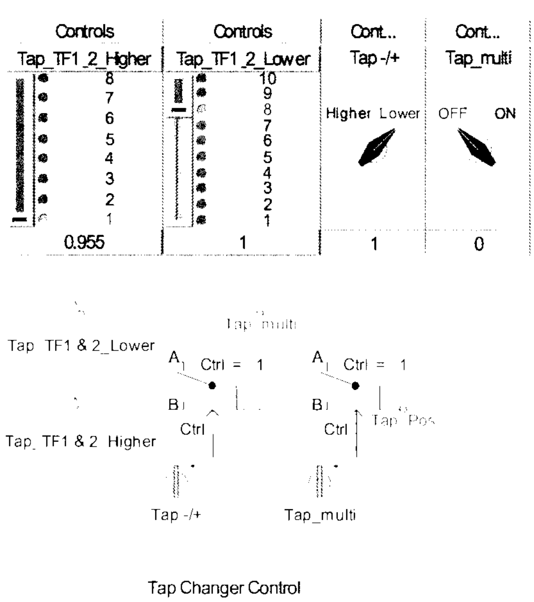


Figure 5.1 Transformer & Grounding transformer module

The tap changer is represented as a HV to LV ratio changer to suit the real tap changer ratios. Nominal ratio of the transformer is 4 and this has to be taken as 1 in the PSCAD model. The tap changer at Panadura is consisting of 18 taps with each 1.5% voltage difference. The tap changer is arranged as to control manually or change step wise in the multiple run mode, as below.



Tap Position	Ratio	Tap Position	Ratio
1	1.105	10	0.970
2	1.090	11	0.955
3	1.075	12	0.940
4	1.060	13	0.925
5	1.045	14	0.910
6	1.030	15	0.895
7	1.015	16	0.880
8	**1.000**	17	0.865
9	0.985	18	0.850

Figure 5.2 Tap changer control module

Representing the network beyond the substation basically depends on approximations. Typically, in any approximated representation, if frequency response analysis at the bus bar level is not expected then a simple Thevinin's equivalent is sufficient.

The load is represented in two ways in the model and as a lumped load. One is specified with real and reactive power but the input values are real values so that input parameters from outputs of others modules could not be used in this module. Therefore, during multiple run functions, the second module with R and L values was used. R and L values are calculated as per the MW and Mvar values at different time slots.

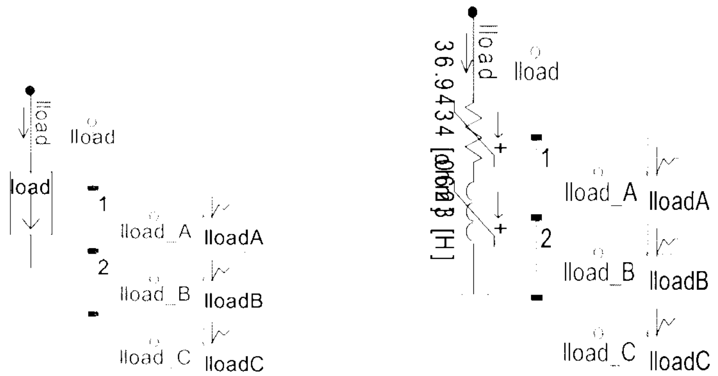


Figure 5.3 *Load & load current measuring module*

Capacitor banks with inrush and detune reactors are represented with equivalent C and L values as in the diagram. Though the real capacitor bank configuration ungrounded double WYE configuration, it is sufficient to represent it with a lumped star connected load for the analysis.

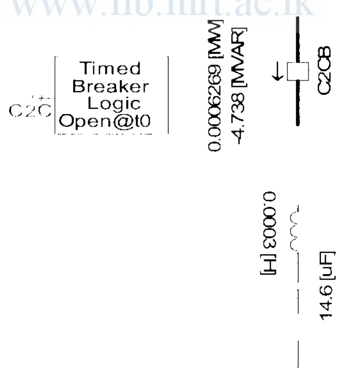


Figure 5.4 *Capacitor bank & Inrush/Detuning reactor module*

With all these main components and other measuring and recording modules, the complete model developed for the Panadura Grid Substation in CEB system is shown in the Figure 5.4

5.3 Running the simulations

First the simulations were run for measured data, real and reactive loads, tap positions, and voltage at source end and recorded data was compared with the actual measured data. This was done with no capacitor banks connected to the LV bus. Further, the real measurements were done with 10 minute interval but it was time consuming to run the simulations with the same time intervals. Therefore the simulations were run only for 30 minute interval.

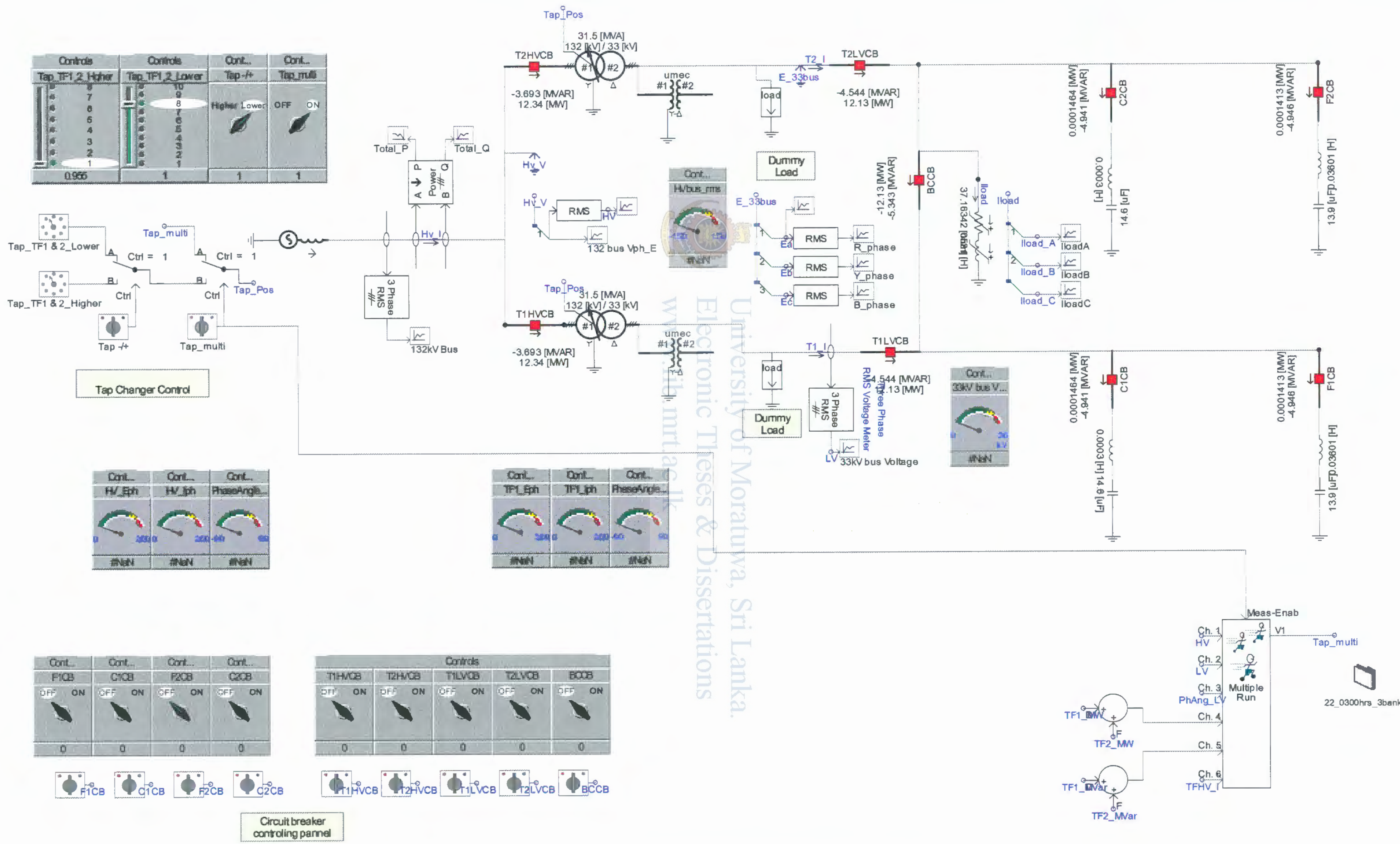


Figure: 5.5 Complete model for Panadura Grid Substation

The results obtained from the simulation shows that the model gives approximately same results as the actual. Next step of the simulations was to run the model with the capacitor banks connected as per the existing switching criteria. This run was done not only for the same tap position as with no capacitors but also for different tap positions until the LV bus voltage gives a close voltage level to its nominal value.

While running the simulations in this manner, all the data required for the analysis was recorded in the output file of the multiple run function block in PSCAD.

The third step in simulation was to energize one more step of the capacitor banks except for durations where all capacitor banks were energized. For example, when the controller switches only two capacitor banks in the real system, simulations were run with the third and fourth banks as well at different tap positions.

Typical output file obtained for the system with 3 capacitor banks switched on to the bus and under different tap positions is given below.

Multiple Run Output File							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.38861778	34.45012437	10.69121078	21.99452264	-4.151149007	.1051607455
2	.9850000000	77.38426922	33.92637354	10.68872963	21.33060859	-4.026310122	.1020034818
3	1.000000000	77.38008298	33.41842128	10.68597805	20.69732342	-3.905589441	.9899367705E-01
4	1.015000000	77.37613631	32.92537989	10.68736488	20.09086688	-3.792102475	.9611173627E-01
5	1.030000000	77.37229255	32.44666079	10.68637580	19.51109591	-3.681892354	.9335744888E-01
6	1.045000000	77.36867257	31.98162290	10.68801147	18.95561675	-3.577934633	.9071955012E-01
Statistical Summary Based on 6 Runs:							

	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
Minimum:	.9700000000	77.36867257	31.98162290	10.68597805	18.95561675	-4.151149007	.9071955012E-01
Maximum:	1.045000000	77.38861778	34.45012437	10.69121078	21.99452264	-3.577934633	.1051607455
Mean:	1.007500000	77.37834523	33.19143046	10.68794510	20.43000570	-3.855829672	.9772443994E-01
Std Dev:	.2806243040E-01	.7466101136E-02	.9235881790	.1894898505E-02	1.136968839	.2146131995	.5402956744E-02
2% Level:	.9498668133	77.36301174	31.29461222	10.68405346	18.09495715	-4.296591303	.8662812324E-01
98% Level:	1.065133187	77.39367873	35.08824871	10.69183675	22.76505425	-3.415068041	.1088207566
Probability Density Functions (%) for Variable 1, HV Voltage							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				
Probability Density Functions (%) for Variable 2, LV Voltage							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				
Probability Density Functions (%) for Variable 3, Ph Ang_LV							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				
Probability Density Functions (%) for Variable 4, LV_MW							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				
Probability Density Functions (%) for Variable 5, LV_MVar							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				
Probability Density Functions (%) for Variable 6, TF_HV_Current							
--							
Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.				

***Table: 5.1** Multiple run out put file for six recording inputs for different tap positions*

Even with the half hour interval time slots, the simulations takes long time. Therefore, running simulation for more and more days is a time consuming task. Therefore, the simulations were done for three selected days only. The recorded data is as per the format annexed in ***Appendix 3-a.*** The data summery is given in ***Appendix 3-b.***

5.4 Voltage raise due to capacitor banks

The substation model was adjusted to have same measurement condition as measured without capacitor banks and voltage at high and low voltage bus bars, real and reactive power, phase angle measured at 33kV bus bar, current through the transformer etc, were recorded. The changes of above parameters by switching on the capacitor banks as per present criteria, for the optimum condition with maximum var compensation, for maximum capacitor banks were also recorded.

The table 5.2 gives an indication how the high voltage and low voltage bus voltages has been affected when changing from present criteria to maximum capacitor bank state with the AVR function as well.

Time	Changes due to maximum cap banks compared to present criteria 21.01.2009				Changes due to maximum cap banks compared to present criteria 22.01.2009				Changes due to maximum cap banks compared to present criteria 24.01.2009			
	Change of HV bus Voltage (kV)	Change of LV bus Voltage (kV)	Change of No of cap banks	Change of Tap position	Change of HV bus Voltage (kV)	Change of LV bus Voltage (kV)	Change of No of cap banks	Change of Tap position	Change of HV bus Voltage (kV)	Change of LV bus Voltage (kV)	Change of No of cap banks	Change of Tap position
00:00:00	0.22	0.13	2	-1	0.10	-0.17	1	-2	0.12	0.31	1	0
00:30:00	0.25	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.31	1	0
01:00:00	0.25	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.31	1	0
01:30:00	0.24	-0.38	2	-2	0.12	0.32	1	0	0.12	0.31	1	0
02:00:00	0.25	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.31	1	0
02:30:00	0.24	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.31	1	0
03:00:00	0.23	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.32	1	0
03:30:00	0.24	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.32	1	0
04:00:00	0.24	0.13	2	-1	0.12	-0.18	1	-1	0.12	0.32	1	0
04:30:00	0.24	-0.37	2	-2	0.12	-0.18	1	-1	0.12	0.31	1	0
05:00:00	0.24	-0.37	2	-2	0.12	0.32	1	0	0.12	0.31	1	0
05:30:00	0.24	0.12	2	-1	0.12	-0.18	1	-1	0.13	0.32	1	0
06:00:00	0.24	0.13	2	-1	0.12	-0.18	1	-1	0.13	0.32	1	0
06:30:00	0.25	0.13	2	-1	0.12	-0.19	1	-1	0.01	0.32	1	0
07:00:00	0.25	-0.38	2	-2	0.12	-0.18	2	-1	0.12	0.31	1	0
07:30:00	0.24	0.13	2	-1	0.12	-0.19	1	-1	0.12	0.31	1	0
08:00:00	0.13	-0.20	1	-1	0.12	-0.19	1	-1	0.12	0.31	1	0
08:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.12	0.31	1	0
09:00:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.12	0.31	1	0
09:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.12	0.31	1	0
10:00:00	0.00	0.00	0	0	0.12	0.31	1	0	0.12	0.31	1	0
10:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	0.31	1	0
11:00:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	0.31	1	0
11:30:00	0.00	0.00	0	0	0.13	0.31	1	0	0.13	0.31	1	0
12:00:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	0.31	1	0
12:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	0.31	1	0
13:00:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	-0.20	1	0
13:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	-0.20	1	0
14:00:00	0.00	0.00	0	0	0.13	0.31	1	0	0.13	0.31	1	0
14:30:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	0.31	1	0
15:00:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	-0.20	1	0
15:30:00	0.00	0.00	0	0	0.00	0.00	0	0	0.12	0.31	1	0
16:00:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	-0.20	1	0
16:30:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	-0.20	1	0
17:00:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	0.31	1	0
17:30:00	0.00	0.00	0	0	0.00	0.00	0	0	0.12	0.32	1	0

18:00:00	0.00	0.00	0	0	0.00	0.00	0	0	0.12	0.32	1	0
18:30:00	0.00	0.00	0	0	0.00	0.00	0	0	0.13	-0.20	1	0
19:00:00	0.00	0.00	0	0	0.13	0.32	1	0	0.13	0.31	1	0
19:30:00	0.00	0.00	0	0	0.12	-0.20	1	-1	0.13	0.31	1	0
20:00:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	0.31	1	0
20:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.13	-0.20	1	0
21:00:00	0.00	0.00	0	0	0.13	0.31	1	0	0.13	0.31	1	0
21:30:00	0.00	0.00	0	0	0.13	-0.20	1	-1	0.12	-0.19	1	0
22:00:00	0.12	0.32	1	0	0.12	-0.20	1	-1	0.12	0.31	1	0
22:30:00	0.12	0.32	1	0	0.12	-0.19	1	-1	0.12	-0.19	1	0
23:00:00	0.12	-0.18	1	-1	0.13	0.32	1	0	0.12	0.31	1	0
23:30:00	0.11	-1.17	1	-1	0.12	-0.18	1	-1	0.12	0.31	1	0

Table: 5.2 *Increase /Decrease in bus voltages due to maximum capacitor connections*

As per the data in the table, the maximum voltage rise in 132kV bus bar is 0.25kV and 0.32kV in 33kV bus bar, under real system conditions (with tap changer). The maximum voltage at the HV bus is 77.80kV. (Refer ***Appendix 3-b***)

The maximum effect to the voltage occurs when all capacitors are connected, at maximum source voltage and at minimum load. To check the effect, simulation was run for maximum continuous source voltage of 145kV at minimum substation load of 17.2MW and 9.6Mvar for various tap positions. The results are shown in following table.

Multiple Run Output File			**All Caps**		**17.2 MW**	**9.6Mvar**	
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	1.000000000	83.07677576	36.85594001	31.20543495	21.37469995	-12.92286353	.1051738480
2	1.015000000	83.06745081	36.30956725	31.20486137	20.74670260	-12.54229066	.1020880757
3	1.030000000	83.05852515	35.77920687	31.20529453	20.14495215	-12.17835456	.9915548672E-01
4	1.045000000	83.04997852	35.26412698	31.20548649	19.56857477	-11.83015222	.9635954657E-01
5	1.060000000	83.04179021	34.76367327	31.20524509	19.01855912	-11.49667914	.9365258054E-01
6	1.075000000	83.03394569	34.27726921	31.20527452	18.49070244	-11.17708379	.9107116275E-01
7	1.090000000	83.02642465	33.80428815	31.20504308	17.98304192	-10.87145676	.8860031208E-01
8	1.105000000	83.01920234	33.34420109	31.20536777	17.49747653	-10.57650063	.8622601926E-01

Multiple Run Output File				**No Caps**	**17.2 MW**	**9.6Mvar**	
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	1.000000000	82.55300216	35.48586479	-29.22323451	19.81771014	11.11511467	.1024325584
2	1.015000000	82.55901578	34.96615854	-29.22323752	19.24149323	10.79224345	.9946125022E-01
3	1.030000000	82.56476859	34.46138792	-29.22324054	18.68997372	10.48319655	.9661804273E-01
4	1.045000000	82.57027546	33.97092109	-29.22324356	18.16176419	10.18719813	.9389568724E-01
5	1.060000000	82.57555021	33.49416116	-29.22324657	17.65557300	9.903525888	.9128743988E-01
6	1.075000000	82.58060570	33.03054389	-29.22324957	17.17019652	9.631506662	.8878702009E-01
7	1.090000000	82.58545392	32.57953542	-29.22325255	16.70451202	9.370512516	.8638857295E-01
8	1.105000000	82.59010604	32.14063033	-29.22325551	16.25747125	9.119957137	.8408663513E-01

Table: 5.3 *Voltage variation for max continuous HV side voltage & Minimum substation load for different tap positions*

Under the selected worst case, with all capacitor banks are switched off, the LV bus voltage will be maintained at 33.494 kV by the AVR adjusting tap position to 4. When all banks are connected at this stage, AVR & tap changer is capable to maintain the bus voltage at 33.344kV. The tap changes from 4 to 1, under this worst case. Practically this is not a desired condition but such a worst case will not be allowed by the system operator.

According to the theoretical calculations, the voltage rise at LV side of a transformer can be approximated as follows.

$$\text{Percentage voltage rise} = (\text{kvar} / \text{kva}) * X_t$$

Where kvar = addition of reactive load

kva = transformer rating

X_t = transformer reactance in %

With present configuration, the maximum effective reactive power injection when either transformers in parallel, or transformers are independent, is 10Mvar (since each transformer is connected with two banks). Therefore, as per the above approximation, for this substation addition of full reactive load of 20 Mvar give a rise of about 1.04kV at 33kV bus voltage. The simulation results confirm the above approximation as in table 5.3.

As indicated in section 4.7, the change of one tap position change the voltage by 0.015 pu and this is about 0.495kV at 33kV. The effect of rise in voltage over the nominal value due to addition of maximum capacitor banks can be handled with two tap positions.

The table 5.3 very clearly indicates that the high voltage side bus voltage at the present real conditions does not overstep the maximum continuous voltage of 83.715kV. The figure also shows that for maximum allowable HV bus voltage and for minimum load, the maximum LV bus voltage rise for same tap position is (36.8559-35.4859) kV equalling to 1.37kV.

The figures 5.6 (a), (b), (c) show the simulation results of how the voltage at the HV bus behaves with the number of capacitor banks, for 21^{st}, 22^{nd} and 24^{th} of January.

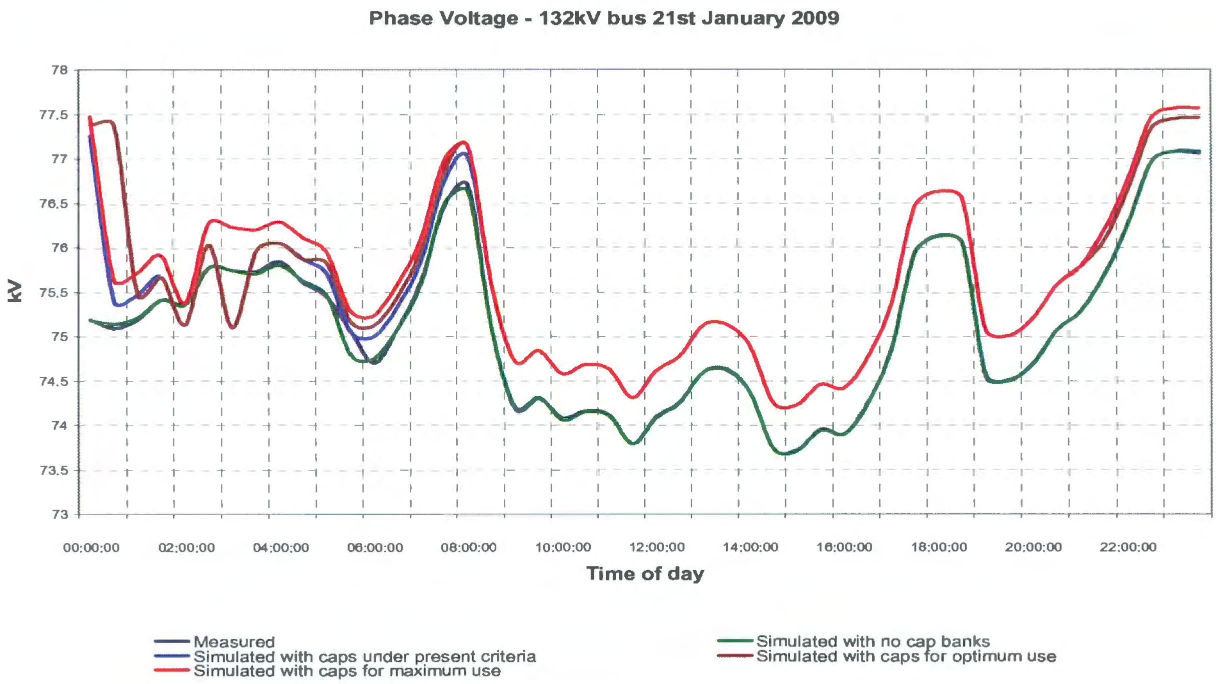


Figure: 5.6 (a)

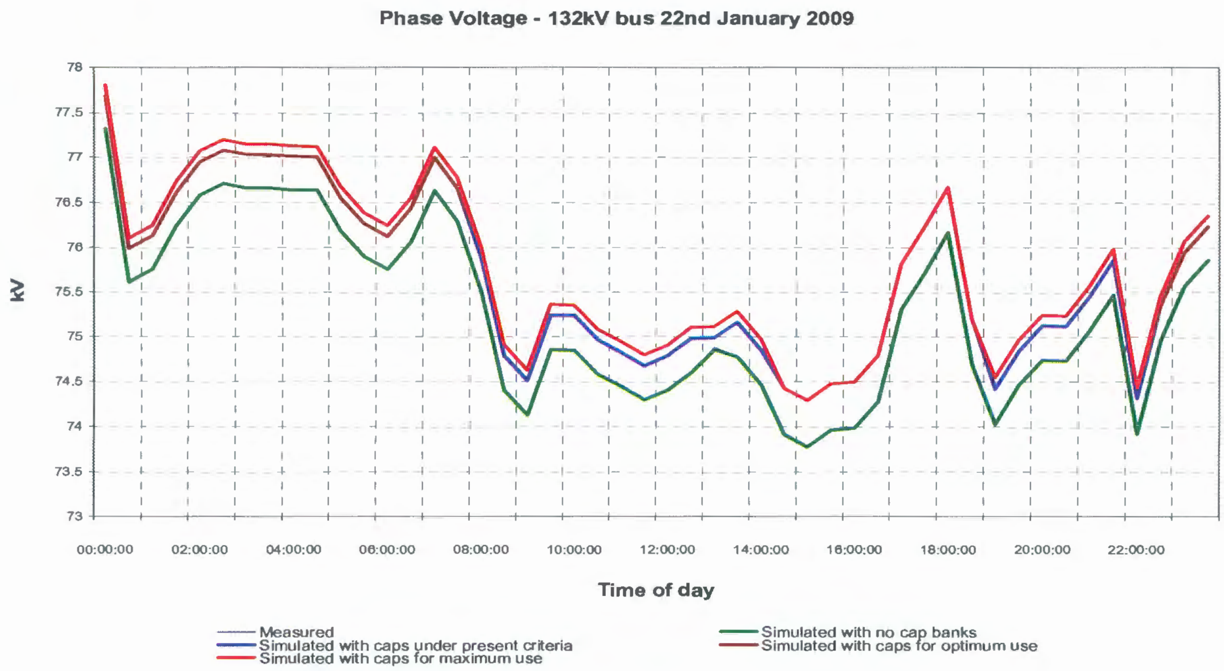


Figure: 5.6 (b)

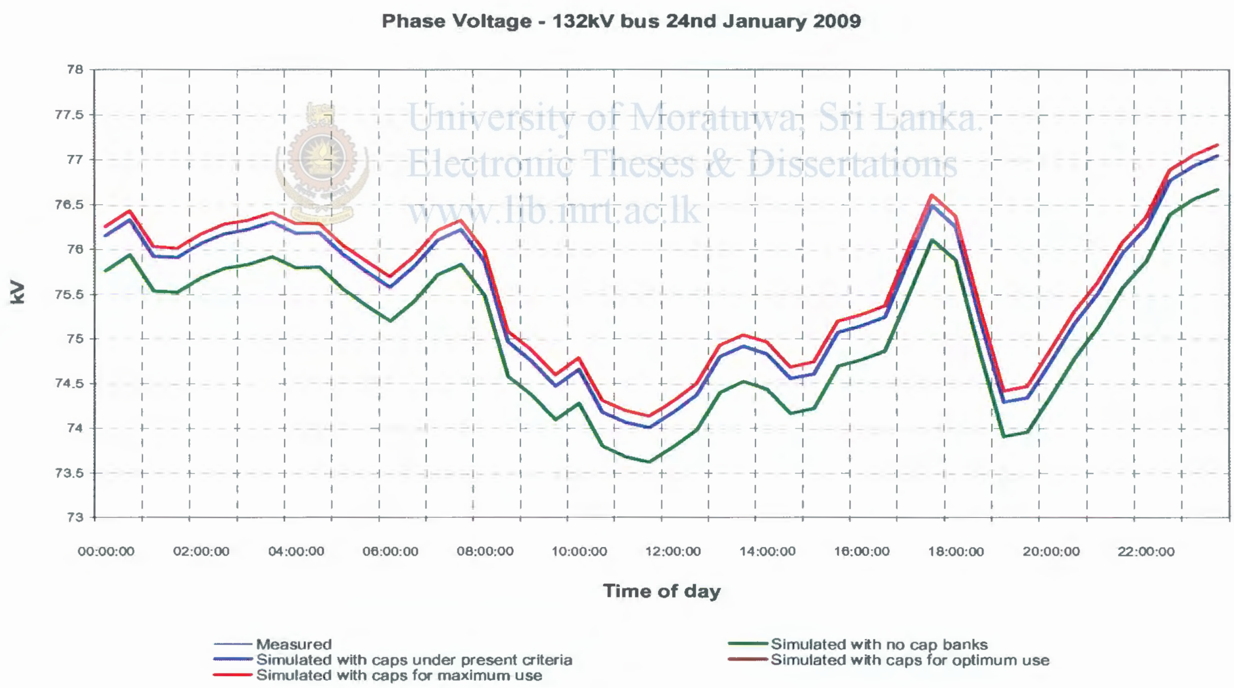


Figure: 5.6 (c)

Figure: 5.6 *HV bus voltage variations under different cap bank configurations – Simulated data for 21st ,22nd &24th Jan 2009*

Considering the above factors, switching the maximum capacitor banks under any real time condition, is obviously possible as far as the voltage rise at bus bar is concerned. With the results analyzed, a real time measurement of 132 kV voltages with all 4 capacitor banks in ON condition, was done at Panaduara substation and recorded as in the format ***Appendix 4.*** The figure 5.7 below shows the variation of high voltage side voltage under above conditions.

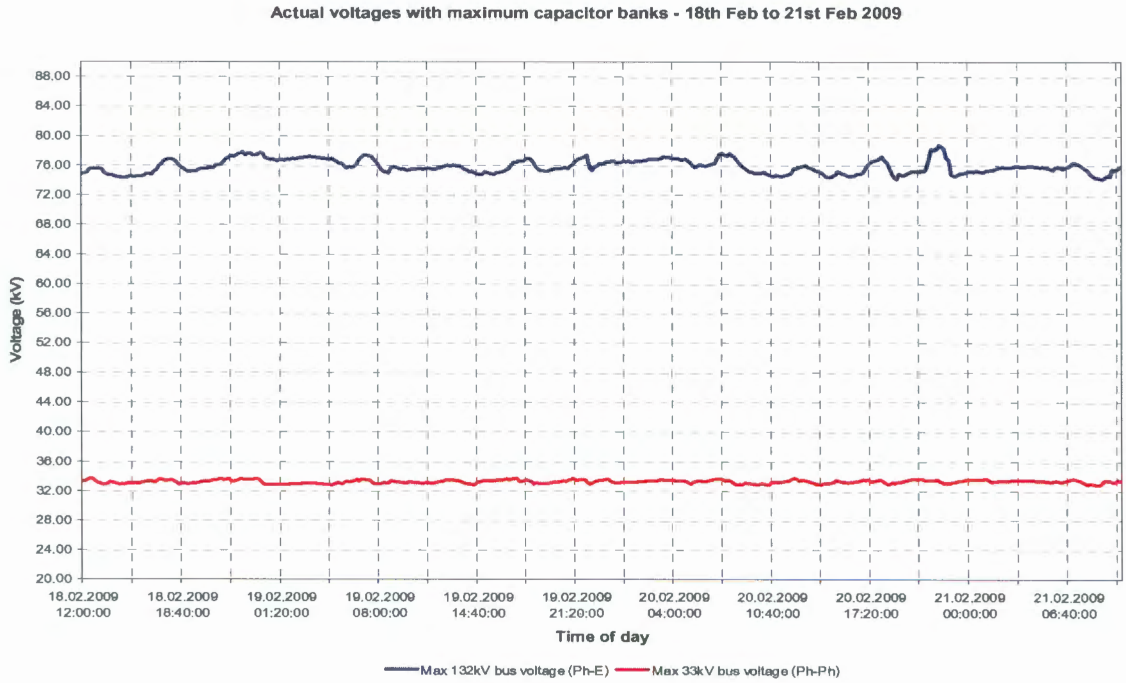


***Figure:* 5.7** *HV bus voltage values with all 4 banks in ON position – Actual measurements*

5.5 Voltage control by OLTC & AVR

As mentioned in the previous paragraph, while providing the necessary reactive power support to the system at grid substation, if the switching of the capacitor banks is not based on voltage, i.e- voltage controlled switching, and then rise of voltages beyond the nominal values has to be maintained by the AVR and tap changer. For this purpose, the voltage at 33kV bus has to be within the controllable limit of the tap positions. Otherwise, the capacitor banks will be tripped by the over voltage relay.

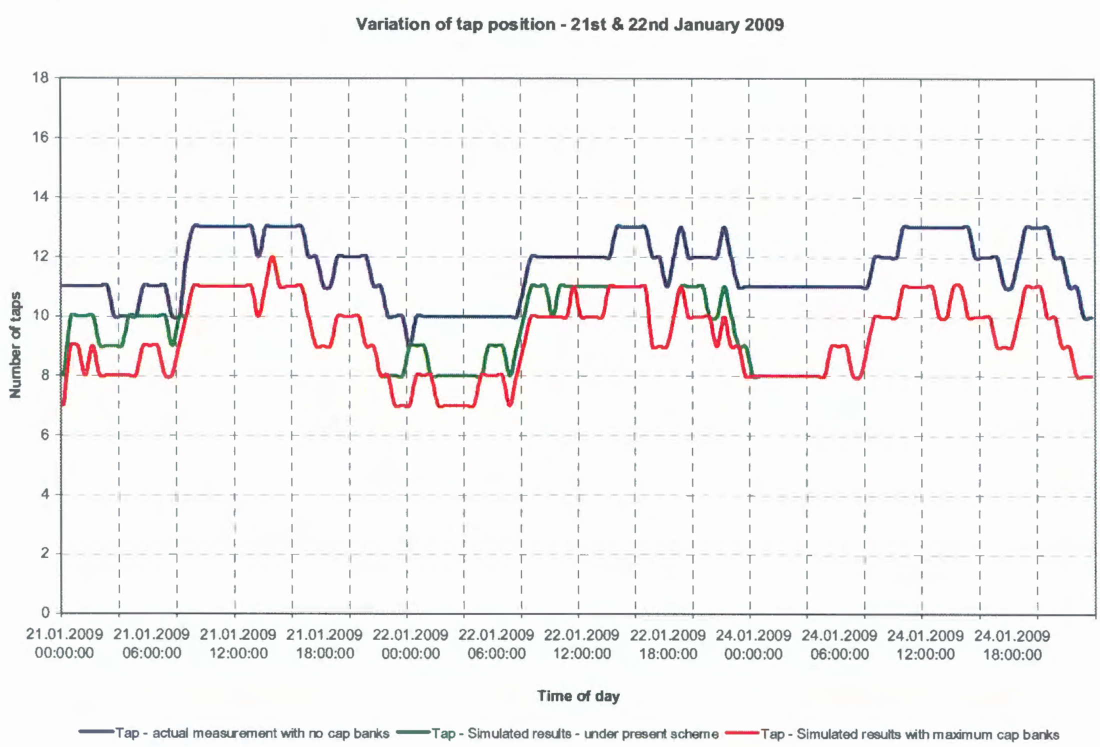


***Figure:* 5.8** *Tap position variation to give constant LV voltage– Simulation results*

The figure 5.8 shows the simulation results of variation of the tap position under maximum var support. It indicates that the tap position remains around the nominal tap and voltage variation has been handled by the taps. A real time measurement also was done to track the varying tap position throughout couple of days with all capacitors connected and the data is shown in figure 5.9.

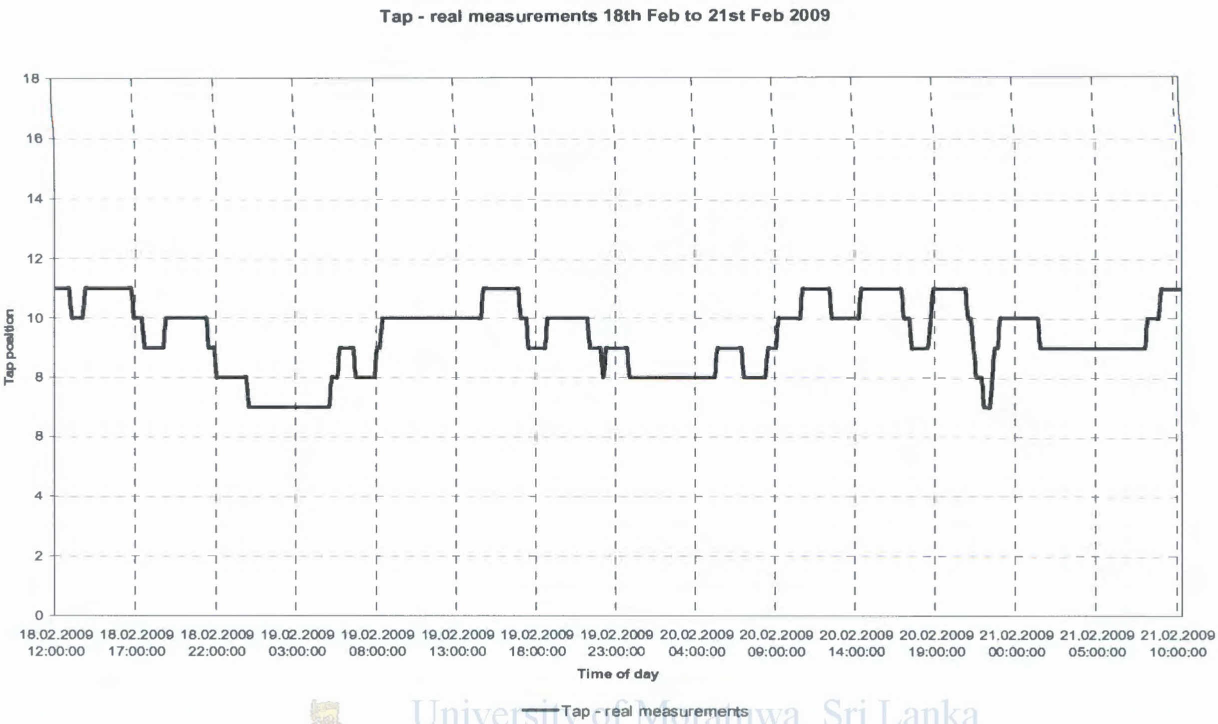


Figure: 5.9 Tap position variations to give constant LV voltage – Actual measurements

5.6 Current through the OLTC

With the present load conditions at the selected substation, the transformers are only partially loaded. Also, the minimum reactive load is around 9 Mvar.

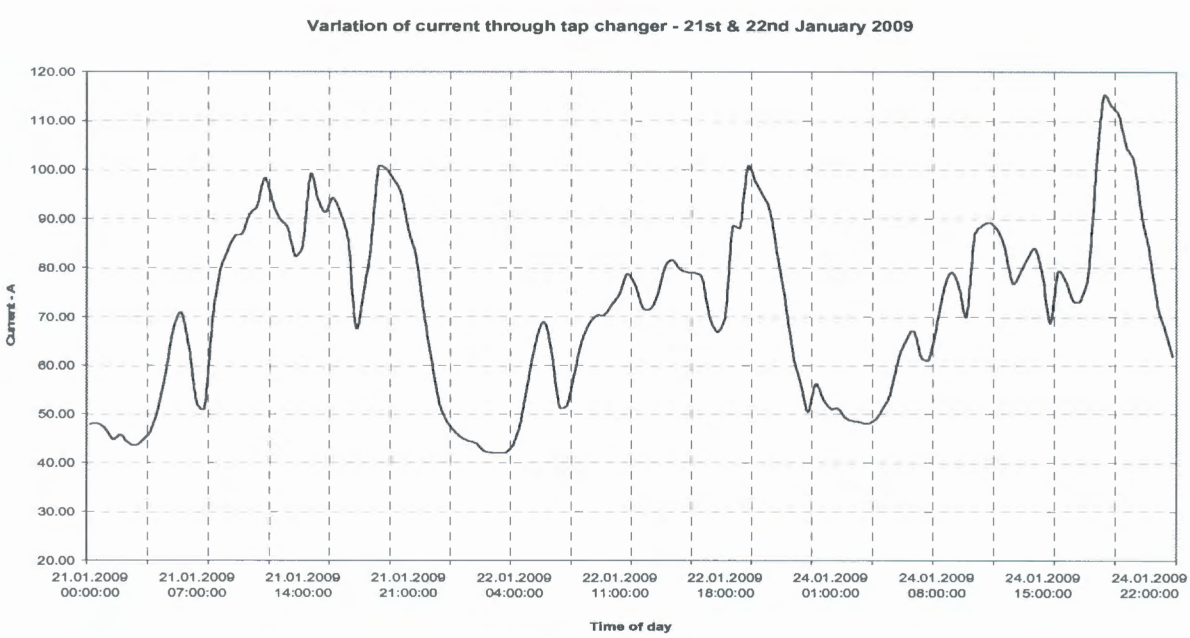


Figure: 5.10 Current variations through OLTC – Simulation results

If all capacitor banks are connected, the maximum leading reactive power flow through a transformer occurs at this stage if the bus section is closed and one transformer is out of service. Even under this condition, it does not exceed the transformer capacities and therefore it is not a factor to be worried about. However simulation was done to check the current variation through the tap changer. The particular tap changer type installed at the transformer high voltage winding can handle 200A current. Figure 5.10 shows it is well within the range of the OLTC switching current capabilities.

5.7 Effect Of resonance due to maximum capacitor banks

The effects of resonance due to adding capacitors were studied using the same PSCAD model. For tracking the frequencies at which the resonance occurs, a module named as "Interface to harmonic impedance solution" available in the master library, was used. The function of the module is to measure the impedance looking from the point of connection at different frequencies and gives an output file.

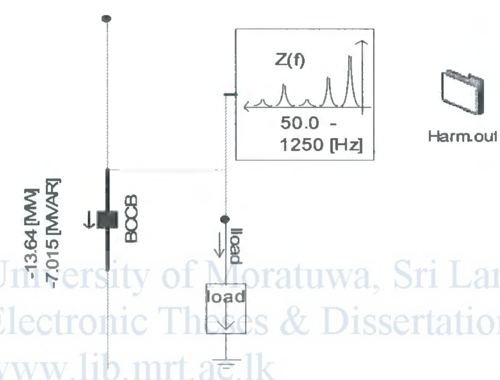


Figure: 5.11 *Module for measurement of resonance frequency*

A typical output of such a simulation run is shown in the Table 5.4. The simulations were done for different load combinations and for different substation configurations as well. By observing the data recorded from such simulation runs for different loads with all four capacitor banks kept connected, impedance Vs frequency graph was drawn. It shows three distinct frequency points where one with minimum impedance and other two with high impedances, irrespective of the load. Refer ***Appendix 5(a) &5(b)***

F(Hz)	|Z0|(ohms)	PHASE(Z0)(Deg)	|Z+|(ohms)	PHASE(Z+)(Deg)	|Z-|(ohms)	PHASE(Z-)(Deg)
50.00000000	55.09203446	-4.098444255	2.097409124	82.98484493	2.097409124	82.98484493
60.00000000	50.44407441	-24.03703513	2.558087278	83.23138944	2.558087278	83.23138944
70.00000000	43.46072201	-38.10848309	3.047037667	83.22463190	3.047037667	83.22463190
80.00000000	37.04461190	-47.88060994	3.573022622	83.03573202	3.573022622	83.03573202
90.00000000	31.75274158	-54.90963345	4.148001435	82.69569991	4.148001435	82.69569991
100.0000000	27.44952485	-60.20104551	4.788935334	82.21114615	4.788935334	82.21114615
110.0000000	23.90208802	-64.35890785	5.521017001	81.56846432	5.521017001	81.56846432
120.0000000	20.91325779	-67.75173676	6.383784086	80.73025346	6.383784086	80.73025346
130.0000000	18.33472075	-70.61360360	7.443618738	79.62166641	7.443618738	79.62166641
140.0000000	16.05674512	-73.10039898	8.821990580	78.09539609	8.821990580	78.09539609

Table: 5.4 *Typical frequency resonance output file*

The first high impedance point is in between 3rd and 4th harmonics and closed to 4th harmonic. The presence of such inter-harmonics or 4th harmonics in the system is very low so that contribution to V_{THD} is less. The 2nd high impedance point is in between 8th and 9th harmonics but very close to the 9th harmonic. The content of 9th harmonics in the system loads is higher therefore this will have an impact on the voltage distortion. The minimum impedance is falling between 4th and 5th harmonic levels and close to 5th harmonic level. This is due to the fact that the filter bank is tuned to 5th harmonic. This point does not exactly come to the 5th harmonic level since the model is approximated to a equivalent source beyond the 132kV bus, neglecting the line capacitances.

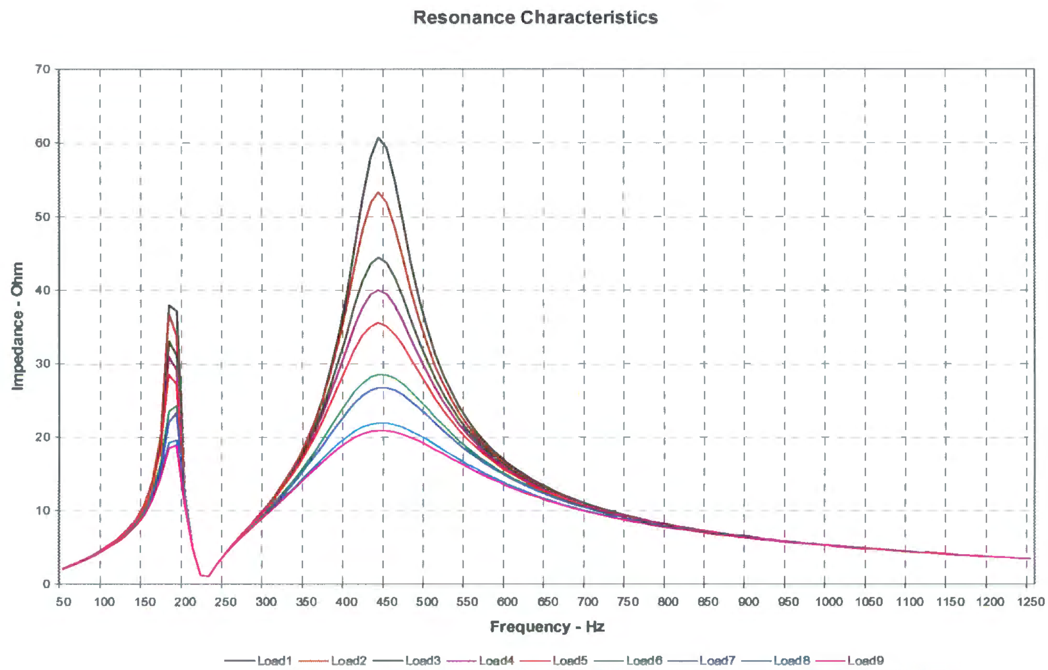
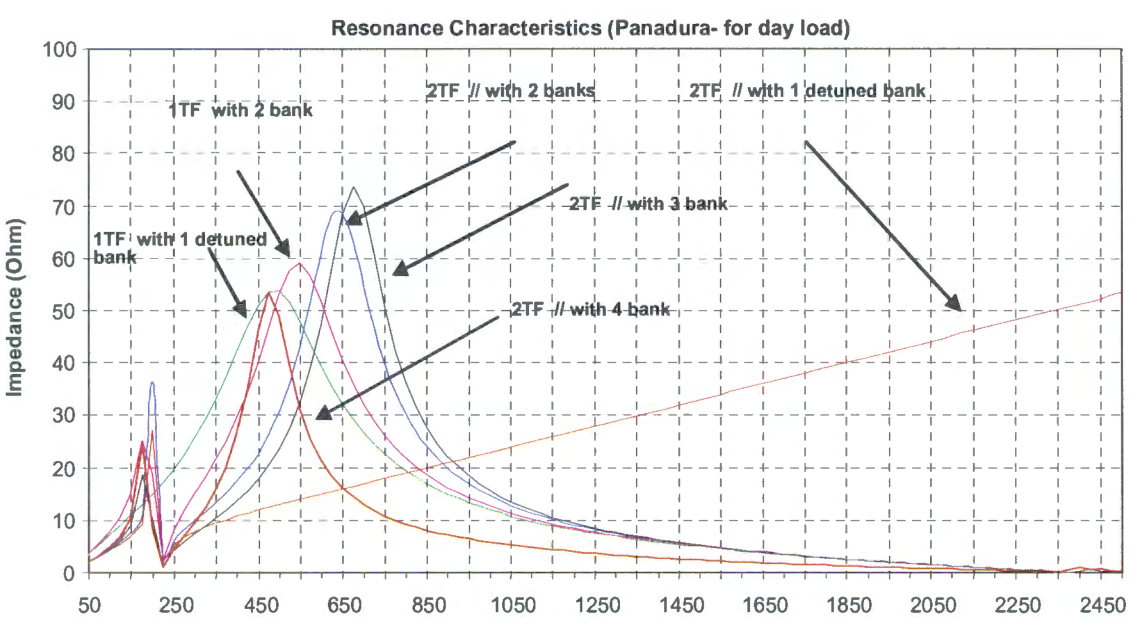
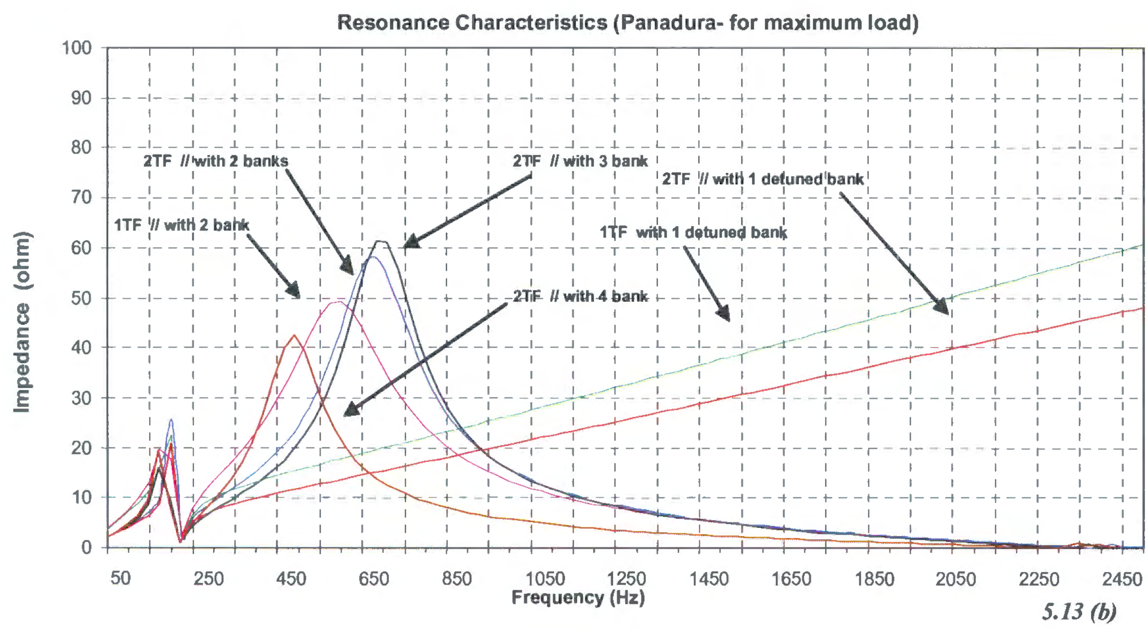


***Figure:* 5.12** *Frequency plot for different load conditions with all banks connected*

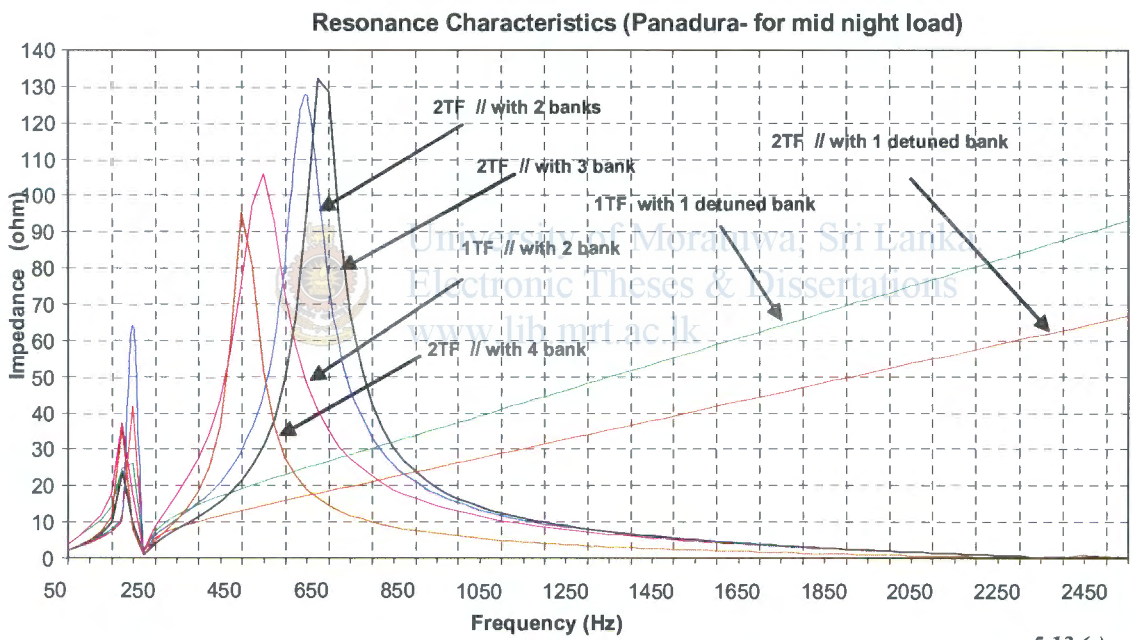
For a typical load condition, simulation was run for different tap positions but there is no significant effect on the resonance frequencies by the tap position. Figures 5.13 (a), (b) and (c) shows the resonance characteristics for different transformer / Cap bank configurations.



5.13 (a)



5.13 (b)



5.13 (c)

Figure: 5.13 *Frequency plot for different load conditions under different bank configurations*

Finally, taking the factors above into consideration, it seems that the series resonance point does not change with the load or capacitor/transformer arrangement therefore it is not a critical issue. However, the high impedance points close to harmonic levels that are present in the system will cause certain voltage distortion at the 33kV bus. Therefore, these high impedance points are to be evaluated from the voltage distortion point of view.

5.8 Effects on voltage distortion caused by harmonics under maximum capacitor banks

The same PSCAD model used for other simulations were slightly modified and added with required components to investigate the voltage distortion at the 33kV bus due switched capacitor banks in the presence of load side harmonics.

The difficulty faced in modelling for distortion level observations, was due to inability to introduce a harmonic load with specified THD level. However, it was possible to inject individual harmonic currents with amplitudes calculated according to actual measurements.

The accuracy of model was checked by recording the I_{THD} from simulation results for a set of measured values as follows (***Appendix 6***).

3rd %			5th %			7th %			9th %			11th %			13th %		
L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
6	14	13	3	3	4	2	2	1	1	1	2	1	1	1	1	1	1

For above data, I_{THD} is around 13% and the simulation result also gives the same results as shown in the figure below.

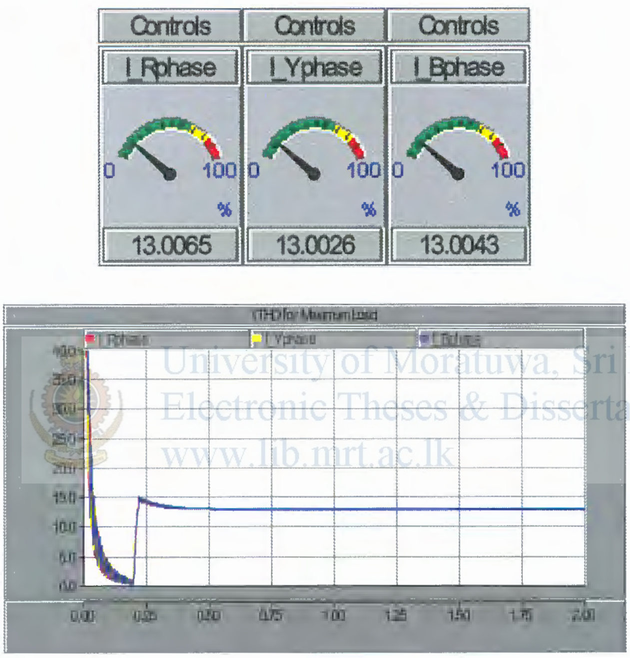


Figure: 5.14 *I_{THD} measurement for a known set of data*

Considering the observations made in resonance studies, the voltage distortion for a certain load condition was measured for each harmonic order. It shows that 3rd, 7th and 9th order harmonics give maximum contribution to the total harmonic level since the system has a high frequency point close to 3rd and 9th harmonic and also the 3rd harmonic current is dominating in load current. The results in figure 5.15 clearly indicate these results.

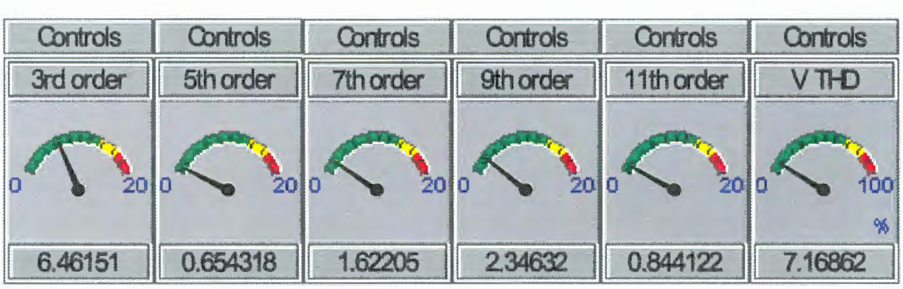


Figure: 5.15 *Individual distortion levels*

The voltage distortion level at the 33kV bus was simulated for maximum load and minimum load conditions for all four capacitor banks switched ON, 3 capacitor banks switched ON, two banks ON, one bank ON and without capacitor banks connected etc,.

Under these configurations, the voltage distortion at 33kV bus level is below 7.2% level (6.5% is the planning value as per IEC 61000-3-6 and 8% tolerance value as per EN 50160) . High distortion is resulted when all capacitor banks are connected. Therefore the impact to allowable voltage distortion levels by maximum use of capacitor banks is under acceptable levels.

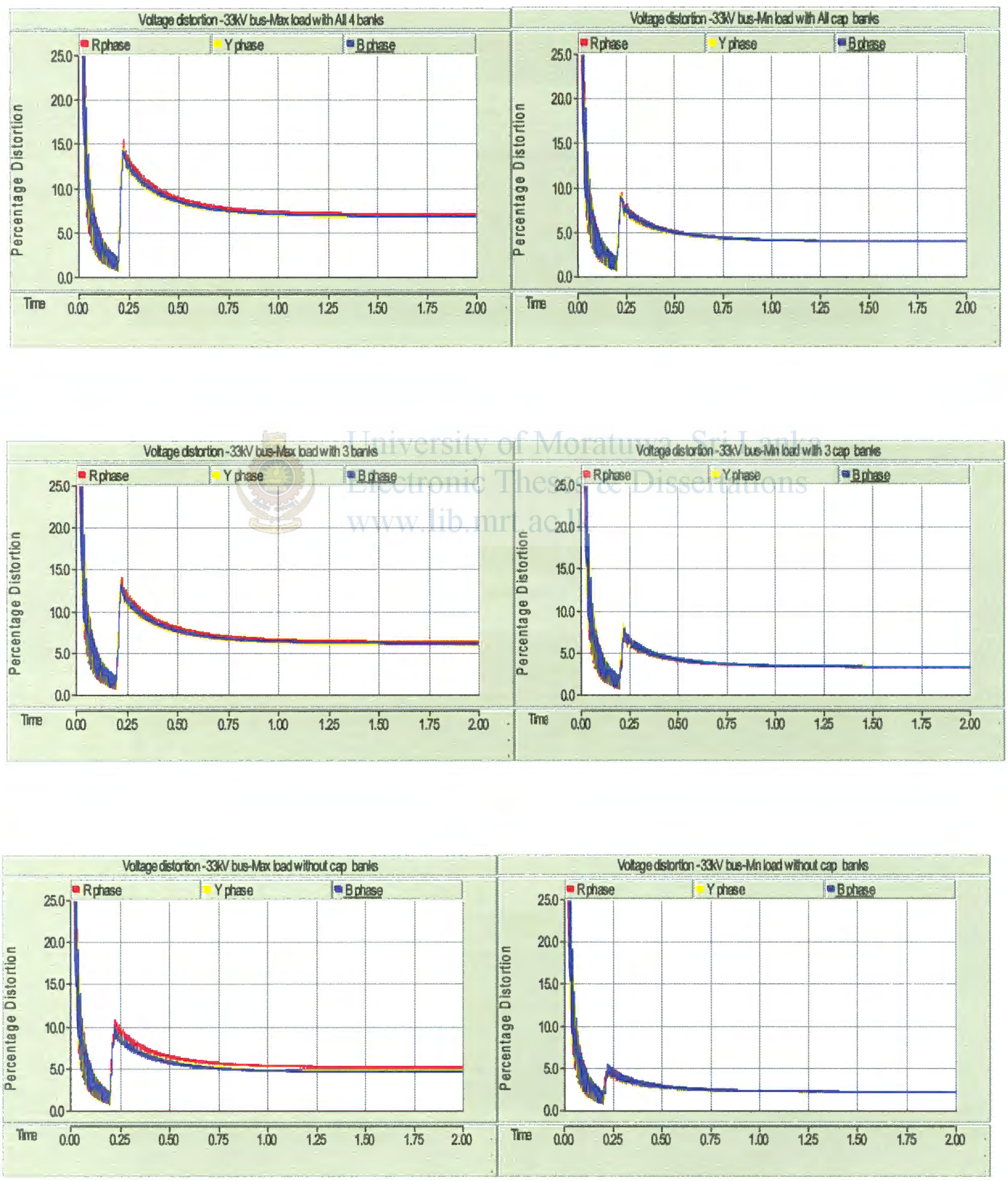
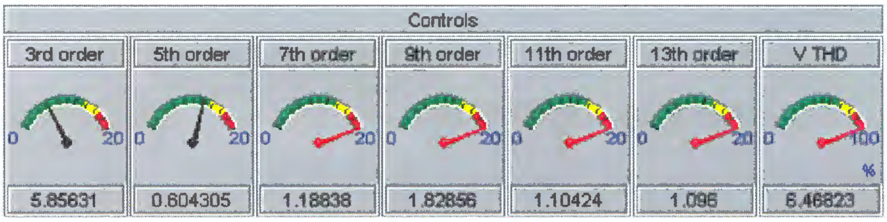


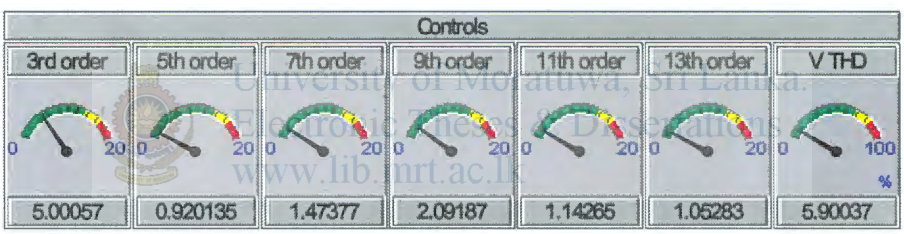
Figure: 5.16 *Voltage distortion measurements (Total harmonic distortion levels)*

For maximum load with all capacitor banks

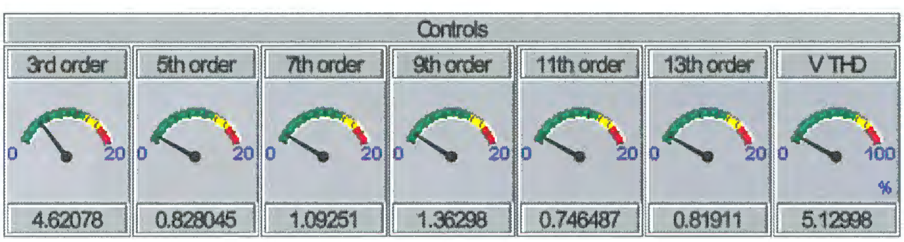


For Maximum load with three capacitor bans

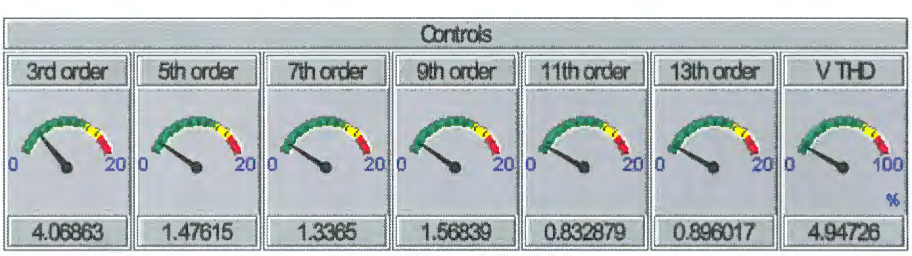
For Maximum load with two filter bans



For Maximum load with one filter and one normal



For Maximum load with one filter



For Maximum load with no filter

Figure: 5.17 *Voltage distortion measurements (Individual harmonic distortion levels)*

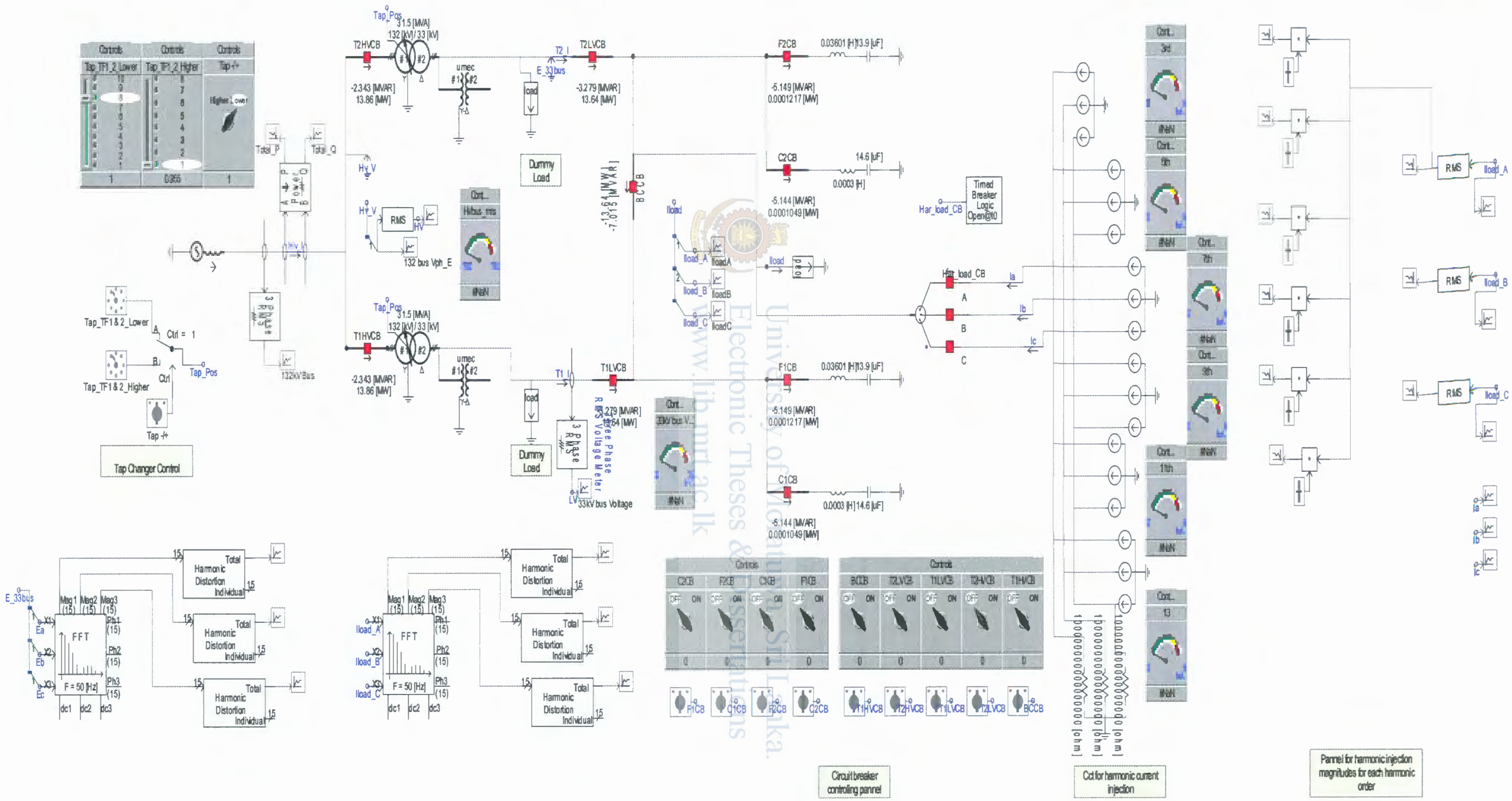


Figure: 5.18 Complete PSCAD model for voltage distortion analysis

Chapter 6

6. A Solution for switching

As discussed so far, it is clear that the power factor regulation with present parameters does neither maximize nor optimize the use of the capacitor banks installed in the selected grid substation where the losses and voltage support is concerned. The time periods in which all the capacitor banks are not switched while having an opportunity for that, were observed. Clearly, there is an opportunity to further utilize the already installed banks to reduce the losses by reducing reactive power drawn from sources and to use as an economical voltage stabilizer. The utilization of capacitor banks with the present power factor/var combined scheme is as in the figure 6.1 below. The switching pattern if pure power factor control is used is also included in the figure.

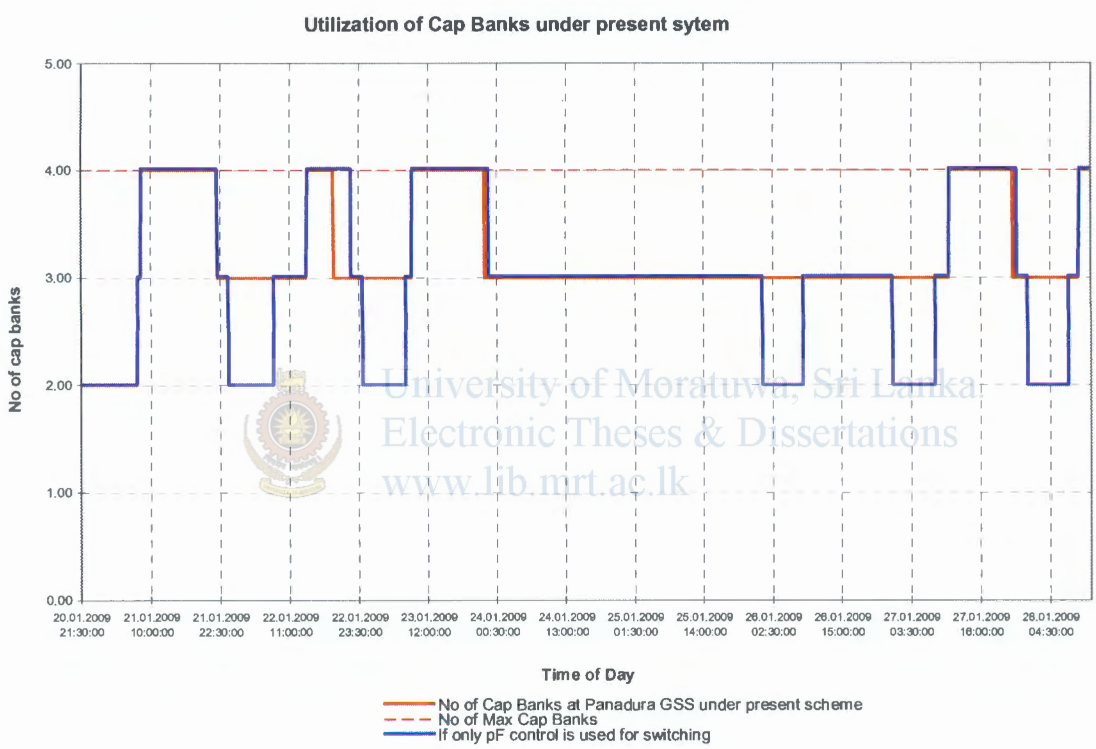


Figure: 6.1 switching pattern under present criteria

Considering the above data, the utilization of the capacitor banks calculated on daily average and with reference to maximum utilization is about 75 %. With the pure power factor control, this becomes to 70.03 %.

Calculation based on; Utilization = ($Mvar_1 * t_1 + Mvar_2 * t_2 + \_\_\_\_\_ + Mvar_n * t_n$*) / Maximum Mvar * 24)*
$Mvar_n$ *= switched capacitor rating at time slot* t_n *and* t_n *is taken as 10 min interval)*

Although these values are high, it does not indicate the optimality of the use. The present scheme contains unnecessary utilization at certain time periods. Also, it contains periods of partial utilization of capacitor banks even the opportunity is there to fully use them.

In real situation, sometimes the network operators manually switch off the banks to avoid high leading power factor and bus voltage rises or switch on the banks which are already in off position due to improved power factor. Therefore, the high utilization factor is not the mere deciding factor for the optimal usage. Loss minimization, voltage support, releasing capacity constraints etc., are the factors to be considered.

6.1 Important factors in new switching criteria

As discussed in the previous chapters, the possibility of connecting the maximum number of capacitor banks into the LV bus under any system conditions is obvious. The analysis shows that the harmful effects can be maintained with marginally affecting the regulations and not violating the technical limitations. Therefore, following conclusions can be made.

- For the selected substation, it is possible to connect all four capacitor banks under any system condition.
- Therefore, any other combinational arrangement, to suit the local requirements is also possible.

The first point can be considered in the system point of view. There are situations where the capacitor banks on the distribution substations are kept unused, while having an acute problem of heavy var requirement in transmission system. This happens mostly when power across the company's transmission system does not coincide with load conditions in locations where the capacitor banks are fixed. This situation can be mostly experienced in substations which are heavily interconnected. Under those conditions, keeping a definitely economical reactive energy source underutilized or unutilized depending on local requirements, while generation or some other means producing and transmitting them in the system, is not justifiable.

For substations like Pannipitiya where it has a installed capacity of 100 Mvar and which is still not put into operation due to some technical problems, this kind of approach may be a very economical solution. Power factor regulation with a large reactive power source will not utilize them fully. Other thing is that it is connected to both 220kV system as well as 132kV system sothat the transmission network will be a good tank for reactive power transferred from substation capacitor banks.

When power system economics are considered, CEB has to take advantages of concepts such as "ON Demand Control" to use the already installed capacitor banks in this manner. If the transmission system needs var at a location different to the location where capacitor banks are installed and if a centralized network control center monitor the load flow in its transmission system, then switching of unused capacitor banks at such a time can be used to inject reactive power. This needs a comprehensive load flow study, fully pledged SCADA system and sometimes remote station control fascility etc., to implement the above schemes. Interestingly, those are already in touch with the CEB transmission network. Therefore, if necessary CEB can use its maximum installed capacitor banks without any difficulty.

Secondly, if the first option is not the real requirement of the network, then what is important is to meet local requirements in each substation. As CEB is considered, its main objective is to maintain the bus bar voltage at the desired limit. Reduction of losses, releasing the line and transformer capacities comes as secondary aspects.

In meeting the local requirements, still the voltage and var control may be the best compared to power factor. Power factor is always an indirect measure of reactive power or the system voltage. Power factor does not consider the effects beyond the substation where sometimes it has to consider the bus voltage rise due to line capacitance. During very light loaded conditions, the line capacitances are predominant and the Ferranti effect comes into effect. In such cases, availability of considerable reactive loads at load centres is a requirement. If the substation reactive power requirement is fully compensated during these periods, the voltage rise at receiving ends will be a problem. In such cases capacitor bank switching based on voltage control may have more benefits. However, the factors like loss minimization, voltage control and the capacity release of the system components can be considered in local station point of view. Providing reactive power from capacitor banks as much as posible to compensate real load requirments while not allowing them to draw from the system is the factor to be considered. This will reduce losses and release the power transformer and transmission line capacity.

6.2 Proposal for switching criteria based on Var control

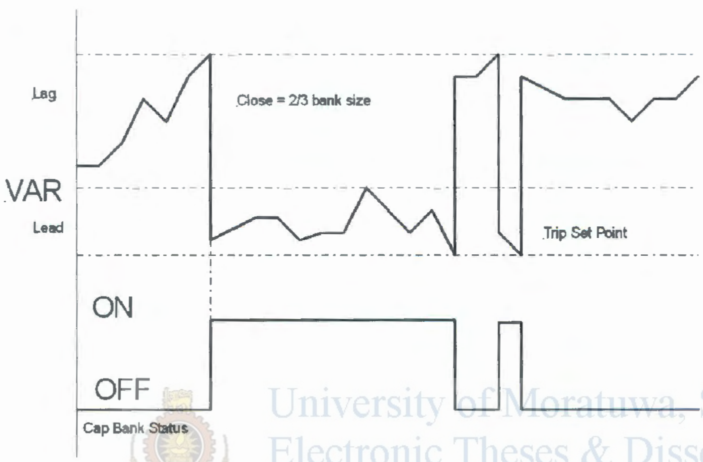


Figure: 6.2 Typical var control concept

Capacitor bank switching based on reactive power requirements is a more flexible and natural means of capacitor control concepts. It adds a fixed amount of lagging reactive power into the system regardless of most other conditions. Since the reduction of losses and the capacity release directly proportional to the reactive current drawn, injecting the reactive power at substation bus level reduces losses beyond bus towards source including the transformer.

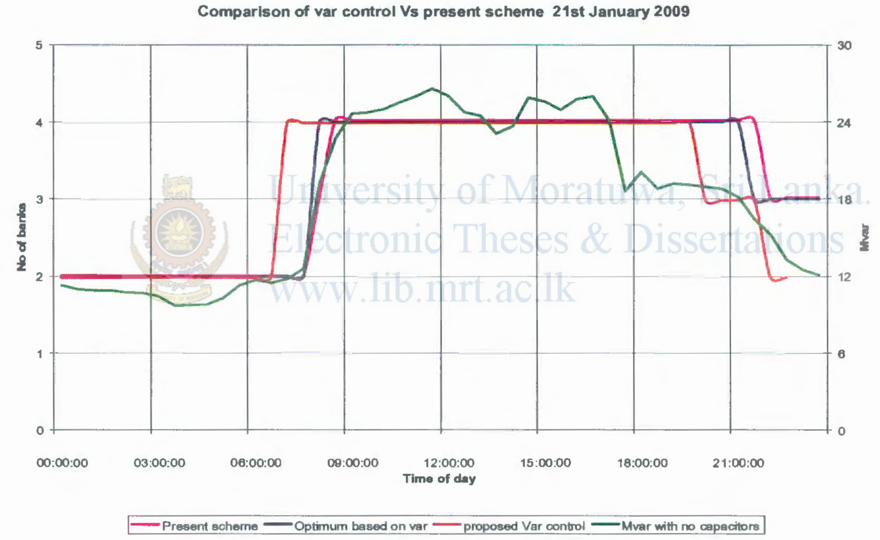
In var control based switching, due consideration has to be given to avoid hunting or PUMPING of the banks. Unless the parameters are properly set this purpose cannot be achieved. Hysteresis or restraint control is suggested to avoid such a hunting problem. As shown in figure 6.2, switching "ON" is based on about 2/3 of a step and switching off is based on an amount more than the balance 1/3 of the step in leading direction. These are typically used values decided with experience.

To avoid responding to sudden reactive power changes, restraint control or integration of inputs over certain time period can be used. These are available in most of the capacitor bank controllers.

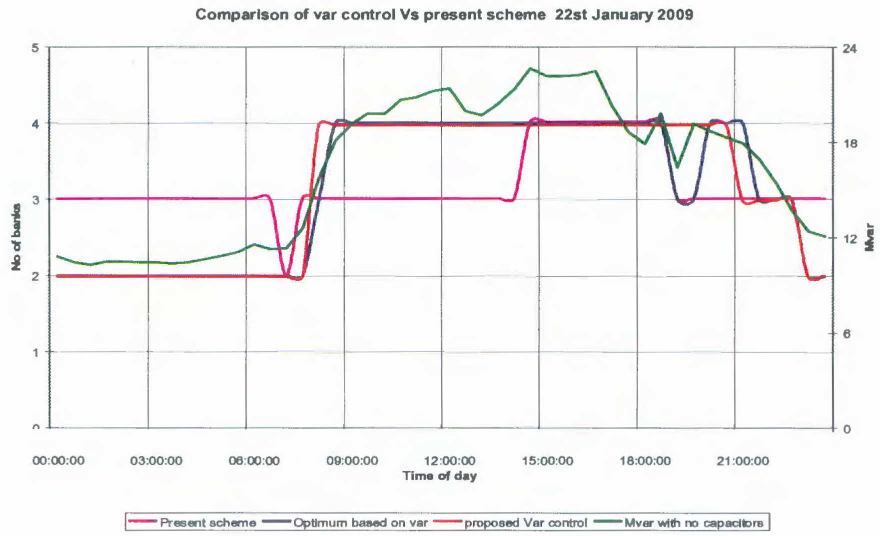
Considering the above basis, parameters for reactive power control switching for master slave control was suggested as follows. The calculated settings can be used for one setting parameter set, considering master slave control. Second set of parameters is to be defined for the independent mode. Multiple sets of parameters and switching between them depending on external inputs are regular features in modern controllers. Considering the results obtained by simulations, following points can be considered in a reactive power control based switching criteria for CEB.

- When transformers are paralleled, one controller feels only a half of the capacity of a switched bank.
- Step size of a bank is 5Mvar.
- Switching ON when lagging reactive power exceeds 2.5 *2/3 =1.6Mvar (lag)
- Switching OFF when leading reactive power exceeds (2.5 *1/3) *1.4 ≈ 1.2Mvar(lead)

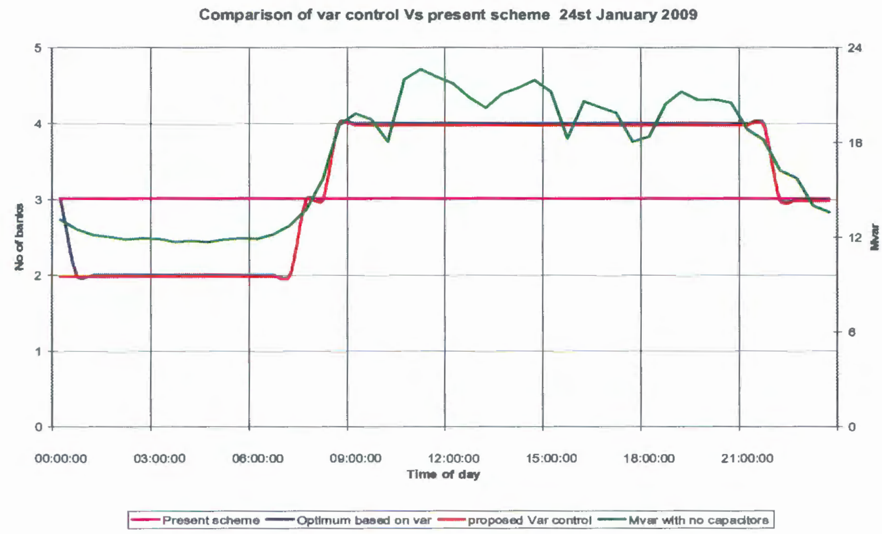
Switching points were selected from simulation results with approximated AVR control and shown in figure 6.3. The switching points based on lowest reactive power drawn from system and power factor close to unity (optimum compared to losses) was also show in the diagram.



6.3 (a)



6.3 (b)



6.3 (c)

Figure: 6.3 *comparison of switched banks under present, optimum and var control schemes*

The three figures show that the proposed switching policy based on reactive power control goes neck to neck with the loss optimized switching pattern than the present switching criteria. No of switching operations were calculated as per the switching points. A typical capacitor bank switch can operate 6times per day considering 50,000 no of operations and 20 years life time. The no of operations of the breakers are within the acceptable limits.

	Number of switching			
Date	Bank 1	Bank 2	Bank 3	Bank 4
21.01.09	0	0	2	2
22.01.09	0	0	2	2
24.01.09	0	0	1	2

Table: 6.1 *No of switching operations under proposed var control scheme*

The utilization factor is calculated based on the same criteria described early in the chapter and equals to 80%. The utilization is approximately same as the present system but the new scheme is closer to the loss optimized pattern.

Increase or decrease of energy loss was calculated based on the point that the losses are directly proportional to I^2. For all three days considered, a decrease of 1.8%, 4.9% and 5.04% was observed and average reduction in energy loss is 3.94%. (Considering only the transformer losses)

From the equation below, it is possible to calculate the capacity release of the substation and hence same capacity must be released from the generation as well [8].

$$\Delta KVA_S = \left[\sqrt{1 - \frac{(KVAR)^2 (Cos\phi)^2}{(KVA_S)^2}} + \frac{Sin\phi(KVAR)}{KVA_S} - 1 \right] KVA_S$$

Where ΔKVA_s - *release of substation*

KVA_s - *Capacity of substation*

$KVAR$ - *Capacity of next step of the banks*

Cos Φ and SinΦ - Cos and sine of power factor before adding next step

For the selected substation, addition of 5Mvar for 2 * 31.5MVA transformers at the conditions as at 8.30hrs on 24th January 2009, the capacity release ΔKVA_s was calculated as,

$$\Delta MVA_s = [\sqrt{\{1-(5 * Cos7.13/63)^2\}} + Sin7.13 * (5 / 63) - 1]63$$

$$= 0.425 \text{ MVA}$$

Date & Time	Under Present criteria								
	MW	Mvar	33 Volt	132 Volt	No of Banks	Ph angle	Utilization	HV A	Tap
24.01.2009 08:30:00	33.01	4.07	32.98	74.97	3	-7.13	7.50	76.08	10

Date & Time	Proposed var control scheme								
	MW	Mvar	33 Volt	132 Volt	No of Banks	Ph angle	Utilization	HV A	Tap
24.01.2009 08:30:00	32.6274	- 0.89685	32.7843	75.0884	4	1.574976	10.00	73.76	9

Table: 6.2 *An extract from simulation results to compare capacity release*

With the simulation results it can be calculated as;

$$\Delta MVA_s = \sqrt{(33.01^2 + 4.07^2)} - \sqrt{(32.6274^2 + .89685^2)}$$

$= 0.620$ MVA, But this is with a tap position change as well.

Therefore the simulation results can be justified. Considering the simulation results, total average energy released by switching from present scheme to proposed var control scheme is 15.64 MWh per day (calculated based on 30min sample time hence totalling energy for 30min samole) . The scheme maintains the tap close to nominal tap while keeping the 33 kV voltages also within the range. (Refer ***Appendix*** 7-Data format for *r*eactive power control switching points and summery of results)

6.3 Proposal for switching criteria based on Voltage control

Voltage control based capacitor switching in a utility substation has to follow a complex algorithm. The difficulty in voltage control based switching is due to the voltage regulator of the power transformers. When both functions try to control voltage at the same time without any coordination between them, then there will be severe mal functioning of the two controllers. This will cause hunting of capacitor banks and tap changer. Therefore, for such a control scheme, an algorithm to coordinate AVR and capacitor bank controller is required. The factors that has to be considered in such a system are,

- During switching on for decreasing bus bar voltages, the capacitors shall come first if the reactive power load is more than a portion of the minimum step of a bank otherwise the tap changer can increase the voltage. The purpose of this is to minimize the losses and adding excess leading reactive power.

- During switching off for increasing terminal voltages, AVR and the capacitor controller shall follow the same philosophy. The reactive power at the time of decision must be considered in deciding whether to reduce the tap or to switch off a capacitor bank.

- Algorithm for an above control is necessary to optimize the use of capacitor banks. If the only requirement is to control the voltage, then proper dead band selection for two controllers also can serve the purpose.

- Differentiate the integration time, the time period over which the measurement is averaged, also can be used with hysteresis control to make the control philosophy more simple.

One other thing to be considered is that when the network control centre increases the voltage at some other station having no capacitor banks by generator voltage adjustments, the substation having capacitor banks also will feel that and the bus voltage will improve. Then the capacitors will tend to switch off responding to outside voltage adjustments. This is not an economical solution.

A voltage selection scheme based on a hysteresis control as in figure 6.4 is evaluated for comparison with the present and proposed var control schemes. The approximated switching points of capacitor banks based on above voltage control scheme, was selected using the simulation results for 21st, 22nd and 24th January 2009. (***Appendix 8*** – Data format for voltage control switching points and summery of results). Figure 6.5 illustrates the comparison of present switching and the switching pattern with the proposed voltage control.

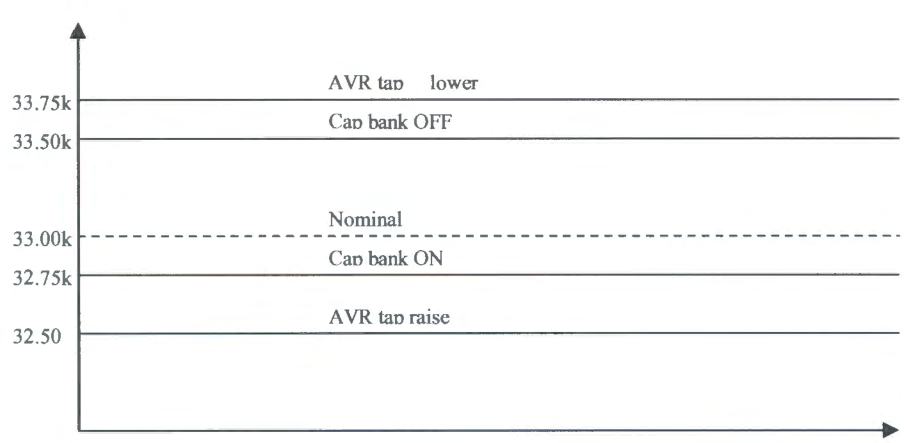
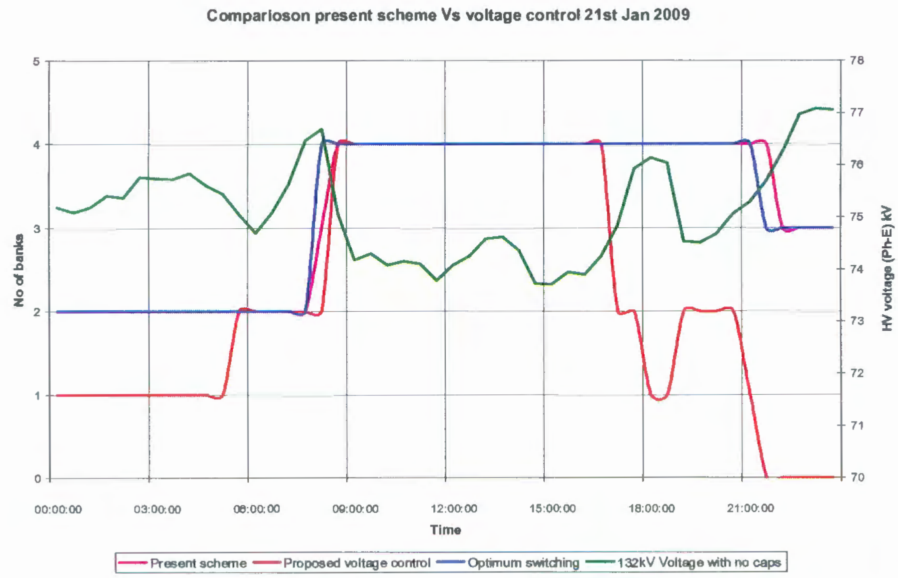
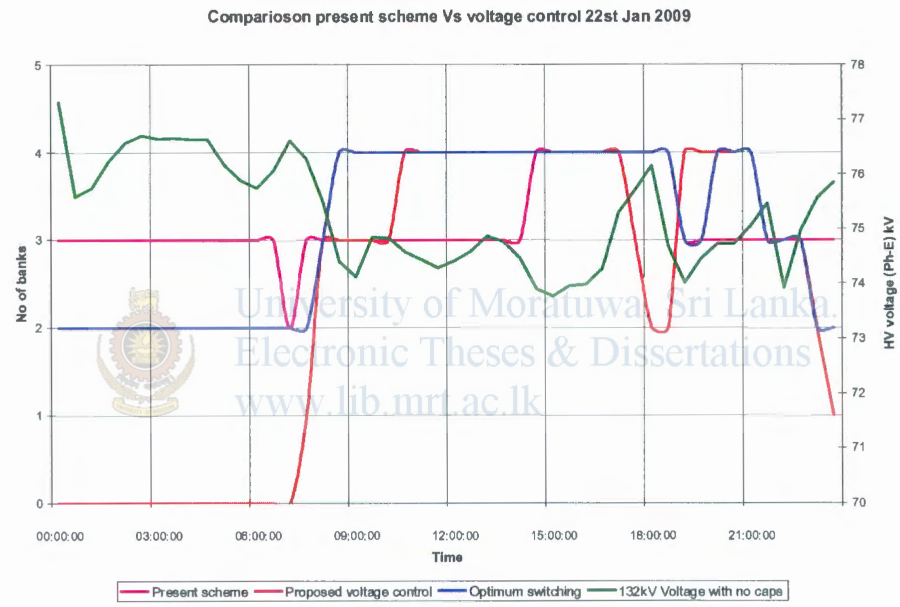


Figure: 6.4 *Proposal for dead bands for AVR and capacitor controller*



6.5 (a)



6.5 (b)

6.5 (c)

Figure:* *6.5 comparison of switched banks under present and voltage control schemes 21st 22nd &24th

The figures show that with the voltage control, maximum number of banks is maintained only at day time from around 9.00hrs to 17.00hrs. During mid night, this comes even up to zero banks, due to the voltage rise. The criterion does not maximize the utilization. Gradual switching off of banks around 17.00 to 18.00 hrs also observed due to reduction of loads after office hours. There is a voltage rise during this period and the load rises after that due to lighting. In comparison to the reactive power control, voltage control scheme is not coincides with the optimum curve.

As the data shows, following conclusions can be made.

- Maximum switching operations per 3rd and 4th banks is about 4 so that the switching does not cause any unnecessary impact.
- Utilization when voltage control is used seems to be low compared to loss optimized switching pattern. It is 55%, 58% and 77% on 21st, 22nd and 24th respectively..
- Due to reduced utilization, energy losses and substation capacity release also not be economical. However it matches with the voltage properly. Therefore, if the need is to give voltage support, then this kind of switching policy is very satisfactory.

6.4 Optimum switching solution

In operating a utility network under real conditions, some dominant local requirements that needed to be controlled by capacitor banks are to be decided. As CEB is concerned, due to the factor of concentrating the generation to certain localized areas, maintaining voltage stability is a considerable factor. Although reactive power control capacitor switching gives more benefits, sometimes it may need to switch off the capacitors in low load conditions due to higher receiving end voltages although the station at which capacitors are connected could deal its voltage rise. In that sense, voltage controlled switching can be an optimized solution for CEB although it is not economical in some aspects described earlier.

Reactive power controlled switching aiming to manually switch off the banks at low load conditions to avoid voltage effects at remote ends was evaluated. The results are shown in figures 6.7 & 6.8 (OFF from 22.30hrs to 7.00hrs next day).

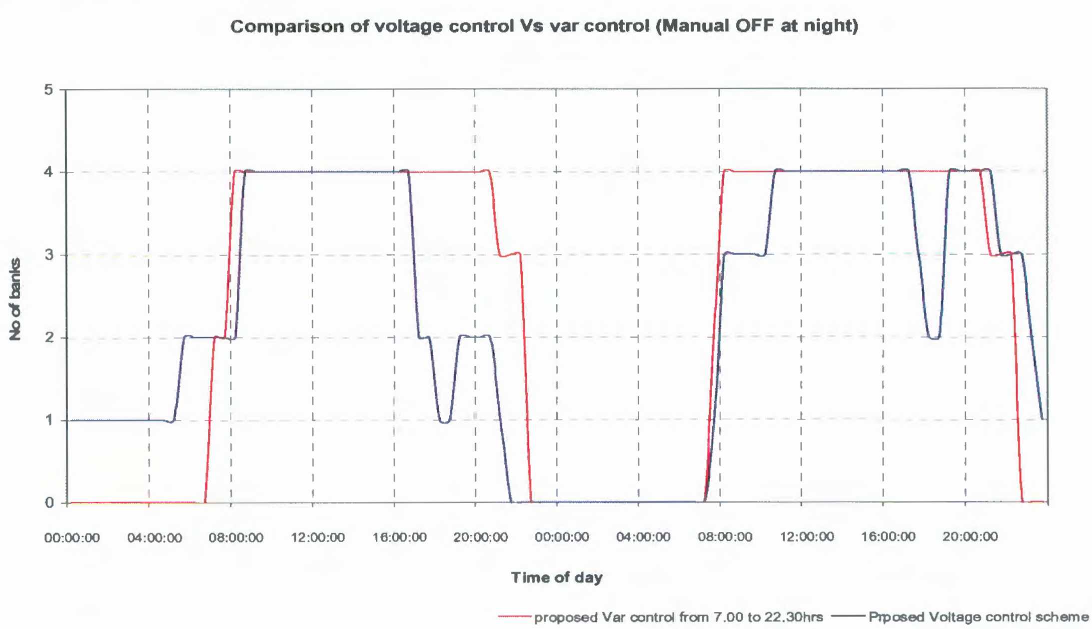


***Figure:* 6.6** *comparison of switched banks under voltage control schemes & var control with manual off - 21st &22nd*

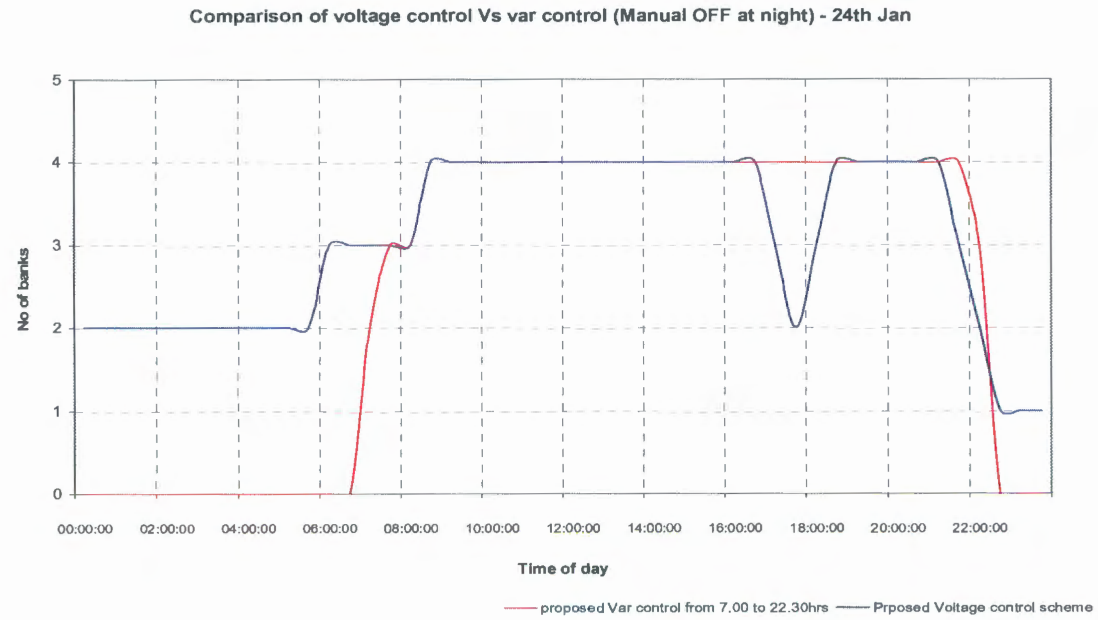


Figure:* 6.7 *comparison of switched banks under voltage control schemes & var control with manual off – 24th Jan

As we see from the drawings if reactive power controlled switching can be used as above, it can be useful. The disadvantage is the functionality of such a manual auto mixed control. However, if both voltage and reactive power combined controller having multiple variable or Boolean switching controllers can be used to switch the banks considering voltage and var, it could be a good idea.

Chapter 7

7. Conclusion and recommendations

7.1 Analysis and results

i. Using capacitor banks at 33kV sub distribution level to compensate reactive power requirement and therein, to maintain voltage stability at same level is economical and effective in the CEB system.

ii. Occasions where the capacitor banks are switched ON and OFF manually by over-riding the auto controller was frequently observed. This says that the switching criteria are not fully fit to the requirements in CEB system. The observations also show that present switching criteria at the selected substation neither maximize nor optimize the utilization.

iii. Simulations with **PSCAD** models prove the technical feasibility of maximum capacitor bank connections to the point at which they are fixed without violating the standards. Voltage rise due to reactive power injection, effects to voltage distortion and resonance due to harmonics with additional capacitor banks, switching capabilities of the on-load tap changer and the capabilities of AVR to handle voltage variations due to reactive power injection are the factors considered in the PSCAD simulations. The results and analysis reveals that it is possible to achieve the purpose without violating otherwise maintaining below the recommended limits of all relevant parameters.

iv. **PSCAD** simulations indicates that the maximum voltage rise under different capacitor bank combinations (with effective Tap control) for 21^{st}, 22^{nd} & 24^{th} are 77.57kV, 77.8kV & 77.17kV respectively. The maximum percentage rise for high voltage side is .33% and that for low voltage side is 0.95%.

v. For the worst case of conditions (which will never be allowed by the network operators),

- Maximum continues voltage at 132 bus bar is 145kV
- The minimum sub station load 17.2MW+9.6Mvar

PSCAD simulations indicate that the maximum low voltage rise is 3.8% and that for HV side is 0.56%.

vi. In the case of effects due to resonance for the selected substation, **PSCAD** simulation results shows that it occurs at an inter-harmonic condition in between 4^{th} and 5^{th} harmonics under any load condition or under any capacitor bank / transformer combination. Normally, the system does not have such inter-harmonics as per the harmonic measurements recorded for the selected sub station. For other sub stations also, such harmonics are not present.

vii. **PSCAD** simulation results indicate that the highest impedance points seen by the harmonic currents sometimes fall at inter-harmonics and sometimes on harmonic frequencies. The harmonics at which these happens slightly changes with the configuration and load as well. However, the voltage distortion levels remains marginally below 8% which is the accepted level [11].

viii. Local voltage variation due to added reactive power can be handled by the AVR and tap changer controls so that any combination of banks is feasible to connect.

ix. The current through the tap changer does not exceed its switching capacity.

x. Reactive power controlled based switching is a very much economical method of capacitor bank controlling as far as the utilization, loss reduction and capacity release is concerned. Only problem a utility may face is that, some times especially in light load conditions with long transmission lines, there may be a necessity to have some reactive power to reduce the Ferranti effects. In such cases, minimizing reactive power consumption is not desired.

xi. In real sense, for a utility like CEB where most of the generation is concentrated to certain areas, maintaining voltage stability may be a real challenge than reducing losses using capacitor banks. In such a, voltage control based capacitor switching will be a good solution.

7.2 Conclusion

Considering all these factors discussed so far, followings are the conclusions from this research study.

i. Present capacitor bank switching philosophy based on power factor regulation does not give maximum benefits to the CEB transmission network. This scheme neither maximizes nor optimises the utilization.

ii. Considering the installed capacities and step sizes in each substation, it is technically possible to utilize the full installed capacities in all substations without violating the technical standards.

iii. Therefore, it is technically feasible to back feed the excess capacitor bank capacity for reactive power compensation in the transmission network.

iv. Use of a switching policy based on reactive power control or voltage control is more useful as far as the CEB system is considered. Reactive power based switching which is simple, is useful for loss minimization and voltage based control is useful when voltage stability is concerned.

v. Considering the factors discussed in 7.1 viii and ix, for network like CEB, it is useful to consider the controllers with multi-parameter or Boolean switching options. Reactive power and voltage can be the parameters to be considered in the switching decisions.

7.3 Recommendations for future studies

When introducing a switching criterion based on the voltage, the co-relation between AVR loop and capacitor controller loop is an important factor and need to be studied in details. Therefore it is recommended to study an algorithm to correlate these two control loops who tries to control the same parameter at the same time, to avoid unnecessary pumping of capacitor banks and hunting the tap changer.

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Appendix 1(a) – Capacitor bank details in CEB system

GSS	Point of connection	Mvar Rating	Currently Available	Configuration	Bank type 1		Bank type 2	
					C / Phase (μF)	L / Phase (mH)	C / Phase (μF)	L / Phase (mH)
Habarana	33kV BB	10	10	tf1-1x5Mvar(type1)	14.6	0.300	13.9	36.01
				tf1-1x5Mvar(type2)				
Panadura	33kV BB	20	20	tf1-2x5Mvar(type1 & 2 each)	14.6	0.300	13.9	36.01
				tf2-2x5Mvar(type1 & 2 each)				
Kiribathkumbura	33kV BB	20	20	tf1&3-2x5Mvar(type1 & 2 each)	14.6	0.300	13.9	36.01
				tf2-2x5Mvar(type1 & 2 each)				
Puttalam	33kV BB	20	20	tf1-2x5Mvar(type1 & 2 each)	14.6	0.300	13.9	36.01
				tf2-2x5Mvar(type1 & 2 each)				
Kurunegala	33kV BB	10	10	tf1-1x5Mvar(type1)	14.6	0.300	13.9	36.01
				tf1-1x5Mvar(type2)				
Galle	33kV BB	20	20	tf1-2x5Mvar(type1)	14.6	0.100		
				tf2-2x5Mvar(type1)				
Matugama	33kV BB	20	20	tf1&3-2x5Mvar(type1)	14.6	0.100		
				tf2-2x5Mvar(type1)				
Old Anuradapura	33kV BB	20	20	tf1-2x5Mvar, tf2-2x5Mvar	14.6	0.100		
Kotugoda (stage 1)	33kV BB	20	20	tf1-2x5Mvar, tf2-2x5Mvar	14.6	0.100		
Kotugoda (stage 2)	33kV BB	30	30	tf1-3x5Mvar, tf2-3x5Mvar	14.6	0.255		
Athurugiriya	33kV BB	20		Not energized due to technical problems				
Thulhiriya	33kV BB	10		Not energized due to technical problems				
Pannipitiya	A TF 33kV winding	100		Not energized due to technical problems				

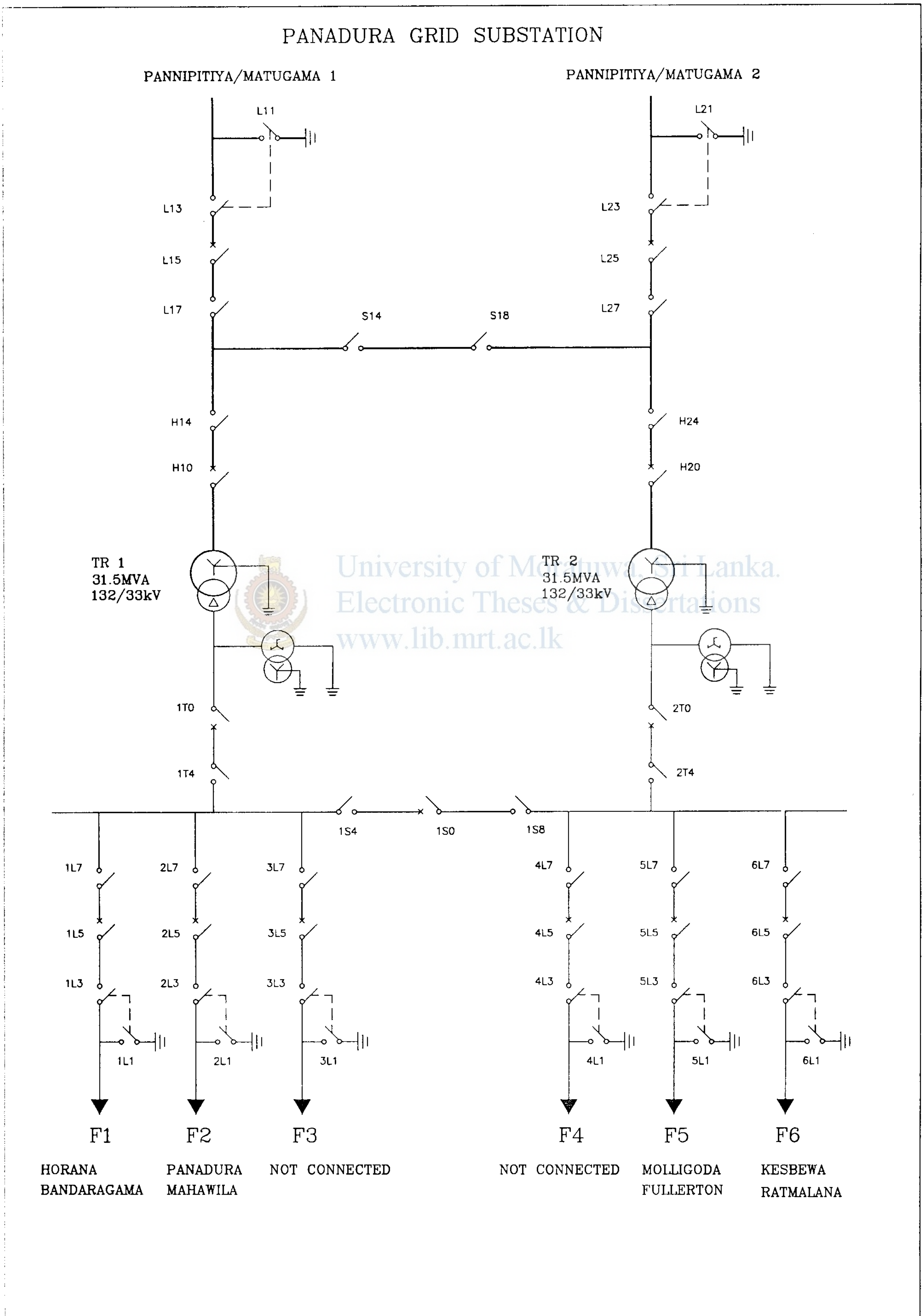
GSS		Fault Level (kA)		Transformers							Earthing TF	
		132kV bus	220kV bus	No	Type	Rating	Vector	Taps	AVR	% Impedance	Rating	Vector
***	Habarana	5.5		1,2	HYUNDAI TL 666	23 31.5 MVA	YNd1	18	MR VIII 350 Y	.1046 at 31.5 MVA	0.2	ZNyn11
***	Panadura	12.5		1,2	HYUNDAI TL 288	23 31.5	YNd1	18	MR VIII Y350	.1000 at 31.5 MVA	0.2	ZNyn11
***	Kiribathkumbura	9.6		1,2	EGB. LINZ. AUSTRIA DOR35500 130E	23 31.5 MVA	YNd1	13	MR VIII 200 Y 60	.1090 at 31.5 MVA	0.2	ZNyn11
				3	PAUWELS TRAFO 13	73 - 100% 31.5MVA	YNd1	13	MR MS III 300-72.5-ED	.1090 at 31.5 MVA	0.2	ZNyn11
***	Puttalam	5.2		1,2	HYUNDAI TL 288	23 31.5	YNd1	18	MR VIII Y350	.1000 at 31.5 MVA	0.2	ZNyn11
***	Kurunegala	5.1		1,2	PAUWELS TRAFO 19	73 - 100% 31.5MVA	YNd1	19	MR MS III 300-72.5-ED	.1000 at 31.5 MVA	0.2	ZNyn11

*	Galle	5		1	ALSTHOM SAVOISIENNE	23.1 30MVA	YNd1	21	ALSTHOM MAC 27	.1040 at 30 MVA	0.2	ZNyn11
				2		31.5				.1029 at 31.5 MVA		
*	Matugama	8.2		1,2	HYUNDAI TL 288	23 31.5	YNd1	18	MR VIII Y350	.0998 at 31.5 MVA	0.2	ZNyn11
				3	PAUWELS TRAFO 18	73 - 100% 31.5MVA	YNd1	18	MR MS III 300-72.5-ED	.1000 at 31.5 MVA	0.2	ZNyn11
*	Old Anuradapura	6.5		1	ABB ELTA TNARCA 31500 132PT	23 31.5 MVA	YNd1	18	MR V III 200 Y 60 1081G	.1000 at 31.5 MVA	0.2	ZNyn11
				2	ALSTHOM SAVOISIENNE THGE 145 11000	10 MVA	YNd1	21	ALSTHOM K4900	.1000 at 10 MVA	0.2	ZNyn11

*	Kotugoda (stage 1)	18	19	1,2	TAKAOKA AUTOTRANSFORMER	200 3 250 3 HV 60 3 LV	YNa0d1	13 (MV)/ 13(LV)	MR	H-M 0.138 at 250 MVA	0.2	ZNyn11
**	Kotugoda (stage 2)									H-L 0.899 at 250MVA		
										M-L 0.899 at 250MVA		

*	Athurugiriya											
*	Thulhiriya											
*	Pannipitiya											

Appendix 1(b) – Substation arrangement – Panadura Grid sub station



Appendix 2(b) - Comparison of measured tap with no capacitor banks and all capacitor banks

ime of day	With capacitors					Without capacitors							
	Day 1	Day 2	Day 3	Day 4		Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12
0.00		7	8	10		11	9	10	11	10	10	10	9
0.30		7	8	10		11	10	10	11	10	10	10	9
1.00		7	8	10		11	10	10	11	10	10	10	9
1.30		7	8	9		11	10	10	11	10	10	10	9
2.00		7	8	9		11	10	10	11	10	10	10	9
2.30		7	8	9		11	10	10	11	10	10	10	9
3.00		7	8	9		11	10	10	11	10	10	10	9
3.30		7	8	9		10	10	10	11	10	10	10	9
4.00		7	8	9		10	10	10	11	10	10	10	9
4.30		7	8	9		10	10	10	11	10	10	10	9
5.00		7	8	9		10	10	10	11	10	10	10	9
5.30		8	9	9		11	10	10	11	10	10	11	10
6.00		9	9	9		11	10	11	11	10	10	11	10
6.30		9	9	9		11	10	11	11	10	10	11	10
7.00		8	8	9		11	10	10	11	10	10	11	10
7.30		8	8	9		10	10	10	11	10	10	11	10
8.00		9	8	9		10	11	11	11	10	11	11	10
8.30		10	9	10		12	12	12	12	10	12	12	10
9.00		10	9	11		13	12	12	12	10	12	13	10
9.30		10	10	11		13	12	13	12	10	12	13	10
10.00		10	10	11		13	12	13	12	10	13	13	10
10.30		10	10			13	12	13	13	12	13	13	10
11.00		10	11			13	12	13	13	12	13	13	10
11.30		10	11			13	12	13	13	12	13	14	10
12.00	11	10	11			13	12	13	13	12	13	14	
12.30	11	10	10			13	12	13	13	12	13	14	
13.00	10	10	10			13	12	12	13	12	13	13	
13.30	10	10	10			12	12	12	13	12	13	13	
14.00	11	10	10			13	12	12	13	12	13	13	
14.30	11	10	11			13	13	13	13	12	13	13	
15.00	11	11	11			13	13	13	13	12	13	13	
15.30	11	11	11			13	13	13	12	12	13	13	
16.00	11	11	11			13	13	13	12	12	13	13	
16.30	11	11	11			13	13	13	12	11	13	13	
17.00	10	10	10			12	12	12	12	11	11	12	
17.30	9	9	9			12	12	11	11	11	11	12	
18.00	9	9	9			11	11	11	11	11	11	11	
18.30	9	9	9			11	12	13	12	11	12	12	
19.00	10	10	11			12	13	13	13	12	13	13	
19.30	10	10	11			12	12	13	13	12	13	13	
20.00	10	10	11			12	12	13	13	12	13	13	
20.30	10	10	11			12	12	12	13	12	13	12	
21.00	10	10	10			12	12	12	12	12	12	12	
21.30	9	9	8			11	12	11	12	11	11	11	
22.00	8	9	7			11	13	11	11	10	10	11	
22.30	8	9	8			10	12	11	11	10	10	10	
23.00	8	9	10			10	11	10	10	10	10	10	
23.30	8	9	10			10	11	11	10	10	10	9	

APPENDIX 3(a) - Format for results on network simulation- PSCAD file for 21st January 2009

Simulation Data for 21.01.2009							
Multiple Run Output File 21_0000_0banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.00524558	33.48471654	-28.91023986	20.78008205	11.47616236	.1165057576
2	.9850000000	77.01242372	32.98050846	-28.91024104	20.15900734	11.13316304	.1130230792
3	1.000000000	77.01928109	32.49117551	-28.91024039	19.56526546	10.80525875	.1096948103
4	1.015000000	77.02583653	32.01607269	-28.91023964	18.99728158	10.49157976	.1065119720
1	.9550000000	75.18346966	33.18511965	-28.90357332	20.40597652	11.26835132	.7713554950E-01
Multiple Run Output File	21_0000_1banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.13063993	33.80064876	-16.97142608	21.17382970	6.461996056	.1074130153
2	.9850000000	77.13405939	33.29007976	-16.97142261	20.53903229	6.268262417	.1042006975
3	1.000000000	77.13732411	32.79464368	-16.97142103	19.93228385	6.083089504	.1011310896
4	1.015000000	77.14044329	32.31368014	-16.97141958	19.35196030	5.905981935	.9819587508E-01
Multiple Run Output File	21_0000_2banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.25832347	34.12434875	-3.338005934	21.57771560	1.258468439	.6794454748E-01
2	.9850000000	77.25789239	33.60726631	-3.339223622	20.92905232	1.221310032	.6591664180E-01
3	1.000000000	77.25750360	33.10557628	-3.337917828	20.30879510	1.184935209	.6397523240E-01
4	1.015000000	77.25712171	32.61861369	-3.335508293	19.71528735	1.149592704	.6211487648E-01
5	1.015000000	77.25712171	32.61861369	-3.335508293	19.71528735	1.149592704	.6211487648E-01
Multiple Run Output File	21_0000_3banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.38861778	34.45230995	10.69121078	21.99452264	-4.151149007	.6915652900E-01
2	.9850000000	77.38426922	33.92853348	10.68872963	21.33060859	-4.026310122	.6708021276E-01
3	1.000000000	77.38008298	33.42055259	10.68597805	20.69732342	-3.905589441	.6510284018E-01
4	1.015000000	77.37613631	32.92748610	10.68736488	20.09086688	-3.792102475	.6320747924E-01
5	1.030000000	77.37229255	32.44874187	10.68637580	19.51109591	-3.681892354	.6140103059E-01
Multiple Run Output File	21_0000_4banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.52127304	34.78613246	23.53346296	22.42309594	-9.765548278	.7427919654E-01
2	.9850000000	77.51293442	34.25562904	23.53508901	21.74406272	-9.470916070	.7205608893E-01
3	1.000000000	77.50495217	33.74110889	23.53504725	21.09589055	-9.188312885	.6991474587E-01
4	1.015000000	77.49730680	33.24172701	23.53789338	20.47591534	-8.918656265	.6787006581E-01
5	1.030000000	77.48998281	32.75699467	23.53466724	19.88322808	-8.660277677	.6591994194E-01
6	1.045000000	77.48296363	32.28621325	23.53510204	19.31578806	-8.413063256	.6405660403E-01
Multiple Run Output File 21_0030_0banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.00524558	33.48694984	-28.91023986	20.78008205	11.47616236	.7661913899E-01
2	.9850000000	77.01242372	32.98271334	-28.91024104	20.15900734	11.13316304	.7432886575E-01
3	1.000000000	77.01928109	32.49335258	-28.91024039	19.56526546	10.80525875	.7214012965E-01
4	1.015000000	77.02583653	32.01822255	-28.91023964	18.99728158	10.49157976	.7004702474E-01
Multiple Run Output File	21_0030_1banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	77.13063993	33.80286647	-16.97142608	21.17382970	6.461996056	.7063815449E-01
2	.9850000000	77.13405939	33.29226967	-16.97142261	20.53903229	6.268262417	.6852573129E-01
3	1.000000000	77.13732411	32.79680637	-16.97142103	19.93228385	6.083089504	.6650712117E-01
4	1.015000000	77.14044329	32.31581619	-16.97141958	19.35196030	5.905981935	.6457687843E-01
Multiple Run Output File	21_0030_2banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.39278847	33.27852734	-2.670006829	19.63244992	.9154634266	.6338808721E-01
2	.9850000000	75.39223421	32.77409036	-2.669217346	19.04162845	.8876354555	.6149058731E-01
3	1.000000000	75.39170817	32.28464290	-2.668665422	18.47697173	.8608543472	.5967500481E-01
4	1.015000000	75.39117052	31.80967227	-2.670789836	17.93781681	.8367669027	.5794394097E-01
Multiple Run Output File	21_0030_3banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.52006321	33.59854148	11.95011566	20.01172131	-4.235325610	.6478155760E-01
2	.9850000000	75.51568776	33.08763200	11.95050773	19.40792785	-4.107581368	.6284184710E-01
3	1.000000000	75.51148304	32.59202894	11.95121222	18.83061055	-3.985746708	.6098139862E-01
4	1.015000000	75.50744840	32.11102547	11.95077679	18.27910791	-3.868604512	.5921376496E-01
Multiple Run Output File	21_0030_4banks						
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.64971731	33.92456369	25.15776741	20.40169061	-9.581636754	.7013364073E-01
2	.9850000000	75.64137957	33.40697012	25.15464744	19.78399641	-9.290850358	.6803271481E-01
3	1.000000000	75.63344434	32.90492621	25.15622969	19.19382981	-9.014038178	.6601222164E-01
4	1.015000000	75.62581500	32.41782706	25.15851896	18.62985243	-8.749207225	.6408217049E-01
Multiple Run Output File 21_0100_0banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.21320236	33.25382425	-29.86454626	18.94153074	10.87636156	.7224249489E-01
2	.9700000000	75.14556977	32.65648976	-29.37426187	18.90572067	10.64172559	.7188783677E-01

APPENDIX 3(b) - Format for Summery of simulation results for 21st . 22nd January 2009

Date & Time	With No cap Banks: Total P (MW)	Total Q (Mvar)	Ave Voltage LV(kV)	Ave. Phase angle	Ave. Voltage HV(kV)	No of Banks	Tap	No caps - Simulation results: Total P (MW)	Total Q (Mvar)	Ave Voltage LV(kV)	Ave Phase angle	Ave. Voltage HV(kV)	No of Banks	Tap	HV Current (A)-rms
21.01.2009 00:00:00	20.43	11.28	33.15	-29.31	75.19	0	11	20.41	11.27	33.19	-28.90	75.18	0	11	54.55
21.01.2009 00:30:00	19.56	11.01	33.16	-29.82	75.09	0	11	19.50	10.97	33.16	-29.37	75.14	0	11	52.42
21.01.2009 01:00:00	19.00	10.91	33.25	-30.32	75.19	0	11	18.94	10.88	33.25	-29.86	75.21	0	11	51.08
21.01.2009 01:30:00	18.54	10.87	33.26	-30.77	75.41	0	11	18.48	10.83	33.26	-30.38	75.41	0	11	50.12
21.01.2009 02:00:00	18.41	10.74	33.42	-30.65	75.38	0	11	18.36	10.71	33.43	-30.25	75.36	0	11	49.50
21.01.2009 02:30:00	18.12	10.67	33.51	-30.89	75.77	0	11	18.08	10.65	33.52	-30.49	75.77	0	11	48.77
21.01.2009 03:00:00	17.75	10.46	33.50	-31.03	75.74	0	11	17.71	10.43	33.51	-30.50	75.74	0	11	47.79
21.01.2009 03:30:00	17.58	9.70	33.07	-29.44	75.73	0	10	17.54	9.68	33.07	-28.88	75.71	0	10	46.46
21.01.2009 04:00:00	18.59	9.72	33.00	-28.05	75.84	0	10	18.55	9.69	33.02	-27.59	75.80	0	10	48.56
21.01.2009 04:30:00	21.13	9.79	32.87	-25.20	75.61	0	10	21.05	9.75	32.87	-29.85	75.62	0	10	53.88
21.01.2009 05:00:00	24.92	10.27	32.79	-22.91	75.44	0	10	24.86	10.24	32.80	-22.39	75.45	0	10	62.30
21.01.2009 05:30:00	28.88	11.30	32.97	-21.96	75.06	0	11	28.73	11.24	32.94	-21.37	74.79	0	11	72.11
21.01.2009 06:00:00	30.42	11.67	32.96	-21.46	74.70	0	11	30.31	11.63	32.96	-20.98	74.75	0	11	75.79
21.01.2009 06:30:00	27.30	11.47	33.21	-22.80	75.09	0	11	27.20	11.43	33.21	-22.80	75.09	0	11	68.51
21.01.2009 07:00:00	22.61	11.77	33.35	-27.37	75.63	0	11	22.56	11.74	33.37	-27.50	75.60	0	11	58.05
21.01.2009 07:30:00	21.97	12.60	33.17	-30.11	76.47	0	10	21.89	12.56	33.17	-29.84	76.50	0	10	58.05
21.01.2009 08:00:00	29.97	19.29	32.88	-32.77	76.69	0	10	29.87	19.23	32.89	-32.77	76.62	0	10	83.19
21.01.2009 08:30:00	34.04	22.76	32.79	-33.78	75.07	0	12	33.94	22.67	32.80	-33.76	75.07	0	12	97.19
21.01.2009 09:00:00	35.72	24.63	33.20	-34.54	74.18	0	13	35.64	24.57	33.22	-34.58	74.20	0	13	103.33
21.01.2009 09:30:00	36.92	24.73	33.01	-33.70	74.30	0	13	36.80	24.65	33.01	-33.81	74.31	0	13	106.35
21.01.2009 10:00:00	37.23	25.00	33.09	-33.77	74.08	0	13	37.11	24.93	33.09	-33.89	74.06	0	13	107.06
21.01.2009 10:30:00	38.52	25.55	32.88	-33.40	74.16	0	13	38.43	25.49	32.90	-33.55	74.15	0	13	111.03
21.01.2009 11:00:00	39.15	25.97	32.82	-33.54	74.11	0	13	39.04	25.89	32.83	-33.56	74.10	0	13	112.99
21.01.2009 11:30:00	40.07	26.61	32.73	-33.57	73.79	0	13	39.91	26.50	32.72	-33.58	73.79	0	13	115.87
21.01.2009 12:00:00	39.79	26.05	33.06	-33.27	74.08	0	13	39.64	25.95	33.05	-33.21	74.09	0	13	113.50
21.01.2009 12:30:00	38.65	24.75	33.21	-32.59	74.25	0	13	38.57	24.70	33.23	-32.63	74.26	0	13	109.16
21.01.2009 13:00:00	37.95	24.47	33.22	-32.74	74.59	0	13	37.85	24.40	33.24	-32.81	74.59	0	13	107.36
21.01.2009 13:30:00	35.72	23.11	32.91	-32.66	74.62	0	12	35.61	23.04	32.91	-32.90	74.63	0	12	100.54
21.01.2009 14:00:00	36.33	23.64	33.10	-33.06	74.36	0	13	36.22	23.57	33.11	-33.05	74.36	0	13	103.48
21.01.2009 14:30:00	40.47	25.87	32.74	-32.60	73.73	0	13	40.33	25.78	32.74	-32.59	73.73	0	13	115.70
21.01.2009 15:00:00	39.83	25.58	32.86	-32.65	73.71	0	13	39.67	25.48	32.85	-32.71	73.72	0	13	113.61
21.01.2009 15:30:00	38.87	24.92	32.92	-32.68	73.95	0	13	38.75	24.85	32.92	-32.67	73.94	0	13	110.71
21.01.2009 16:00:00	40.07	25.78	32.95	-32.68	73.90	0	13	39.93	25.70	32.95	-32.77	73.90	0	13	114.09
21.01.2009 16:30:00	38.93	26.02	33.14	-33.76	74.25	0	13	38.82	25.94	33.15	-33.75	74.24	0	13	111.55
21.01.2009 17:00:00	37.31	24.08	33.21	-32.87	74.85	0	12	37.21	24.02	33.21	-32.84	74.86	0	12	103.98
21.01.2009 17:30:00	30.88	18.64	33.36	-31.17	75.93	0	12	30.77	18.57	33.36	-31.11	75.94	0	12	84.28
21.01.2009 18:00:00	33.25	20.13	33.16	-31.24	76.13	0	11	33.15	20.06	33.17	-31.19	76.12	0	11	89.83
21.01.2009 18:30:00	37.45	18.81	32.91	-26.94	76.04	0	11	37.34	18.75	32.91	-26.67	76.05	0	11	97.42
21.01.2009 19:00:00	43.82	19.22	32.81	-23.99	74.54	0	12	43.66	19.15	32.81	-23.68	74.56	0	12	113.05
21.01.2009 19:30:00	43.76	19.12	32.91	-23.98	74.51	0	12	43.62	19.06	32.91	-23.60	74.50	0	12	112.53
21.01.2009 20:00:00	42.98	18.97	33.07	-24.25	74.69	0	12	42.84	18.91	33.07	-23.82	74.70	0	12	110.19
21.01.2009 20:30:00	42.05	18.79	33.27	-24.49	75.07	0	12	41.92	18.74	33.27	-24.08	75.07	0	12	107.44
21.01.2009 21:00:00	40.18	18.14	33.50	-24.73	75.28	0	12	40.06	18.09	33.50	-24.31	75.28	0	12	102.20
21.01.2009 21:30:00	36.51	16.44	33.24	-24.70	75.69	0	11	36.38	16.38	33.24	-24.24	75.70	0	11	92.14
21.01.2009 22:00:00	32.48	15.23	33.59	-25.49	76.27	0	11	32.38	15.19	33.59	-25.13	76.27	0	11	81.90
21.01.2009 22:30:00	27.13	13.29	33.23	-26.50	76.97	0	10	27.05	13.25	33.23	-26.09	76.97	0	10	68.84
21.01.2009 23:00:00	23.54	12.48	33.38	-28.37	77.08	0	10	23.47	12.44	33.38	-27.92	77.08	0	10	60.63
21.01.2009 23:30:00	21.46	12.09	33.45	-29.81	77.06	0	10	21.39	12.05	33.45	-29.40	77.08	0	10	56.06
22.01.2009 00:00:00	19.40	10.82	33.06	-29.54	77.31	0	9	18.75	10.45	32.56	-29.14	77.32	0	9	49.70
22.01.2009 00:30:00	18.18	10.48	32.93	-30.38	75.59	0	10	18.12	10.44	32.93	-29.96	75.61	0	10	48.66
22.01.2009 01:00:00	17.74	10.29	32.93	-30.53	75.75	0	10	17.68	10.26	32.93	-30.13	75.75	0	10	47.60
22.01.2009 01:30:00	17.60	10.50	33.21	-31.30	76.23	0	10	17.54	10.46	33.21	-30.82	76.23	0	10	47.19
22.01.2009 02:00:00	17.50	10.51	33.34	-31.47	76.57	0	10	17.44	10.48	33.34	-30.99	76.57	0	10	46.85
22.01.2009 02:30:00	17.27	10.47	33.36	-31.70	76.70	0	10	17.21	10.43	33.36	-31.23	76.70	0	10	46.33
22.01.2009 03:00:00	17.22	10.46	33.39	-31.76	76.65	0	10	17.17	10.43	33.39	-31.28	76.66	0	10	46.21
22.01.2009 03:30:00	17.28	10.38	33.39	-31.43	76.66	0	10	17.22	10.35	33.39	-31.00	76.65	0	10	46.21
22.01.2009 04:00:00	18.31	10.47	33.37	-30.13	76.63	0	10	18.25	10.44	33.37	-29.76	76.63	0	10	48.31
22.01.2009 04:30:00	21.14	10.66	33.31	-27.19	76.63	0	10	21.07	10.63	33.31	-26.77	76.63	0	10	54.11
22.01.2009 05:00:00	24.70	10.88	33.11	24.35	76.18	0	10	24.63	10.85	33.11	-23.77	76.18	0	10	61.82
22.01.2009 05:30:00	28.31	11.10	32.91	21.90	75.89	0	10	28.20	11.06	32.91	-21.42	75.89	0	10	69.81
22.01.2009 06:00:00	29.88	11.58	32.88	-21.62	75.75	0	10	29.79	11.55	32.88	-21.19	75.75	0	10	73.60

Date & Time	Simulation results - caps on with present criteria: Total P (MW)	Total Q (Mvar)	Ave Voltage LV(kV)	Ave Phase angle	Ave Voltage HV(kV)	No of Banks	Tap	HV Current (A)-rms	Simulation results - optimum caps possible: Total P (MW)	Total Q (Mvar)	Ave Voltage LV(kV)	Ave Phase angle	Ave Voltage HV(kV)	No of Banks	Tap	HV Current (A)-rms
21.01.2009 00:00:00	20.31	1.19	33.11	-3.34	77.26	2	8	45.24	20.31	1.18	33.11	-3.34	77.26	2	8	45.24
21.01.2009 00:30:00	19.63	0.92	33.28	-2.67	75.39	2	10	44.82	18.48	0.86	32.28	-2.67	75.39	2	9	42.20
21.01.2009 01:00:00	19.07	0.76	33.37	-2.28	75.47	2	10	43.43	18.50	0.74	32.86	-2.28	75.47	2	10	42.12
21.01.2009 01:30:00	18.61	0.71	33.38	-2.19	75.67	2	10	42.37	18.05	0.69	32.87	-2.19	75.67	2	10	41.10
21.01.2009 02:00:00	18.24	0.48	33.32	1.49	75.13	2	10	41.60	17.70	0.46	32.82	-1.49	75.13	2	10	40.35
21.01.2009 02:30:00	17.66	0.35	33.13	-1.14	76.03	2	9	39.89	17.66	0.35	33.13	-1.15	76.03	2	9	39.89
21.01.2009 03:00:00	17.29	0.14	33.12	-0.48	76.00	2	9	39.07	17.29	0.14	33.12	-0.48	76.00	2	9	39.07
21.01.2009 03:30:00	17.67	0.34	33.20	-1.11	75.96	2	9	39.77	17.67	-0.34	33.20	1.11	75.96	2	9	39.78
21.01.2009 04:00:00	18.69	-0.29	33.14	0.88	76.05	2	9	42.11	18.69	-0.29	33.14	0.88	76.05	2	9	42.11
21.01.2009 04:30:00	21.86	-0.14	33.49	0.36	75.87	2	10	49.41	21.21	-0.13	32.98	0.36	75.87	2	10	47.92
21.01.2009 05:00:00	25.81	0.41	33.42	-0.91	75.70	2	10	58.34	25.04	0.40	32.92	-0.91	75.70	2	9	56.57
21.01.2009 05:30:00	28.92	1.32	33.06	-2.61	75.05	2	10	66.09	28.06	1.28	32.56	-2.61	75.05	2	10	64.11
21.01.2009 06:00:00	30.52	1.70	33.07	-3.18	75.00	2	10	69.69	29.60	1.65	32.57	3.18	75.00	2	10	67.62
21.01.2009 06:30:00	27.39	1.35	33.32	-2.82	75.34	2	10	62.14	26.57	1.31	32.82	2.82	75.34	2	9	60.28
21.01.2009 07:00:00	22.71	1.57	33.48	-3.94	75.85	2	10	51.53	22.03	1.52	32.97	-3.94	75.85	2	9	49.99
21.01.2009 07:30:00	22.05	2.51	33.29	-6.49	76.75	2	9	49.82	21.39	2.43	32.79	-6.48	76.75	2	8	48.34
21.01.2009 08:00:00	30.63	4.49	33.31	-8.34	77.01	3	10	70.24	30.28	-0.58	33.11	1.09	77.14	4	9	67.84
21.01.2009 08:30:00	34.36	3.04	33.00	-5.06	75.58	4	10	78.79	34.36	3.04	33.00	-5.06	75.58	4	10	78.79
21.01.2009 09:00:00	36.06	4.42	33.42	-6.99	74.72	4	11	83.23	34.97	4.28	32.91	-6.99	74.72	4	11	80.69
21.01.2009 09:30:00	37.23	4.76	33.21	7.28	74.84	4	11	86.51	36.10	4.61	32.70	-7.28	74.84	4	11	83.88
21.01.2009 10:00:00	37.55	4.94	33.28	-7.49	74.58	4	11	87.07	36.41	4.79	32.78	-7.49	74.58	4	11	84.43
21.01.2009 10:30:00	38.88	5.75	33.09	-8.41	74.68	4	11	90.88	37.70	5.57	32.58	-8.41	74.68	4	11	88.12
21.01.2009 11:00:00	39.50	6.24	33.02	-8.98	74.63	4	11	92.62	38.30	6.05	32.52	-8.98	74.63	4	11	89.82
21.01.2009 11:30:00	41.64	7.20	33.43	-9.81	74.31	4	11	98.24	40.36	6.98	32.91	9.80	74.31	4	11	95.22
21.01.2009 12:00:00	40.10	6.02	33.24	8.54	74.61	4	11	93.30	40.10	6.02	33.24	-8.54	74.61	4	11	93.30
21.01.2009 12:30:00	39.03	4.53	33.43	-6.62	74.78	4	11	89.88	39.03	4.53	33.43	-6.62	74.78	4	11	89.88
21.01.2009 13:00:00	38.30	4.24	33.43	-6.31	75.12	4	11	88.16	38.30	4.24	33.43	-6.31	75.12	4	11	88.16
21.01.2009 13:30:00	36.06	3.25	33.11	-5.15	75.14	4	10	82.36	36.06	3.25	33.11	-5.15	75.14	4	10	82.36
21.01.2009 14:00:00	36.65	3.55	33.30	-5.53	74.89	4	11	84.59	35.54	3.44	32.80	-5.53	74.89	4	11	82.02
21.01.2009 14:30:00	42.08	6.43	33.45	8.69	74.25	4	12	98.88	40.79	6.23	32.93	-8.68	74.25	4	12	95.83
21.01.2009 15:00:00	40.13	5.79	33.04	-8.21	74.23	4	11	93.85	40.13	5.79	33.04	-8.21	74.23	4	11	93.85
21.01.2009 15:30:00	39.20	5.06	33.11	-7.36	74.46	4	11	91.29	39.20	5.06	33.11	-7.36	74.46	4	11	91.29
21.01.2009 16:00:00	40.40	5.89	33.14	-8.30	74.42	4	11	94.20	40.40	5.89	33.14	-8.30	74.42	4	11	94.20
21.01.2009 16:30:00	39.27	5.90	33.34	-8.54	74.76	4	11	91.12	39.27	5.90	33.34	-8.54	74.76	4	11	91.12
21.01.2009 17:00:00	37.68	3.87	33.42	-5.86	75.37	4	10	85.33	37.68	3.87	33.42	-5.86	75.37	4	10	85.33
21.01.2009 17:30:00	30.24	-1.76	33.07	3.34	76.46	4	9	67.88	30.24	-1.76	33.07	3.34	76.46	4	9	67.88
21.01.2009 18:00:00	33.59	-0.07	33.39	0.12	76.63	4	9	74.59	33.59	-0.07	33.39	0.12	76.63	4	9	74.59
21.01.2009 18:30:00	37.84	-1.09	33.13	1.65	76.55	4	9	84.56	37.84	-1.09	33.13	1.65	76.55	4	9	84.56
21.01.2009 19:00:00	44.21	-0.56	33.02	0.73	75.07	4	10	100.6	42.89	-0.54	32.52	0.73	75.06	4	10	97.54
21.01.2009 19:30:00	44.17	-0.77	33.12	1.00	75.01	4	10	100.1	42.85	-0.75	32.62	1.00	75.01	4	10	97.14
21.01.2009 20:00:00	43.38	1.12	33.28	1.48	75.21	4	10	97.90	42.08	-1.09	32.78	1.48	75.20	4	10	94.96
21.01.2009 20:30:00	42.46	-1.55	33.49	2.09	75.58	4	10	95.26	41.19	-1.50	32.98	2.09	75.58	4	10	92.41
21.01.2009 21:00:00	39.36	-2.41	33.21	3.51	75.79	4	9	87.80	39.36	-2.41	33.21	3.51	75.79	4	9	87.80
21.01.2009 21:30:00	36.88	-3.90	33.47	6.03	76.20	4	9	81.93	36.19	1.20	33.15	-1.90	76.08	3	9	80.96
21.01.2009 22:00:00	31.26	-2.95	33.00	0.54	76.65	3	8	69.20	31.26	-0.30	33.00	0.54	76.65	3	8	69.20
21.01.2009 22:30:00	26.93	-1.91	33.16	4.05	77.34	3	8	59.50	26.93	-1.91	33.16	4.05	77.34	3	8	59.50
21.01.2009 23:00:00	23.37	-2.85	33.31	6.95	77.45	3	8	51.67	23.37	-2.85	33.31	6.95	77.45	3	8	51.67
21.01.2009 23:30:00	21.30	3.30	33.38	8.79	77.46	3	8	47.21	21.30	-3.30	33.38	8.79	77.46	3	8	47.21
22.01.2009 00:00:00	19.84	4.34	33.49	12.34	77.70	3	9	44.93	19.47	0.78	33.18	2.30	77.57	2	9	43.89
22.01.2009 00:30:00	18.60	-4.56	33.36	13.79	75.98	3	9	42.51	18.25	0.52	33.05	1.64	75.86	2	9	41.31
22.01.2009 01:00:00	18.15	-4.75	33.37	14.68	76.12	3	9	41.63	17.81	0.34	33.05	-1.09	76.00	2	9	40.31
22.01.2009 01:30:00	17.47	-4.67	33.15	14.96	76.60	3	8	39.79	17.66	0.37	33.33	-1.19	76.48	2	9	39.67
22.01.2009 02:00:00	17.37	-4.77	33.28	15.35	76.95	3	8	39.48	17.57	0.30	33.47	-0.99	76.83	2	9	39.30
22.01.2009 02:30:00	17.14	-4.83	33.30	15.73	77.08	3	8	39.00	17.33	0.25	33.48	-0.83	76.95	2	9	38.76
22.01.2009 03:00:00	17.10	-4.86	33.33	15.87	77.03	3	8	38.90	17.26	0.23	33.48	-0.75	76.95	2	9	38.60
22.01.2009 03:30:00	17.15	-4.94	33.33	16.08	77.03	3	8	39.05	16.83	0.14	33.01	0.47	76.90	2	8	37.60
22.01.2009 04:00:00	18.18	-4.84	33.31	14.89	77.01	3	8	41.20	17.84	0.24	32.99	-0.77	76.88	2	8	39.84
22.01.2009 04:30:00	20.99	4.59	33.24	12.33	77.00	3	8	47.15	20.59	0.46	32.93	1.29	76.88	2	8	45.98
22.01.2009 05:00:00	24.53	-4.19	33.05	9.70	76.55	3	5	54.93	24.07	0.79	32.74	-1.89	76.43	2	8	53.95
22.01.2009 05:30:00	28.95	3.91	33.34	7.69	76.26	3	9	64.85	27.57	1.12	32.54	-2.34	76.14	2	8	62.08
22.01.2009 06:00:00	30.57	-3.39	33.31	6.32	76.12	3	9	68.36	29.97	1.66	32.98	-3.17	76.13	2	9	67.60

Date & Time	Simulation results - maximum caps possible: Total P (MW)	Total Q (Mvar)	Ave Voltage LV(kV)	Ave Phase angle	Ave Voltage HV(kV)	No of Banks	Tap	HV Current (A)-rms
21.01.2009 00:00:00	20.48	-8.92	33.24	23.54	77.48	4	7	47.99
21.01.2009 00:30:00	19.78	9.29	33.41	25.15	75.64	4	9	48.10
21.01.2009 01:00:00	19.22	-9.50	33.50	26.31	75.72	4	9	47.03
21.01.2009 01:30:00	18.19	-9.27	33.00	27.01	75.91	4	8	44.76
21.01.2009 02:00:00	18.39	-9.76	33.45	27.97	75.38	4	9	45.68
21.01.2009 02:30:00	17.80	-9.77	33.26	28.76	76.27	4	8	44.12
21.01.2009 03:00:00	17.43	9.98	33.25	29.78	76.23	4	8	43.63
21.01.2009 03:30:00	17.81	-10.52	33.33	30.56	76.20	4	8	44.80
21.01.2009 04:00:00	18.84	-10.42	33.27	28.95	76.29	4	8	46.77
21.01.2009 04:30:00	21.38	-10.17	33.12	25.44	76.11	4	8	51.77
21.01.2009 05:00:00	25.24	-9.60	33.05	20.82	75.94	4	8	59.27
21.01.2009 05:30:00	29.14	-8.75	33.18	16.70	75.29	4	9	67.62
21.01.2009 06:00:00	30.75	-8.37	33.20	15.23	75.24	4	9	70.82
21.01.2009 06:30:00	27.60	-8.88	33.45	17.84	75.59	4	9	63.89
21.01.2009 07:00:00	22.21	-8.50	33.10	20.94	76.10	4	8	52.13
21.01.2009 07:30:00	22.22	-7.70	33.42	19.10	76.99	4	8	51.13
21.01.2009 08:00:00	30.28	-0.58	33.11	1.09	77.14	4	9	67.85
21.01.2009 08:30:00	34.36	3.04	33.00	-5.06	75.58	4	10	78.79
21.01.2009 09:00:00	36.06	4.42	33.42	-6.99	74.72	4	11	83.23
21.01.2009 09:30:00	37.23	4.76	33.21	-7.28	74.84	4	11	86.51
21.01.2009 10:00:00	37.55	4.94	33.28	-7.49	74.58	4	11	87.07
21.01.2009 10:30:00	38.88	5.75	33.09	-8.41	74.68	4	11	90.88
21.01.2009 11:00:00	39.50	6.24	33.02	-8.98	74.63	4	11	92.62
21.01.2009 11:30:00	41.64	7.20	33.43	-9.81	74.31	4	11	98.24
21.01.2009 12:00:00	40.10	6.02	33.24	-8.54	74.61	4	11	93.30
21.01.2009 12:30:00	39.03	4.53	33.43	-6.62	74.78	4	11	89.88
21.01.2009 13:00:00	38.30	4.24	33.43	-6.31	75.12	4	11	88.16
21.01.2009 13:30:00	36.06	3.25	33.11	-5.15	75.14	4	10	82.36
21.01.2009 14:00:00	36.65	3.55	33.30	-5.53	74.89	4	11	84.59
21.01.2009 14:30:00	42.08	6.43	33.45	-8.69	74.25	4	12	98.88
21.01.2009 15:00:00	40.13	5.79	33.04	-8.21	74.23	4	11	93.85
21.01.2009 15:30:00	39.20	5.06	33.11	-7.36	74.46	4	11	91.29
21.01.2009 16:00:00	40.40	5.89	33.14	8.30	74.42	4	11	94.20
21.01.2009 16:30:00	39.27	5.90	33.34	8.54	74.76	4	11	91.12
21.01.2009 17:00:00	37.68	3.87	33.42	-5.86	75.37	4	10	85.33
21.01.2009 17:30:00	30.24	1.76	33.07	3.34	76.46	4	9	67.88
21.01.2009 18:00:00	33.59	-0.07	33.39	0.12	76.63	4	9	74.59
21.01.2009 18:30:00	37.84	-1.09	33.13	1.65	76.55	4	9	84.56
21.01.2009 19:00:00	44.21	-0.56	33.02	0.73	75.07	4	10	100.6
21.01.2009 19:30:00	44.17	0.77	33.12	1.00	75.01	4	10	100.1
21.01.2009 20:00:00	43.38	-1.12	33.28	1.48	75.21	4	10	97.90
21.01.2009 20:30:00	42.46	-1.55	33.49	2.09	75.58	4	10	95.26
21.01.2009 21:00:00	39.36	-2.41	33.21	3.51	75.79	4	9	87.80
21.01.2009 21:30:00	36.88	3.90	33.47	6.03	76.20	4	9	81.93
21.01.2009 22:00:00	31.86	5.38	33.32	9.58	76.77	4	8	70.61
21.01.2009 22:30:00	27.45	-7.07	33.48	14.44	77.46	4	8	61.58
21.01.2009 23:00:00	23.12	-7.84	33.13	18.73	77.57	4	7	52.75
21.01.2009 23:30:00	21.08	-8.30	32.21	21.50	77.57	4	7	48.79
22.01.2009 00:00:00	19.64	-9.37	33.32	25.52	77.80	4	7	46.60
22.01.2009 00:30:00	18.39	-9.55	33.18	27.44	76.10	4	8	45.18
22.01.2009 01:00:00	17.95	-9.37	33.18	28.48	76.24	4	8	44.48
22.01.2009 01:30:00	17.81	9.88	33.47	29.03	76.72	4	8	43.97
22.01.2009 02:00:00	17.19	9.73	33.10	29.51	77.06	4	7	42.48
22.01.2009 02:30:00	16.96	-9.79	33.12	30.01	77.19	4	7	42.07
22.01.2009 03:00:00	16.92	9.83	33.15	30.17	77.15	4	7	42.00
22.01.2009 03:30:00	16.97	-9.92	33.15	30.30	77.14	4	7	42.19
22.01.2009 04:00:00	17.99	9.80	33.13	28.59	77.12	4	7	44.05
22.01.2009 04:30:00	20.76	-9.54	33.07	24.67	77.12	4	7	49.33
22.01.2009 05:00:00	25.00	-9.36	33.36	20.53	76.67	4	8	58.06
22.01.2009 05:30:00	28.63	-8.89	33.16	17.26	76.38	4	8	65.66
22.01.2009 06:00:00	30.24	8.37	33.13	15.47	76.24	4	8	68.82

APPENDIX 4- Data format for measured data in Panadura Grid substation with all capacitor banks connected

Transformer 1 - 33 kV Side Data

Date & Time	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Voltage / 33kV bus L1	Voltage / 33kV bus L2	Voltage / 33kV bus L3	Power factor L1	Power factor L2	Power factor L3
18.02.2009 12:00:00	6.15	6.23	6.25	0.60	0.65	0.72	33.01	33.25	33.30	0.99525	0.994637	0.993487
18.02.2009 12:10:00	6.05	6.14	6.16	0.59	0.62	0.71	33.03	33.28	33.32	0.995302	0.99487	0.993494
18.02.2009 12:20:00	6.00	6.09	6.11	0.49	0.52	0.60	33.18	33.43	33.46	0.996627	0.996339	0.995151
18.02.2009 12:30:00	5.85	5.95	5.96	0.35	0.37	0.45	33.38	33.62	33.66	0.998256	0.998063	0.997167
18.02.2009 12:40:00	5.87	5.97	5.97	0.33	0.37	0.44	33.36	33.59	33.64	0.998465	0.998085	0.997282
18.02.2009 12:50:00	5.86	5.95	5.95	0.28	0.32	0.38	33.06	33.30	33.34	0.998888	0.99852	0.997928
18.02.2009 13:00:00	5.84	5.90	5.92	0.26	0.31	0.35	32.85	33.09	33.13	0.998982	0.998607	0.998223
18.02.2009 13:10:00	5.91	5.99	5.98	0.28	0.34	0.39	32.80	33.04	33.08	0.998866	0.998371	0.997836
18.02.2009 13:20:00	5.89	5.97	5.96	0.29	0.36	0.40	32.61	32.84	32.88	0.998767	0.998234	0.99772
18.02.2009 13:30:00	5.94	6.00	6.01	0.34	0.39	0.43	32.54	32.78	32.81	0.998398	0.99789	0.997464
18.02.2009 13:40:00	6.00	6.08	6.08	0.43	0.49	0.54	32.67	32.90	32.95	0.997458	0.996729	0.996025
18.02.2009 13:50:00	6.14	6.21	6.21	0.49	0.56	0.61	32.90	33.14	33.19	0.996838	0.995917	0.995221
18.02.2009 14:00:00	6.23	6.29	6.29	0.56	0.63	0.67	32.82	33.06	33.11	0.996044	0.994968	0.994309
18.02.2009 14:10:00	6.34	6.41	6.41	0.63	0.71	0.76	32.75	32.98	33.04	0.995078	0.993898	0.993026
18.02.2009 14:20:00	6.47	6.54	6.54	0.72	0.80	0.85	32.67	32.91	32.97	0.993949	0.992579	0.991684
18.02.2009 14:30:00	6.62	6.71	6.69	0.78	0.86	0.93	32.61	32.85	32.91	0.993205	0.991848	0.990524
18.02.2009 14:40:00	6.57	6.64	6.65	0.75	0.83	0.89	32.63	32.86	32.92	0.993494	0.992343	0.991208
18.02.2009 14:50:00	6.61	6.68	6.70	0.77	0.83	0.89	32.62	32.86	32.91	0.993234	0.992312	0.991233
18.02.2009 15:00:00	6.46	6.54	6.56	0.69	0.74	0.81	32.76	33.01	33.05	0.994297	0.993622	0.992418
18.02.2009 15:10:00	6.43	6.52	6.52	0.68	0.75	0.81	32.77	33.01	33.06	0.99441	0.993413	0.992299
18.02.2009 15:20:00	6.44	6.53	6.53	0.71	0.78	0.85	32.71	32.95	33.00	0.994046	0.992892	0.991622
18.02.2009 15:30:00	6.37	6.45	6.44	0.67	0.75	0.80	32.74	32.98	33.03	0.994571	0.993363	0.992333
18.02.2009 15:40:00	6.34	6.41	6.41	0.67	0.74	0.79	32.76	33.00	33.05	0.994524	0.993384	0.992531
18.02.2009 15:50:00	6.37	6.45	6.46	0.72	0.78	0.84	32.75	32.99	33.05	0.993754	0.992769	0.991602
18.02.2009 16:00:00	6.29	6.38	6.37	0.68	0.75	0.82	32.80	33.04	33.09	0.994122	0.993115	0.991788
18.02.2009 16:10:00	6.29	6.38	6.38	0.68	0.74	0.81	32.89	33.13	33.18	0.994242	0.993333	0.992019
18.02.2009 16:20:00	6.14	6.23	6.21	0.57	0.64	0.70	32.97	33.21	33.26	0.995722	0.994698	0.993657
18.02.2009 16:30:00	5.80	5.88	5.87	0.32	0.39	0.44	33.01	33.25	33.30	0.998469	0.99785	0.997246
18.02.2009 16:40:00	5.51	5.57	5.56	0.07	0.14	0.17	32.99	33.23	33.28	0.999914	0.999699	0.999548
18.02.2009 16:50:00	5.45	5.49	5.50	0.06	0.12	0.13	32.83	33.08	33.12	0.999935	0.999774	0.999704
18.02.2009 17:00:00	5.38	5.42	5.43	-0.02	0.04	0.05	33.11	33.35	33.39	0.999991	0.999974	0.999949
18.02.2009 17:10:00	5.42	5.47	5.46	-0.03	0.04	0.05	33.24	33.48	33.53	0.999984	0.999974	0.999956
18.02.2009 17:20:00	5.33	5.38	5.38	-0.13	-0.07	-0.05	33.23	33.48	33.52	0.99969	0.999908	0.999953
18.02.2009 17:30:00	5.12	5.18	5.18	-0.25	-0.19	-0.17	33.07	33.31	33.35	0.998825	0.999339	0.999484
18.02.2009 17:40:00	5.10	5.16	5.16	-0.29	-0.23	-0.21	33.13	33.36	33.41	0.998424	0.999016	0.999192
18.02.2009 17:50:00	5.03	5.08	5.09	-0.36	-0.31	-0.30	33.21	33.44	33.48	0.997488	0.998175	0.998295
18.02.2009 18:00:00	5.01	5.04	5.05	-0.37	-0.32	-0.32	33.15	33.38	33.42	0.997244	0.997939	0.997985
18.02.2009 18:10:00	5.18	5.20	5.22	-0.34	-0.29	-0.30	33.03	33.26	33.31	0.997806	0.998421	0.998354
18.02.2009 18:20:00	5.54	5.56	5.58	-0.27	-0.22	-0.22	32.81	33.04	33.09	0.998814	0.999244	0.999191
18.02.2009 18:30:00	6.01	6.02	6.06	-0.18	-0.13	-0.14	32.58	32.82	32.87	0.999529	0.999774	0.999718

Transformer 2 - 132 Side Data

Date & Time	Ph Volt / 132 kV Bus L1	Ph Volt / 132 kV Bus L2	Ph Volt / 132 kV Bus L3	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Power Factor L1	Power Factor L2	Power Factor L3
18.02.2009 12:00:00	74.26	74.32	74.80	6.33	6.42	6.43	0.15	0.71	0.25	-0.9900	0.9900	-0.9900
18.02.2009 12:10:00	74.39	74.45	74.90	6.22	6.31	6.32	0.10	0.60	0.18	-1.0000	-0.9900	-1.0000
18.02.2009 12:20:00	74.48	74.55	74.99	6.15	6.24	6.23	0.08	0.57	0.16	1.0000	-1.0000	-1.0000
18.02.2009 12:30:00	74.80	74.90	75.37	6.09	6.22	6.18	-0.05	0.44	0.04	-1.0000	-1.0000	-1.0000
18.02.2009 12:40:00	75.09	75.15	75.59	5.91	6.03	5.99	-0.21	0.26	-0.12	-1.0000	1.0000	-1.0000
18.02.2009 12:50:00	74.96	74.99	75.44	5.92	6.05	6.03	-0.20	0.27	-0.11	-1.0000	-1.0000	-1.0000
18.02.2009 13:00:00	74.99	75.05	75.53	5.86	5.97	5.96	-0.25	0.21	-0.19	-1.0000	-1.0000	-1.0000
18.02.2009 13:10:00	74.86	74.93	75.47	5.90	5.99	6.00	-0.23	0.22	-0.19	-1.0000	-1.0000	-1.0000
18.02.2009 13:20:00	74.90	74.96	75.47	5.98	6.06	6.04	-0.22	0.25	-0.17	-1.0000	-1.0000	1.0000
18.02.2009 13:30:00	74.36	74.48	74.93	5.97	6.06	6.03	0.19	0.27	0.15	-1.0000	-1.0000	-1.0000
18.02.2009 13:40:00	74.32	74.36	74.80	6.03	6.11	6.11	-0.15	0.31	-0.10	-1.0000	-1.0000	1.0000
18.02.2009 13:50:00	74.10	74.20	74.67	6.14	6.22	6.21	-0.03	0.48	0.05	-1.0000	-1.0000	-1.0000
18.02.2009 14:00:00	74.13	74.20	74.67	6.25	6.31	6.34	0.00	0.49	0.04	1.0000	-1.0000	-1.0000
18.02.2009 14:10:00	73.97	74.01	74.48	6.37	6.45	6.45	0.06	0.57	0.12	-1.0000	-1.0000	-1.0000
18.02.2009 14:20:00	73.85	73.94	74.45	6.47	6.54	6.55	0.12	0.64	0.17	-1.0000	-1.0000	-1.0000
18.02.2009 14:30:00	73.75	73.91	74.32	6.69	6.74	6.75	0.27	0.81	0.33	-1.0000	-0.9900	-1.0000
18.02.2009 14:40:00	73.75	73.85	74.32	6.73	6.81	6.83	0.26	0.81	0.32	-1.0000	-0.9900	-1.0000
18.02.2009 14:50:00	73.72	73.81	74.29	6.71	6.78	6.82	0.24	0.77	0.29	-1.0000	0.9900	-1.0000
18.02.2009 15:00:00	73.75	73.85	74.29	6.73	6.81	6.83	0.26	0.78	0.33	-1.0000	-0.9900	-1.0000
18.02.2009 15:10:00	73.94	74.04	74.55	6.54	6.63	6.64	0.15	0.65	0.20	-1.0000	-0.9900	-1.0000
18.02.2009 15:20:00	73.97	74.07	74.51	6.60	6.66	6.56	0.17	0.71	0.25	-1.0000	-0.9900	-1.0000
18.02.2009 15:30:00	73.85	73.94	74.42	6.57	6.65	6.65	0.19	0.75	0.26	-1.0000	-0.9900	-1.0000
18.02.2009 15:40:00	73.88	74.01	74.48	6.45	6.50	6.52	0.14	0.66	0.20	-1.0000	-0.9900	-1.0000
18.02.2009 15:50:00	73.94	73.97	74.48	6.44	6.50	6.52	0.18	0.70	0.23	-1.0000	-0.9900	-1.0000
18.02.2009 16:00:00	73.97	74.07	74.55	6.46	6.56	6.58	0.20	0.70	0.26	-1.0000	-0.9900	-1.0000
18.02.2009 16:10:00	74.10	74.13	74.64	6.39	6.46	6.48	0.13	0.66	0.22	-1.0000	-0.9900	-1.0000
18.02.2009 16:20:00	74.36	74.42	74.86	6.41	6.49	6.50	0.15	0.68	0.23	-1.0000	-0.9900	-1.0000
18.02.2009 16:30:00	74.36	74.42	74.90	6.12	6.11	6.11	-0.04	0.39	0.04	1.0000	-1.0000	1.0000
18.02.2009 16:40:00	74.26	74.29	74.77	5.85	5.96	5.94	-0.20	0.27	-0.14	1.0000	-1.0000	-1.0000
18.02.2009 16:50:00	74.67	74.67	75.18	5.09	5.21	5.19	-0.67	-0.28	-0.65	0.9900	-1.0000	0.9900
18.02.2009 17:00:00	74.86	74.90	75.34	5.45	5.53	5.54	-0.42	-0.02	-0.41	-1.0000	-1.0000	-1.0000
18.02.2009 17:10:00	75.40	75.47	75.91	5.36	5.44	5.43	-0.53	-0.13	-0.51	0.9900	-1.0000	0.9900
18.02.2009 17:20:00	75.59	75.66	76.14	5.41	5.48	5.48	-0.49	-0.07	-0.48	-1.0000	-1.0000	-1.0000
18.02.2009 17:30:00	76.04	76.04	76.55	5.24	5.34	5.31	-0.68	-0.28	-0.65	0.9900	-1.0000	0.9900
18.02.2009 17:40:00	76.20	76.23	76.74	5.03	5.11	5.09	-0.73	-0.34	-0.70	0.9900	1.0000	0.9900
18.02.2009 17:50:00	76.36	76.39	76.87	5.06	5.16	5.13	-0.76	-0.38	-0.74	0.9900	-1.0000	0.9900
18.02.2009 18:00:00	76.36	76.36	76.80	4.88	4.98	4.97	-0.83	-0.49	-0.82	0.9900	0.9900	0.9900
18.02.2009 18:10:00	76.33	76.29	76.74	4.92	5.03	5.00	-0.85	-0.50	-0.85	0.9900	0.9900	0.9900
18.02.2009 18:20:00	76.01	76.01	76.49	5.17	5.26	5.27	-0.79	-0.44	-0.81	0.9900	-1.0000	0.9900
18.02.2009 18:30:00	75.50	75.50	75.98	5.57	5.66	5.68	-0.72	-0.34	-0.74	0.9900	-1.0000	0.9900

Transformer 1 - 132 Side Data

Date & Time	Ph Vol/ 132 kV Bus L1	Ph Vol/ 132 kV Bus L2	Ph Vol/ 132 kV Bus L3	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Power Factor L1	Power Factor L2	Power Factor L3
18.02.2009 12:00:00	74.22	74.41	74.86	6.36	6.36	6.38	0.05	0.48	0.18	1.0000	1.0000	1.0000
18.02.2009 12:10:00	74.35	74.51	74.96	6.22	6.27	6.28	0.01	0.42	0.14	1.0000	1.0000	1.0000
18.02.2009 12:20:00	74.38	74.57	75.02	6.13	6.21	6.20	-0.01	0.40	0.13	1.0000	1.0000	1.0000
18.02.2009 12:30:00	74.83	74.99	75.43	6.11	6.20	6.18	-0.15	0.26	-0.01	1.0000	1.0000	1.0000
18.02.2009 12:40:00	74.99	75.11	75.53	5.94	6.04	6.01	-0.29	0.10	-0.16	1.0000	1.0000	1.0000
18.02.2009 12:50:00	74.92	75.05	75.53	5.96	6.05	6.01	-0.28	0.12	-0.15	1.0000	1.0000	1.0000
18.02.2009 13:00:00	74.96	75.15	75.59	5.88	5.95	5.96	-0.32	0.05	-0.22	1.0000	1.0000	1.0000
18.02.2009 13:10:00	74.86	75.08	75.53	5.89	5.98	6.00	-0.32	0.05	-0.22	1.0000	1.0000	1.0000
18.02.2009 13:20:00	74.86	74.99	75.43	5.99	6.06	6.01	-0.31	0.10	-0.20	1.0000	1.0000	1.0000
18.02.2009 13:30:00	74.35	74.48	74.92	5.97	6.02	6.02	-0.27	0.11	-0.17	1.0000	1.0000	1.0000
18.02.2009 13:40:00	74.19	74.35	74.8	6.03	6.07	6.08	-0.23	0.14	-0.13	1.0000	1.0000	1.0000
18.02.2009 13:50:00	74	74.22	74.67	6.12	6.17	6.16	-0.11	0.29	0.00	1.0000	1.0000	1.0000
18.02.2009 14:00:00	74.03	74.19	74.7	6.25	6.27	6.30	-0.09	0.30	-0.01	1.0000	1.0000	1.0000
18.02.2009 14:10:00	73.87	74.06	74.51	6.36	6.39	6.41	0.01	0.40	0.08	1.0000	1.0000	1.0000
18.02.2009 14:20:00	73.78	73.97	74.45	6.46	6.47	6.52	0.04	0.46	0.14	1.0000	1.0000	1.0000
18.02.2009 14:30:00	73.65	73.91	74.38	6.71	6.72	6.72	0.17	0.60	0.27	1.0000	1.0000	1.0000
18.02.2009 14:40:00	73.68	73.84	74.32	6.75	6.76	6.77	0.15	0.61	0.27	1.0000	1.0000	1.0000
18.02.2009 14:50:00	73.65	73.84	74.26	6.71	6.73	6.74	0.15	0.58	0.26	1.0000	1.0000	1.0000
18.02.2009 15:00:00	73.65	73.87	74.32	6.74	6.78	6.79	0.16	0.59	0.28	1.0000	1.0000	1.0000
18.02.2009 15:10:00	73.91	74.1	74.51	6.58	6.63	6.62	0.05	0.46	0.17	1.0000	1.0000	1.0000
18.02.2009 15:20:00	73.91	74.06	74.54	6.58	6.63	6.65	0.07	0.50	0.19	1.0000	1.0000	1.0000
18.02.2009 15:30:00	73.81	73.97	74.41	6.57	6.60	6.61	0.11	0.54	0.22	1.0000	1.0000	1.0000
18.02.2009 15:40:00	73.84	74.03	74.48	6.47	6.48	6.49	0.05	0.48	0.16	1.0000	1.0000	1.0000
18.02.2009 15:50:00	73.84	74.03	74.48	6.48	6.52	6.53	0.09	0.51	0.19	1.0000	1.0000	1.0000
18.02.2009 16:00:00	73.94	74.1	74.57	6.48	6.51	6.55	0.11	0.52	0.22	1.0000	1.0000	1.0000
18.02.2009 16:10:00	73.97	74.16	74.64	6.40	6.43	6.43	0.07	0.49	0.19	1.0000	1.0000	1.0000
18.02.2009 16:20:00	74.26	74.41	74.89	6.42	6.47	6.48	0.05	0.47	0.18	1.0000	1.0000	1.0000
18.02.2009 16:30:00	74.26	74.41	74.89	6.14	6.17	6.17	-0.12	0.28	0.00	1.0000	1.0000	1.0000
18.02.2009 16:40:00	74.13	74.29	74.83	5.87	5.91	5.91	-0.27	0.11	-0.15	1.0000	1.0000	1.0000
18.02.2009 16:50:00	74.54	74.67	75.18	5.11	5.14	5.15	-0.73	-0.43	-0.66	-0.9900	1.0000	-0.9900
18.02.2009 17:00:00	74.7	74.89	75.4	5.45	5.51	5.52	-0.49	-0.18	-0.42	1.0000	1.0000	1.0000
18.02.2009 17:10:00	75.27	75.43	75.88	5.37	5.40	5.41	-0.60	0.29	-0.53	-0.9900	1.0000	-0.9900
18.02.2009 17:20:00	75.56	75.72	76.2	5.43	5.47	5.48	-0.57	-0.24	-0.50	-0.9900	1.0000	1.0000
18.02.2009 17:30:00	75.94	76.1	76.55	5.25	5.31	5.29	-0.74	-0.43	-0.66	-0.9900	1.0000	-0.9900
18.02.2009 17:40:00	76.16	76.32	76.8	5.09	5.14	5.12	-0.79	-0.47	-0.72	-0.9900	1.0000	-0.9900
18.02.2009 17:50:00	76.26	76.42	76.86	5.09	5.14	5.12	-0.83	-0.54	-0.77	-0.9900	-0.9900	-0.9900
18.02.2009 18:00:00	76.39	76.42	76.9	4.91	4.96	4.96	-0.91	-0.62	-0.85	-0.9800	-0.9900	-0.9900
18.02.2009 18:10:00	76.23	76.35	76.8	4.94	5.01	4.99	-0.91	-0.65	-0.87	-0.9800	-0.9900	-0.9800
18.02.2009 18:20:00	75.91	76.07	76.51	5.20	5.24	5.24	-0.86	-0.59	-0.83	-0.9900	-0.9900	-0.9900
18.02.2009 18:30:00	75.37	75.59	76.1	5.58	5.64	5.66	-0.81	-0.51	-0.76	-0.9900	1.0000	-0.9900

APPENDIX 4- Data format for measured data in Panadura Grid substation with all capacitor banks connected

Transformer 1 - 33 kV Side Data

Date & Time	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Voltage / 33kV bus L1	Voltage / 33kV bus L2	Voltage / 33kV bus L3	Power factor L1	Power factor L2	Power factor L3
18.02.2009 12:00:00	6.15	6.23	6.25	0.60	0.65	0.72	33.01	33.25	33.30	0.99525	0.994637	0.993487
18.02.2009 12:10:00	6.05	6.14	6.16	0.59	0.62	0.71	33.03	33.28	33.32	0.995302	0.99487	0.993494
18.02.2009 12:20:00	6.00	6.09	6.11	0.49	0.52	0.60	33.18	33.43	33.46	0.996627	0.996339	0.995151
18.02.2009 12:30:00	5.85	5.95	5.96	0.35	0.37	0.45	33.38	33.62	33.66	0.998256	0.998063	0.997167
18.02.2009 12:40:00	5.87	5.97	5.97	0.33	0.37	0.44	33.36	33.59	33.64	0.998465	0.998085	0.997282
18.02.2009 12:50:00	5.86	5.95	5.95	0.28	0.32	0.38	33.06	33.30	33.34	0.998888	0.99852	0.997928
18.02.2009 13:00:00	5.84	5.90	5.92	0.26	0.31	0.35	32.85	33.09	33.13	0.998982	0.998607	0.998223
18.02.2009 13:10:00	5.91	5.99	5.98	0.28	0.34	0.39	32.80	33.04	33.08	0.998866	0.998371	0.997836
18.02.2009 13:20:00	5.89	5.97	5.96	0.29	0.36	0.40	32.61	32.84	32.88	0.998767	0.998234	0.99772
18.02.2009 13:30:00	5.94	6.00	6.01	0.34	0.39	0.43	32.54	32.78	32.81	0.998398	0.99789	0.997464
18.02.2009 13:40:00	6.00	6.08	6.08	0.43	0.49	0.54	32.67	32.90	32.95	0.997458	0.996729	0.996025
18.02.2009 13:50:00	6.14	6.21	6.21	0.49	0.56	0.61	32.90	33.14	33.19	0.996838	0.995917	0.995221
18.02.2009 14:00:00	6.23	6.29	6.29	0.56	0.63	0.67	32.82	33.06	33.11	0.996044	0.994968	0.994309
18.02.2009 14:10:00	6.34	6.41	6.41	0.63	0.71	0.76	32.75	32.98	33.04	0.995078	0.993898	0.993026
18.02.2009 14:20:00	6.47	6.54	6.54	0.72	0.80	0.85	32.67	32.91	32.97	0.993949	0.992579	0.991684
18.02.2009 14:30:00	6.62	6.71	6.69	0.78	0.86	0.93	32.61	32.85	32.91	0.993205	0.991848	0.990524
18.02.2009 14:40:00	6.57	6.64	6.65	0.75	0.83	0.89	32.63	32.86	32.92	0.993494	0.992343	0.991208
18.02.2009 14:50:00	6.61	6.68	6.70	0.77	0.83	0.89	32.62	32.86	32.91	0.993234	0.992312	0.991233
18.02.2009 15:00:00	6.46	6.54	6.56	0.69	0.74	0.81	32.76	33.01	33.05	0.994297	0.993622	0.992418
18.02.2009 15:10:00	6.43	6.52	6.52	0.68	0.75	0.81	32.77	33.01	33.06	0.99441	0.993413	0.992299
18.02.2009 15:20:00	6.44	6.53	6.53	0.71	0.78	0.85	32.71	32.95	33.00	0.994046	0.992892	0.991622
18.02.2009 15:30:00	6.37	6.45	6.44	0.67	0.75	0.80	32.74	32.98	33.03	0.994571	0.993363	0.992333
18.02.2009 15:40:00	6.34	6.41	6.41	0.67	0.74	0.79	32.76	33.00	33.05	0.994524	0.993384	0.992531
18.02.2009 15:50:00	6.37	6.45	6.46	0.72	0.78	0.84	32.75	32.99	33.05	0.993754	0.992769	0.991602
18.02.2009 16:00:00	6.29	6.38	6.37	0.68	0.75	0.82	32.80	33.04	33.09	0.994122	0.993115	0.991788
18.02.2009 16:10:00	6.29	6.38	6.38	0.68	0.74	0.81	32.89	33.13	33.18	0.994242	0.993333	0.992019
18.02.2009 16:20:00	6.14	6.23	6.21	0.57	0.64	0.70	32.97	33.21	33.26	0.995722	0.994698	0.993657
18.02.2009 16:30:00	5.80	5.88	5.87	0.32	0.39	0.44	33.01	33.25	33.30	0.998469	0.99785	0.997246
18.02.2009 16:40:00	5.51	5.57	5.56	0.07	0.14	0.17	32.99	33.23	33.28	0.999914	0.999699	0.999548
18.02.2009 16:50:00	5.45	5.49	5.50	0.06	0.12	0.13	32.83	33.08	33.12	0.999935	0.999774	0.999704
18.02.2009 17:00:00	5.38	5.42	5.43	-0.02	0.04	0.05	33.11	33.35	33.39	0.999991	0.999974	0.999949
18.02.2009 17:10:00	5.42	5.47	5.46	-0.03	0.04	0.05	33.24	33.48	33.53	0.999984	0.999974	0.999956
18.02.2009 17:20:00	5.33	5.38	5.38	-0.13	-0.07	-0.05	33.23	33.48	33.52	0.99969	0.999908	0.999953
18.02.2009 17:30:00	5.12	5.18	5.18	-0.25	-0.19	-0.17	33.07	33.31	33.35	0.998825	0.999339	0.999484
18.02.2009 17:40:00	5.10	5.16	5.16	-0.29	-0.23	-0.21	33.13	33.36	33.41	0.998424	0.999016	0.999192
18.02.2009 17:50:00	5.03	5.08	5.09	-0.36	-0.31	-0.30	33.21	33.44	33.48	0.997488	0.998175	0.998295
18.02.2009 18:00:00	5.01	5.04	5.05	-0.37	-0.32	-0.32	33.15	33.38	33.42	0.997244	0.997939	0.997985
18.02.2009 18:10:00	5.18	5.20	5.22	-0.34	-0.29	-0.30	33.03	33.26	33.31	0.997806	0.998421	0.998354
18.02.2009 18:20:00	5.54	5.56	5.58	-0.27	-0.22	-0.22	32.81	33.04	33.09	0.998814	0.999244	0.999191
18.02.2009 18:30:00	6.01	6.02	6.06	-0.18	-0.13	-0.14	32.58	32.82	32.87	0.999529	0.999774	0.999718

Transformer 2 - 132 Side Data

Date & Time	Ph Volt / 132 kV Bus L1	Ph Volt / 132 kV Bus L2	Ph Volt / 132 kV Bus L3	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Power Factor L1	Power Factor L2	Power Factor L3
18.02.2009 12:00:00	74.26	74.32	74.80	6.33	6.42	6.43	0.15	0.71	0.25	-0.9900	0.9900	-0.9900
18.02.2009 12:10:00	74.39	74.45	74.90	6.22	6.31	6.32	0.10	0.60	0.18	-1.0000	0.9900	-1.0000
18.02.2009 12:20:00	74.48	74.55	74.99	6.15	6.24	6.23	0.08	0.57	0.16	-1.0000	-1.0000	-1.0000
18.02.2009 12:30:00	74.80	74.90	75.37	6.09	6.22	6.18	-0.05	0.44	0.04	-1.0000	-1.0000	-1.0000
18.02.2009 12:40:00	75.09	75.15	75.59	5.91	6.03	5.99	-0.21	0.26	-0.12	-1.0000	-1.0000	-1.0000
18.02.2009 12:50:00	74.96	74.99	75.44	5.92	6.05	6.03	-0.20	0.27	-0.11	-1.0000	-1.0000	-1.0000
18.02.2009 13:00:00	74.99	75.05	75.53	5.86	5.97	5.96	-0.25	0.21	-0.19	-1.0000	-1.0000	-1.0000
18.02.2009 13:10:00	74.86	74.93	75.47	5.90	5.99	6.00	-0.23	0.22	-0.19	-1.0000	-1.0000	-1.0000
18.02.2009 13:20:00	74.90	74.96	75.47	5.98	6.06	6.04	-0.22	0.25	-0.17	-1.0000	-1.0000	-1.0000
18.02.2009 13:30:00	74.36	74.48	74.93	5.97	6.06	6.03	-0.19	0.27	-0.15	-1.0000	-1.0000	-1.0000
18.02.2009 13:40:00	74.32	74.36	74.80	6.03	6.11	6.11	-0.15	0.31	-0.10	-1.0000	-1.0000	-1.0000
18.02.2009 13:50:00	74.10	74.20	74.67	6.14	6.22	6.21	-0.03	0.48	0.05	-1.0000	-1.0000	-1.0000
18.02.2009 14:00:00	74.13	74.20	74.67	6.25	6.31	6.34	0.00	0.49	0.04	-1.0000	-1.0000	-1.0000
18.02.2009 14:10:00	73.97	74.01	74.48	6.37	6.45	6.45	0.06	0.57	0.12	-1.0000	-1.0000	-1.0000
18.02.2009 14:20:00	73.85	73.94	74.45	6.47	6.54	6.55	0.12	0.64	0.17	-1.0000	-1.0000	-1.0000
18.02.2009 14:30:00	73.75	73.91	74.32	6.69	6.74	6.75	0.27	0.81	0.33	-1.0000	-0.9900	-1.0000
18.02.2009 14:40:00	73.75	73.85	74.32	6.73	6.81	6.83	0.26	0.81	0.32	-1.0000	-0.9900	-1.0000
18.02.2009 14:50:00	73.72	73.81	74.29	6.71	6.78	6.82	0.24	0.77	0.29	-1.0000	0.9900	-1.0000
18.02.2009 15:00:00	73.75	73.85	74.29	6.73	6.81	6.83	0.26	0.78	0.33	1.0000	-0.9900	-1.0000
18.02.2009 15:10:00	73.94	74.04	74.55	6.54	6.63	6.64	0.15	0.65	0.20	-1.0000	-0.9900	-1.0000
18.02.2009 15:20:00	73.97	74.07	74.51	6.60	6.66	6.66	0.17	0.71	0.25	-1.0000	-0.9900	-1.0000
18.02.2009 15:30:00	73.85	73.94	74.42	6.57	6.65	6.65	0.19	0.75	0.26	-1.0000	-0.9900	-1.0000
18.02.2009 15:40:00	73.88	74.01	74.48	6.45	6.50	6.52	0.14	0.66	0.20	-1.0000	-0.9900	-1.0000
18.02.2009 15:50:00	73.94	73.97	74.48	6.44	6.50	6.52	0.18	0.70	0.23	-1.0000	-0.9900	-1.0000
18.02.2009 16:00:00	73.97	74.07	74.55	6.46	6.56	6.58	0.20	0.70	0.26	-1.0000	-0.9900	-1.0000
18.02.2009 16:10:00	74.10	74.13	74.64	6.39	6.46	6.48	0.13	0.66	0.22	-1.0000	-0.9900	-1.0000
18.02.2009 16:20:00	74.36	74.42	74.86	6.41	6.49	6.50	0.15	0.68	0.23	-1.0000	-0.9900	-1.0000
18.02.2009 16:30:00	74.36	74.42	74.90	6.12	6.11	[illegible]	0.04	0.39	0.04	1.0000	-1.0000	1.0000
18.02.2009 16:40:00	74.26	74.29	74.77	5.85	5.96	5.94	-0.20	0.27	-0.14	-1.0000	-1.0000	-1.0000
18.02.2009 16:50:00	74.67	74.67	75.18	5.09	5.21	5.19	-0.67	-0.28	-0.65	0.9900	-1.0000	0.9900
18.02.2009 17:00:00	74.86	74.90	75.34	5.45	5.53	5.54	-0.42	-0.02	-0.41	-1.0000	-1.0000	-1.0000
18.02.2009 17:10:00	75.40	75.47	75.91	5.36	5.44	5.43	-0.53	-0.13	-0.51	0.9900	-1.0000	0.9900
18.02.2009 17:20:00	75.59	75.66	76.14	5.41	5.48	5.48	-0.49	-0.07	-0.48	-1.0000	-1.0000	-1.0000
18.02.2009 17:30:00	76.04	76.04	76.55	5.24	5.34	5.31	-0.68	-0.28	-0.65	0.9900	-1.0000	0.9900
18.02.2009 17:40:00	76.20	76.23	76.74	5.03	5.11	5.09	-0.73	-0.34	-0.70	0.9900	-1.0000	0.9900
18.02.2009 17:50:00	76.36	76.39	76.87	5.06	5.16	5.13	-0.76	-0.38	-0.74	0.9900	-1.0000	0.9900
18.02.2009 18:00:00	76.36	76.36	76.80	4.88	4.98	4.97	-0.83	-0.49	-0.82	0.9900	0.9900	0.9900
18.02.2009 18:10:00	76.33	76.29	76.74	4.92	5.03	5.00	-0.85	-0.50	-0.85	0.9900	0.9900	0.9900
18.02.2009 18:20:00	76.01	76.01	76.49	5.17	5.26	5.27	-0.79	-0.44	-0.81	0.9900	-1.0000	0.9900
18.02.2009 18:30:00	75.50	75.50	75.98	5.57	5.66	5.68	-0.72	0.34	-0.74	0.9900	-1.0000	0.9900

Transformer 1 - 132 Side Data

Date & Time	Ph Vol/ 132 kV Bus L1	Ph Vol/ 132 kV Bus L2	Ph Vol/ 132 kV Bus L3	MW L1	MW L2	MW L3	Mvar L1	Mvar L2	Mvar L3	Power Factor L1	Power Factor L2	Power Factor L3
18.02.2009 12:00:00	74.22	74.41	74.86	6.36	6.36	6.38	0.05	0.48	0.18	1.0000	1.0000	1.0000
18.02.2009 12:10:00	74.35	74.51	74.96	6.22	6.27	6.28	0.01	0.42	0.14	1.0000	1.0000	1.0000
18.02.2009 12:20:00	74.38	74.57	75.02	6.13	6.21	6.20	-0.01	0.40	0.13	1.0000	1.0000	1.0000
18.02.2009 12:30:00	74.83	74.99	75.43	6.11	6.20	6.18	-0.15	0.26	-0.01	1.0000	1.0000	1.0000
18.02.2009 12:40:00	74.99	75.11	75.53	5.94	6.04	6.01	-0.29	0.10	-0.16	1.0000	1.0000	1.0000
18.02.2009 12:50:00	74.92	75.05	75.53	5.96	6.05	6.01	-0.28	0.12	-0.15	1.0000	1.0000	1.0000
18.02.2009 13:00:00	74.96	75.15	75.59	5.88	5.95	5.96	0.32	0.05	-0.22	1.0000	1.0000	1.0000
18.02.2009 13:10:00	74.86	75.08	75.53	5.89	5.98	6.00	-0.32	0.05	-0.22	1.0000	1.0000	1.0000
18.02.2009 13:20:00	74.86	74.99	75.43	5.99	6.06	6.01	-0.31	0.10	-0.20	1.0000	1.0000	1.0000
18.02.2009 13:30:00	74.35	74.48	74.92	5.97	6.02	6.02	-0.27	0.11	-0.17	1.0000	1.0000	1.0000
18.02.2009 13:40:00	74.19	74.35	74.8	6.03	6.07	6.08	-0.23	0.14	-0.13	1.0000	1.0000	1.0000
18.02.2009 13:50:00	74	74.22	74.67	6.12	6.17	6.16	-0.11	0.29	0.00	1.0000	1.0000	1.0000
18.02.2009 14:00:00	74.03	74.19	74.7	6.25	6.27	6.30	-0.09	0.30	-0.01	1.0000	1.0000	1.0000
18.02.2009 14:10:00	73.87	74.06	74.51	6.36	6.39	6.41	0.01	0.40	0.08	1.0000	1.0000	1.0000
18.02.2009 14:20:00	73.78	73.97	74.45	6.46	6.47	6.52	0.04	0.46	0.14	1.0000	1.0000	1.0000
18.02.2009 14:30:00	73.65	73.91	74.38	6.71	6.72	6.72	0.17	0.60	0.27	1.0000	1.0000	1.0000
18.02.2009 14:40:00	73.68	73.84	74.32	6.75	6.76	6.77	0.15	0.61	0.27	1.0000	1.0000	1.0000
18.02.2009 14:50:00	73.65	73.84	74.26	6.71	6.73	6.74	0.15	0.58	0.26	1.0000	1.0000	1.0000
18.02.2009 15:00:00	73.65	73.87	74.32	6.74	6.78	6.79	0.16	0.59	0.28	1.0000	1.0000	1.0000
18.02.2009 15:10:00	73.91	74.1	74.51	6.58	6.63	6.62	0.05	0.46	0.17	1.0000	1.0000	1.0000
18.02.2009 15:20:00	73.91	74.06	74.54	6.58	6.63	6.65	0.07	0.50	0.19	1.0000	1.0000	1.0000
18.02.2009 15:30:00	73.81	73.97	74.41	6.57	6.60	6.61	0.11	0.54	0.22	1.0000	1.0000	1.0000
18.02.2009 15:40:00	73.84	74.03	74.48	6.47	6.48	6.49	0.05	0.48	0.16	1.0000	1.0000	1.0000
18.02.2009 15:50:00	73.84	74.03	74.48	6.48	6.52	6.53	0.09	0.51	0.19	1.0000	1.0000	1.0000
18.02.2009 16:00:00	73.94	74.1	74.57	6.48	6.51	6.55	0.11	0.52	0.22	1.0000	1.0000	1.0000
18.02.2009 16:10:00	73.97	74.16	74.64	6.40	6.43	6.43	0.07	0.49	0.19	1.0000	1.0000	1.0000
18.02.2009 16:20:00	74.26	74.41	74.89	6.42	6.47	6.48	0.05	0.47	0.18	1.0000	1.0000	1.0000
18.02.2009 16:30:00	74.26	74.41	74.89	6.14	6.17	[illegible]	-0.12	0.28	0.00	[illegible]	1.0000	1.0000
18.02.2009 16:40:00	74.13	74.29	74.83	5.87	5.91	5.91	-0.27	0.11	-0.15	1.0000	1.0000	1.0000
18.02.2009 16:50:00	74.54	74.67	75.18	5.11	5.14	5.15	0.73	-0.43	-0.66	-0.9900	1.0000	-0.9900
18.02.2009 17:00:00	74.7	74.89	75.4	5.45	5.51	5.52	-0.49	-0.18	-0.42	1.0000	1.0000	1.0000
18.02.2009 17:10:00	75.27	75.43	75.88	5.37	5.40	5.41	-0.60	-0.29	-0.53	-0.9900	1.0000	-0.9900
18.02.2009 17:20:00	75.56	75.72	76.2	5.43	5.47	5.48	-0.57	-0.24	-0.50	-0.9900	1.0000	1.0000
18.02.2009 17:30:00	75.94	76.1	76.55	5.25	5.31	5.29	-0.74	-0.43	-0.66	-0.9900	1.0000	-0.9900
18.02.2009 17:40:00	76.16	76.32	76.8	5.09	5.14	5.12	-0.79	-0.47	-0.72	-0.9900	1.0000	-0.9900
18.02.2009 17:50:00	76.26	76.42	76.86	5.09	5.14	5.12	-0.83	-0.54	-0.77	-0.9900	-0.9900	-0.9900
18.02.2009 18:00:00	76.39	76.42	76.9	4.91	4.96	4.96	-0.91	-0.62	-0.85	-0.9800	-0.9900	-0.9900
18.02.2009 18:10:00	76.23	76.35	76.8	4.94	5.01	4.99	-0.91	-0.65	-0.87	-0.9800	-0.9900	-0.9800
18.02.2009 18:20:00	75.91	76.07	76.51	5.20	5.24	5.24	-0.86	-0.59	-0.83	-0.9900	-0.9900	-0.9900
18.02.2009 18:30:00	75.37	75.59	76.1	5.58	5.64	5.66	-0.81	-0.51	-0.76	-0.9900	1.0000	-0.9900

Appendix 5(a) - Format for Frequency-Impedance simulation data – PSCAD files for different loads

F(Hz)	|Z+|(ohms) Load1	|Z+|(ohms) Load2	|Z+|(ohms) Load3	|Z+|(ohms) Load4	|Z+|(ohms) Load5	|Z+|(ohms) Load6	|Z+|(ohms) Load7	|Z+|(ohms) Load8	|Z+|(ohms) Load9
50	2.0765887	2.0974091	2.0938632	2.0924098	2.0904169	2.0380374	2.0166673	2.0358159	2.0277524
60	2.5324908	2.5580873	2.5532651	2.5511371	2.5482138	2.4822916	2.4554765	2.4774542	2.4670118
70	3.0162483	3.0470377	3.0405371	3.037462	3.0332319	2.9516432	2.9185768	2.9426786	2.9293315
80	3.5364887	3.5730226	3.5642736	3.5598639	3.5537925	3.4536223	3.4132049	3.4384057	3.4214321
90	4.1049853	4.1480014	4.1361797	4.129873	4.1211864	3.9983713	3.9490821	3.9738656	3.9522605
100	4.7384353	4.7889353	4.7728116	4.7637661	4.7513098	4.6000412	4.5397269	4.5617876	4.5341188
110	5.4616401	5.521017	5.4986775	5.485579	5.4675564	5.2792297	5.204738	5.2204323	5.1845905
120	6.313534	6.3837841	6.3520728	6.3327479	6.3062025	6.0674403	5.9739428	5.9772097	5.9299477
130	7.3595296	7.4436187	7.3969111	7.367479	7.3271645	7.0157807	6.8954229	6.8754771	6.8114973
140	8.7194927	8.8219906	8.7491315	8.7018956	8.6374988	8.2133364	8.0522694	7.9881293	7.8981076
150	10.640346	10.768344	10.643549	10.560785	10.448883	9.8299192	9.60091	9.4465598	9.3123762
160	13.724152	13.88629	13.634243	13.464871	13.239596	12.226899	11.867781	11.504469	11.28621
170	19.881867	20.046926	19.34241	18.875272	18.278965	16.260304	15.599972	14.650473	14.248471
180	37.950898	36.802963	33.072782	30.915345	28.517119	23.455769	22.043799	19.21962	18.428301
190	37.148986	33.897713	31.054411	29.267838	27.233357	24.25234	23.319389	19.584215	18.86131
200	12.372599	12.10434	11.969455	11.860278	11.714053	11.70184	11.706542	11.016954	10.91408
210	4.8556057	4.8222601	4.8148178	4.8076943	4.7979541	4.8344668	4.8511058	4.7788975	4.7755018
220	1.2363445	1.2344949	1.2344579	1.2343385	1.23418	1.2377061	1.2392401	1.2364586	1.2368056
230	1.0498503	1.0510206	1.0508435	1.0507704	1.0506633	1.0476728	1.0464051	1.0474522	1.0469511
240	2.7516257	2.758756	2.7565104	2.7551997	2.7533405	2.7308829	2.7215471	2.7238488	2.7192654
250	4.1658817	4.1804173	4.1733415	4.168822	4.1624651	4.1078978	4.0855856	4.0819208	4.0695309
260	5.4367975	5.4587562	5.4438002	5.4338296	5.4198797	5.3228248	5.2837336	5.2646531	5.241087
270	6.6464259	6.6753073	6.648887	6.6308245	6.6056691	6.4554109	6.3957629	6.3504241	6.3122625
280	7.8487364	7.8837037	7.8412999	7.8118352	7.7709887	7.5549175	7.4703841	7.3860644	7.3295131
290	9.0846843	9.1244881	9.0601282	9.0149227	8.9525669	8.6549274	8.5402268	8.4015203	8.3221643
300	10.389967	10.43271	10.338255	10.271457	10.179836	9.7804254	9.6289569	9.4168265	9.3094313
310	11.799755	11.842477	11.706593	11.610148	11.478737	10.951355	10.75481	10.445516	10.303863
320	13.352232	13.390217	13.19683	13.059484	12.87382	12.18433	11.932264	11.496195	11.312963
330	15.091855	15.117475	14.843414	14.64924	14.389271	13.493189	13.172557	12.573051	12.339779
340	17.072884	17.073643	16.684977	16.4112	16.048968	14.888592	14.483316	13.675672	13.382861
350	19.363542	19.318682	18.765009	18.378816	17.875299	16.37663	15.867334	14.798405	14.435844
360	22.050869	21.925415	21.130988	20.585	19.886073	17.956283	17.320441	15.929453	15.486874
370	25.245594	24.97982	23.830134	23.056415	22.088367	19.615551	18.828497	17.05001	16.518157
380	29.084116	28.57512	26.89811	25.801556	24.467869	21.326394	20.363775	18.133858	17.505988
390	33.718426	32.78955	30.33428	28.788945	26.972701	23.039317	21.881592	19.147976	18.421663
400	39.269064	37.626983	34.05546	31.913326	29.493543	24.67978	23.318908	20.054701	19.233615
410	45.684875	42.889757	37.82742	34.956922	31.849006	26.150176	24.597344	20.815705	19.910797
420	52.433237	47.984648	41.207167	37.575353	33.795311	27.3414	25.63279	21.39739	20.426915
430	58.116626	51.83139	43.591001	39.360318	35.080352	28.154837	26.351306	21.776488	20.764525
440	60.734608	53.269008	44.459271	39.999918	35.534858	28.528612	26.706835	21.944206	20.917864
450	59.26789	51.93395	43.694875	39.444014	35.146967	28.455773	26.693117	21.907481	20.893508
460	54.765617	48.568935	41.649979	37.923158	34.061192	27.984302	26.343902	21.686997	20.708729
470	49.120345	44.320928	38.889969	35.806758	32.505447	27.199644	25.721813	21.312829	20.388199
480	43.625783	40.035601	35.907196	33.439908	30.705922	26.200215	24.901883	20.819258	19.960102
490	38.797738	36.122359	33.009969	31.063924	28.837307	25.077173	23.956855	20.240211	19.452659
500	34.721277	32.705208	30.346518	28.814936	27.01248	23.903527	22.948088	19.606103	18.891628
510	31.319711	29.774232	27.965365	26.753892	25.293569	22.731609	21.922217	18.942231	18.298912
520	28.478543	27.271568	25.863967	24.897188	23.708165	21.595455	20.911746	18.268378	17.6921
530	26.089803	25.130025	24.017909	23.238206	22.263064	20.514995	19.937501	17.599207	17.084634
540	24.06372	23.287678	22.395973	21.760142	20.953748	19.500216	19.011535	16.945033	16.48632
550	22.32902	21.692017	20.967102	20.442902	19.77027	18.554563	18.139739	16.312695	15.903973
560	20.830007	20.300046	19.703195	19.266503	18.700623	17.677432	17.323909	15.706387	15.342051
570	19.523275	19.07705	18.579924	18.212567	17.732559	16.865876	16.563261	15.128356	14.803232
580	18.374857	17.995108	17.576682	17.264848	16.854492	16.115724	15.855478	14.579467	14.288878
590	17.35799	17.031727	16.676184	16.409271	16.055889	15.422288	15.19742	14.059634	13.799418
600	16.451409	16.168709	15.863993	15.633778	15.327384	14.780784	14.585571	13.568141	13.334626
610	15.638068	15.391242	15.128046	14.928091	14.660757	14.18658	14.016335	13.103874	12.893844
620	14.904178	14.687194	14.45825	14.28346	14.04884	13.635323	13.486196	12.665485	12.476137
630	14.238489	14.046559	13.846124	13.692431	13.485409	13.123006	12.991823	12.251512	12.080404
640	13.631746	13.461025	13.28452	13.148645	12.965061	12.645977	12.530113	11.86045	11.70546
650	13.076275	12.923648	12.767379	12.64666	12.483107	12.200942	12.098216	11.49081	11.350092

Appendix 5(b) - Format for Frequency-Impedance(ohm) simulation data – PSCAD files for different transformer/capacitor bank configurations

F(Hz)	For average day load 1TF/1Cap bank	1TF/2Cap bank	2TF/1Cap bank	2TF/2Cap bank	2TF/3Cap bank	2TF/4Cap bank
50	3.530260	3.591255	2.016445	2.035243	2.055395	2.074929
75	5.313060	5.539419	3.042179	3.107011	3.183534	3.254573
100	7.120951	7.744491	4.105991	4.265768	4.484816	4.675830
125	8.968542	10.505054	5.265659	5.600677	6.177524	6.641357
150	10.875430	14.745388	6.692222	7.359336	9.020576	10.250893
175	12.867165	25.204047	9.146337	10.661300	18.693724	24.698128
200	14.976218	18.551817	27.229516	36.213069	9.671190	8.241301
225	17.243000	2.166686	1.887790	1.964931	1.065868	1.090080
250	19.716856	8.079875	5.298313	6.031489	4.114747	4.545774
275	22.456639	11.761127	6.764813	8.150131	6.005077	7.077194
300	25.529742	14.897932	7.782135	9.884352	7.559317	9.531297
325	29.006933	17.991607	8.615559	11.556918	9.018825	12.280023
350	32.947171	21.293213	9.350691	13.299837	10.493612	15.652772
375	37.361262	24.989046	10.024531	15.200462	12.054919	20.088103
400	42.137835	29.251677	10.656322	17.340795	13.764658	26.254480
425	46.924712	34.241158	11.257460	19.815303	15.689199	35.031167
450	51.023587	40.048845	11.835362	22.744632	17.909482	46.230745
475	53.491381	46.530088	12.395197	26.290303	20.531949	53.586688
500	53.623020	52.974996	12.940760	30.670715	23.703096	48.964812
525	51.485055	57.828502	13.474931	36.169622	27.629890	39.252751
550	47.847218	59.266917	13.999960	43.097309	32.605903	31.202271
575	43.613621	56.823264	14.517633	51.569503	39.029587	25.481002
600	39.415893	51.875145	15.029388	60.791128	47.342252	21.413938
625	35.565934	46.187816	15.536393	67.860890	57.606469	18.429040
650	32.165034	40.820416	16.039606	68.678242	68.086350	16.161306
675	29.209391	36.150675	16.539813	62.933276	73.596942	14.384586
700	26.653525	32.211771	17.037663	54.501372	69.912271	12.955730
725	24.441205	28.915403	17.533692	46.462679	60.509478	11.781131
750	22.518469	26.149466	18.028345	39.795924	50.738096	10.797517
775	20.838114	23.811764	18.521990	34.483977	42.661202	9.960799
800	19.360497	21.818154	19.014932	30.263566	36.379988	9.239403
825	18.052937	20.101941	19.507423	26.874673	31.517726	8.610168
850	16.888677	18.610928	19.999672	24.112956	27.702075	8.055739
875	15.845839	17.304307	20.491849	21.827558	24.651749	7.562864
900	14.906494	16.150033	20.984098	19.908644	22.167253	7.121251
925	14.055885	15.122763	21.476533	18.275906	20.108355	6.722792
950	13.281809	14.202283	21.969249	16.869959	18.375530	6.361010
975	12.574116	13.372330	22.462321	15.646272	16.897003	6.030669
1000	11.924315	12.619706	22.955810	14.570971	15.620081	5.727493
1025	11.325261	11.933607	23.449766	13.617917	14.505393	5.447950
1050	10.770908	11.305117	23.944225	12.766670	13.523026	5.189103
1075	10.256114	10.726823	24.439215	12.001045	12.649901	4.948485
1100	9.776477	10.192516	24.934760	11.308079	11.867954	4.724009
1125	9.328217	9.696959	25.430872	10.677277	11.162862	4.513899
1150	8.908066	9.235707	25.927563	10.100057	10.523133	4.316633
1175	8.513188	8.804965	26.424838	9.569339	9.939448	4.130898
1200	8.141112	8.401475	26.922698	9.079233	9.404171	3.955557
1225	7.789676	8.022424	27.421142	8.624799	8.910990	3.789618
1250	7.456978	7.665372	27.920167	8.201867	8.454644	3.632216

F(Hz)	For maximum day load 1TF/1Cap bank	1TF/2Cap bank	2TF/1Cap bank	2TF/2Cap bank	2TF/3Cap bank	2TF/4Cap bank
50	3.524365	3.581632	2.016361	2.035122	2.055281	2.074724
75	5.255470	5.447640	3.024282	3.088072	3.163514	3.233115
100	7.003480	7.461877	4.049372	4.203509	4.414909	4.597521
125	8.895943	9.826122	5.140100	5.454989	5.994782	6.421034
150	11.330262	13.128408	6.443683	7.048253	8.523768	9.567186
175	16.076957	19.775276	8.594992	9.874775	15.907987	19.495743
200	22.447167	17.657433	20.906112	25.499368	9.623860	8.336056
225	2.049656	2.140753	1.868376	1.943815	1.083532	1.083864
250	6.505582	7.618587	5.114276	5.787748	4.017643	4.413507
275	8.504007	10.704126	6.444826	7.671812	5.763283	6.724512
300	9.805664	13.149262	7.344118	9.154046	7.151852	8.855633
325	10.806146	15.425295	8.068965	10.539409	8.419956	11.123531
350	11.645743	17.735598	8.701909	11.943550	9.670049	13.751300
375	12.388261	20.205431	9.278754	13.434567	10.963204	16.977953
400	13.067663	22.934539	9.818198	15.068668	12.347271	21.103845
425	13.704057	26.012821	10.331310	16.903839	13.868626	26.464678
450	14.310263	29.517310	10.825242	19.007863	15.579121	33.118277
475	14.894899	33.487164	11.304910	21.465081	17.542041	39.710729
500	15.463985	37.861951	11.773841	24.383001	19.838763	42.440985
525	16.021842	42.368989	12.234643	27.897238	22.577063	39.263915
550	16.571638	46.394709	12.689294	32.167684	25.501171	33.388963
575	17.115728	49.016581	13.139308	37.343605	30.000699	27.860186
600	17.655886	49.436108	13.585866	43.439704	35.105280	23.474292
625	18.193454	47.589876	14.029891	50.018629	41.418861	20.116535
650	18.729454	44.194817	14.472109	55.696191	48.864133	17.528897
675	19.264668	40.171380	14.913055	58.230534	56.427295	15.497257
700	19.799691	36.174346	15.353304	56.332872	61.448699	13.868775
725	20.334978	32.523051	15.793095	51.205827	61.056825	12.537637
750	20.870872	29.316439	16.232752	45.054015	55.709670	11.430272
775	21.407633	26.546324	16.672501	39.274499	48.490393	10.494702
800	21.945450	24.164021	17.112516	34.336602	41.644374	9.693490
825	22.484464	22.111769	17.552934	30.255257	35.902734	8.999135
850	23.024772	20.335355	17.993862	26.903102	31.267252	8.391057
875	23.566441	18.788095	18.435379	24.135682	27.541661	7.853586
900	24.109511	17.431275	18.877545	21.828746	24.522008	7.374599
925	24.654003	16.233299	19.320404	19.884123	22.042782	6.944582
950	25.199922	15.168525	19.763985	18.226445	19.978888	6.555971
975	25.747262	14.216135	20.208308	16.798223	18.237591	6.202681
1000	26.296007	13.359181	20.653383	15.555461	16.750131	5.879760
1025	26.846134	12.583789	21.099214	14.464220	15.465080	5.583143
1050	27.397616	11.878542	21.545800	13.498066	14.343528	5.309459
1075	27.950421	11.233984	21.993135	12.636193	13.355646	5.055891
1100	28.504514	10.642236	22.441208	11.862052	12.478277	4.820068
1125	29.059859	10.096691	22.890008	11.162347	11.693217	4.599978
1150	29.616418	9.591775	23.339520	10.526294	10.985986	4.393903
1175	30.174153	9.122760	23.789729	9.945065	10.344945	4.200369
1200	30.733027	8.685609	24.240618	9.411371	9.760636	4.018101
1225	31.292999	8.276863	24.692169	8.919149	9.225307	3.845996
1250	31.854034	7.893537	25.144363	8.463313	8.732545	3.683087

F(Hz)	For minimum night load 1TF/1Cap bank	1TF/2Cap bank	2TF/1Cap bank	2TF/2Cap bank	2TF/3Cap bank	2TF/4Cap bank
50	3.779017	3.845555	2.092375	2.112594	2.134393	2.155489
75	5.758072	5.994559	3.167987	3.238324	3.321984	3.399629
100	7.911532	8.525269	4.298236	4.473812	4.717358	4.930368
125	10.490014	11.900216	5.553742	5.928717	6.587846	7.123927
150	14.324683	17.708778	7.141791	7.910127	9.912780	11.457938
175	24.527421	37.517340	10.015644	11.874050	23.924537	36.288834
200	25.968217	17.879006	42.081602	64.233050	9.261599	7.918342
225	2.105339	2.201814	1.914168	1.918392	1.074020	1.098615
250	7.233596	8.679735	5.531610	6.317856	4.249488	4.712852
275	9.895121	13.188902	7.162076	8.741547	6.309917	7.516765
300	11.783752	17.414971	8.323262	10.811071	8.066108	10.391897
325	13.320506	22.005768	9.294211	12.891174	9.772193	13.831177
350	14.661991	27.461483	10.165769	15.156109	11.556953	18.431290
375	15.881203	34.392081	10.977031	17.749776	13.517815	25.277703
400	17.017616	43.708900	11.748041	20.840104	15.755211	36.824218
425	18.094950	56.810516	12.490416	24.661623	18.395051	59.235130
450	19.128596	75.262972	13.211525	29.576365	21.614682	95.372688
475	20.129135	96.911965	13.916371	36.185259	25.684469	80.675038
500	21.104155	106.14002	14.608525	45.550535	31.045376	51.362739
525	22.059275	92.772252	15.290641	59.630013	38.467343	36.227899
550	22.998756	73.751761	15.964740	81.749820	49.393646	27.884247
575	23.925892	58.886276	16.632402	112.891827	66.676421	22.698587
600	24.843262	48.363700	17.294878	127.70480	95.305034	19.176699
625	25.752905	40.832696	17.953170	103.45389	132.07433	16.627454
650	26.656452	35.262687	18.608092	76.404502	128.40875	14.693300
675	27.555211	31.002695	19.260304	58.483810	93.006296	13.172135
700	28.450237	27.647105	19.910349	46.889053	67.584813	11.941529
725	29.342387	24.936958	20.558672	38.997594	52.109166	10.923115
750	30.232356	22.701478	21.205641	33.336489	42.180528	10.064450
775	31.120709	20.824359	21.851560	29.092740	35.371041	9.329121
800	32.007908	19.224024	22.496680	25.796501	30.435310	8.691060
825	32.894327	17.841729	23.141210	23.161624	26.698711	8.131107
850	33.780273	16.634177	23.785322	21.005322	23.771086	7.634865
875	34.665994	15.568791	24.429159	19.205918	21.413236	7.191302
900	35.551694	14.620611	25.072838	17.679512	19.471104	6.791818
925	36.437534	13.770200	25.716458	16.366481	17.841286	6.429609
950	37.323647	13.002202	26.360098	15.223341	16.451925	6.099219
975	38.210138	12.304326	27.003824	14.217658	15.251592	5.796221
1000	39.097090	11.666619	27.647691	13.324762	14.202535	5.516984
1025	39.984570	11.080939	28.291740	12.525557	13.276433	5.258500
1050	40.872627	10.540554	28.936008	11.805041	12.451627	5.018256
1075	41.761301	10.039856	29.580522	11.151259	11.711277	4.794134
1100	42.650620	9.574132	30.225304	10.554574	11.042092	4.584339
1125	43.540602	9.139394	30.870372	10.007127	10.433443	4.387336
1150	44.431262	8.732242	31.515737	9.502447	9.876727	4.201805
1175	45.322606	8.349763	32.161409	9.035157	9.364909	4.026607
1200	46.214637	7.989441	32.807395	8.600750	8.892176	3.860748
1225	47.107353	7.649098	33.453698	8.195425	8.453687	3.703364
1250	48.000750	7.326833	34.100319	7.815946	8.045373	3.553693

APPENDIX 6 - Data format for harmonic measurement – Panaduara grid sub station

Date	Time	THD %			3rd %			5th %			7th %			9th %			11th %			13th %		
		L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
01.02.2009	17:00:00	1.20	1.40	1.30	0.50	0.60	0.50	0.70	0.60	0.80	0.20	0.20	0.30	0.10	0.20	0.20	0.30	0.30	0.20	0.20	0.10	0.20
01.02.2009	17:10:00	1.00	1.90	1.40	0.40	0.40	0.40	0.50	0.60	0.80	0.30	0.40	0.40	0.10	0.20	0.20	0.40	0.40	0.40	0.30	0.60	0.30
01.02.2009	17:20:00	3.50	2.00	2.00	0.70	0.80	0.50	0.90	0.80	1.10	0.40	0.50	0.30	0.50	0.50	0.30	0.40	0.60	0.50	0.40	0.50	0.70
01.02.2009	17:30:00	1.30	1.20	1.50	0.30	0.40	0.30	0.90	0.80	1.10	0.50	0.60	0.40	0.30	0.20	0.20	0.40	0.40	0.40	0.30	0.30	0.30
01.02.2009	17:40:00	1.30	1.10	1.40	0.30	0.40	0.30	0.90	0.80	1.10	0.30	0.30	0.30	0.20	0.10	0.10	0.40	0.40	0.40	0.30	0.30	0.30
01.02.2009	17:50:00	1.20	1.10	1.40	0.30	0.40	0.50	0.90	0.90	1.20	0.20	0.30	0.20	0.20	0.10	0.10	0.40	0.30	0.50	0.30	0.20	0.30
01.02.2009	18:00:00	1.30	1.20	1.40	0.30	0.40	0.40	1.00	0.90	1.20	0.30	0.30	0.30	0.20	0.10	0.10	0.40	0.40	0.50	0.40	0.20	0.30
01.02.2009	18:10:00	1.30	1.30	1.50	0.40	0.50	0.40	1.00	0.90	1.20	0.30	0.40	0.30	0.20	0.10	0.10	0.40	0.40	0.40	0.30	0.20	0.30
01.02.2009	18:20:00	1.30	1.30	1.40	0.40	0.50	0.40	0.90	0.90	1.10	0.30	0.40	0.30	0.20	0.10	0.10	0.40	0.40	0.40	0.20	0.20	0.30
01.02.2009	18:30:00	1.30	1.30	1.40	0.40	0.50	0.50	1.10	1.00	1.20	0.30	0.30	0.30	0.10	0.10	0.20	0.40	0.40	0.40	0.30	0.20	0.20
01.02.2009	18:40:00	1.40	1.40	1.40	0.50	0.50	0.50	0.90	0.80	1.00	0.30	0.30	0.30	0.10	0.10	0.10	0.40	0.50	0.40	0.20	0.20	0.10
01.02.2009	18:50:00	1.10	1.10	1.20	0.50	0.50	0.40	0.80	0.80	0.90	0.20	0.30	0.30	0.20	0.10	0.10	0.30	0.40	0.40	0.20	0.10	0.20
01.02.2009	19:00:00	1.70	1.60	1.70	0.60	0.70	0.60	0.70	0.60	0.70	0.20	0.30	0.30	0.20	0.20	0.20	0.30	0.30	0.30	0.20	0.10	0.20
01.02.2009	19:10:00	1.20	1.10	1.30	0.40	0.50	0.40	0.70	0.60	0.70	0.20	0.30	0.30	0.20	0.10	0.10	0.30	0.30	0.20	0.20	0.20	0.20
01.02.2009	19:20:00	0.80	0.80	0.90	0.30	0.30	0.20	0.70	0.60	0.70	0.20	0.30	0.30	0.10	0.10	0.10	0.20	0.30	0.20	0.20	0.20	0.20
01.02.2009	19:30:00	1.20	1.20	1.20	0.40	0.50	0.40	0.70	0.60	0.80	0.20	0.30	0.30	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20	0.20
01.02.2009	19:40:00	1.60	0.90	1.00	0.80	0.40	0.30	0.80	0.70	0.80	0.30	0.30	0.30	0.10	0.10	0.10	0.30	0.30	0.20	0.20	0.20	0.20
01.02.2009	19:50:00	1.20	1.10	1.20	0.50	0.40	0.50	0.80	0.70	0.90	0.20	0.30	0.30	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20	0.20
01.02.2009	20:00:00	1.10	1.10	1.20	0.50	0.40	0.50	0.80	0.70	0.90	0.20	0.30	0.20	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.20	0.30
01.02.2009	20:10:00	1.10	0.90	1.10	0.40	0.30	0.30	0.80	0.80	0.90	0.20	0.20	0.20	0.10	0.10	0.10	0.20	0.20	0.10	0.30	0.30	0.30
01.02.2009	20:20:00	1.10	1.30	1.40	0.50	0.40	0.40	1.00	0.80	1.10	0.20	0.20	0.20	0.10	0.10	0.10	0.20	0.20	0.20	0.30	0.30	0.30
01.02.2009	20:30:00	1.30	1.20	1.30	0.60	0.40	0.40	0.90	0.80	1.00	0.20	0.30	0.30	0.10	0.10	0.10	0.20	0.30	0.20	0.30	0.30	0.30
01.02.2009	20:40:00	1.30	1.20	1.30	0.60	0.40	0.40	0.90	0.90	1.00	0.20	0.20	0.20	0.10	0.10	0.10	0.30	0.30	0.20	0.30	0.30	0.30
01.02.2009	20:50:00	1.40	1.30	1.50	0.60	0.40	0.50	1.00	0.90	1.00	0.20	0.30	0.30	0.20	0.10	0.10	0.30	0.20	0.20	0.30	0.30	0.30
01.02.2009	21:00:00	1.30	1.40	1.40	0.50	0.60	0.50	0.90	0.90	1.10	0.20	0.20	0.30	0.20	0.10	0.10	0.20	0.20	0.20	0.30	0.30	0.30
01.02.2009	21:10:00	1.30	1.10	1.30	0.50	0.40	0.50	0.90	0.80	1.00	0.20	0.20	0.30	0.10	0.10	0.10	0.30	0.20	0.20	0.30	0.30	0.30
01.02.2009	21:20:00	1.40	1.40	1.40	0.60	0.60	0.50	1.00	0.90	1.10	0.20	0.30	0.20	0.10	0.10	0.10	0.20	0.30	0.20	0.30	0.30	0.30
01.02.2009	21:30:00	1.80	1.80	1.80	0.70	0.70	0.60	1.10	1.00	1.20	0.30	0.30	0.30	0.20	0.20	0.20	0.30	0.20	0.20	0.30	0.30	0.30
01.02.2009	21:40:00	1.40	1.40	1.90	0.60	0.40	0.50	1.10	1.10	1.20	0.20	0.30	0.30	0.10	0.10	0.10	0.30	0.30	0.20	0.30	0.30	0.30
01.02.2009	21:50:00	1.60	1.40	1.70	0.70	0.60	0.60	1.10	1.10	1.30	0.20	0.30	0.30	0.20	0.20	0.20	0.30	0.30	0.20	0.20	0.30	0.30
01.02.2009	22:00:00	1.60	1.40	1.60	0.60	0.50	0.50	1.40	1.20	1.40	0.20	0.30	0.30	0.20	0.10	0.20	0.20	0.30	0.30	0.20	0.30	0.30
01.02.2009	22:10:00	1.50	1.30	1.60	[illegible]	[illegible]	[illegible]	1.40	1.20	1.50	0.20	0.30	0.30	0.10	0.10	0.20	0.30	0.30	0.30	0.20	0.30	0.30
01.02.2009	22:20:00	1.50	1.50	1.50	0.50	[illegible]	0.40	1.40	1.20	1.40	0.30	0.30	0.30	0.10	0.10	0.10	0.30	0.40	0.30	0.10	0.20	0.20
01.02.2009	22:30:00	6.60	4.60	9.20	1.10	[illegible]	5.40	1.40	1.20	1.50	0.40	0.30	0.30	0.20	0.20	0.20	0.30	0.40	0.40	0.10	0.20	0.20
01.02.2009	22:40:00	1.50	1.50	1.50	0.30	[illegible]	[illegible]	1.30	1.20	1.30	0.30	0.30	0.20	0.10	0.10	0.20	0.40	0.40	0.50	0.20	0.20	0.20
01.02.2009	22:50:00	1.50	1.40	1.70	0.40	0.60	0.50	1.30	1.10	1.50	0.30	0.30	0.30	0.10	0.10	0.10	0.30	0.50	0.40	0.20	0.20	0.10
01.02.2009	23:00:00	1.60	1.50	1.90	0.50	0.60	0.70	1.40	1.20	1.60	0.40	0.30	0.30	0.20	0.10	0.20	0.50	0.40	0.60	0.30	0.20	0.30
01.02.2009	23:10:00	1.50	1.40	1.70	0.40	0.50	0.70	1.20	1.10	1.50	0.30	0.40	0.30	0.20	0.10	0.20	0.50	0.50	0.60	0.30	0.10	0.30
01.02.2009	23:20:00	1.40	1.40	1.80	0.40	0.40	0.60	1.10	1.10	1.50	0.30	0.40	0.40	0.20	0.20	0.20	0.50	0.60	0.60	0.30	0.10	0.20
01.02.2009	23:30:00	1.40	1.30	1.70	0.30	0.40	0.50	1.10	0.80	1.30	0.40	0.40	0.50	0.30	0.20	0.20	0.60	0.70	0.70	0.20	0.30	0.20
01.02.2009	23:40:00	1.60	1.40	1.80	0.40	0.60	0.50	1.20	0.80	1.50	0.30	0.40	0.40	0.30	0.10	0.20	0.60	0.60	0.60	0.20	0.30	0.20
01.02.2009	23:50:00	1.50	1.10	1.70	0.20	0.30	0.50	1.10	0.70	1.40	0.30	0.30	0.40	0.30	0.10	0.10	0.70	0.70	0.70	0.30	0.20	0.20
02.02.2009	00:00:00	1.40	1.20	1.70	0.40	0.40	0.60	1.10	0.90	1.30	0.30	0.40	0.40	0.30	0.10	0.10	0.70	0.60	0.70	0.30	0.20	0.20
02.02.2009	00:10:00	1.50	1.40	1.80	0.40	0.50	0.80	1.10	0.90	1.40	0.20	0.60	0.30	0.20	0.20	0.20	0.70	0.70	0.70	0.30	0.20	0.20
02.02.2009	00:20:00	1.50	1.40	1.90	0.40	0.40	0.40	1.30	1.10	1.60	0.30	0.60	0.40	0.10	0.20	0.30	0.50	0.60	0.50	0.20	0.10	0.20
02.02.2009	00:30:00	1.50	1.40	1.80	0.30	0.40	0.60	1.30	1.30	1.60	0.30	0.60	0.40	0.10	0.20	0.20	0.50	0.60	0.50	0.20	0.20	0.20
02.02.2009	00:40:00	1.80	1.40	2.00	0.40	0.50	[illegible]	1.60	1.10	1.70	0.30	0.60	0.40	0.10	0.20	0.20	0.50	0.60	0.50	0.10	0.20	0.20
02.02.2009	00:50:00	2.20	1.80	2.10	0.80	0.60	0.80	1.50	0.90	1.60	0.40	0.60	0.60	0.20	0.20	0.20	0.60	0.70	0.60	0.30	0.20	0.40
02.02.2009	01:00:00	1.70	2.10	2.10	1.00	1.00	[illegible]	1.50	1.00	1.70	0.30	0.60	0.50	0.20	0.20	0.20	0.40	0.60	0.40	0.20	0.20	0.30
02.02.2009	01:10:00	1.80	1.20	2.00	0.60	0.30	0.50	1.50	0.90	1.70	0.40	0.50	0.60	0.30	0.20	0.10	0.40	0.50	0.50	0.20	0.30	0.30
02.02.2009	01:20:00	2.20	2.20	2.20	0.70	0.80	1.00	1.50	0.80	1.60	0.40	0.50	0.60	0.30	0.20	0.20	0.50	0.50	0.60	0.20	0.20	0.20
02.02.2009	01:30:00	2.10	1.70	2.30	0.70	0.60	0.80	1.60	0.80	1.70	0.40	0.40	0.50	0.30	0.20	0.20	0.60	0.50	0.70	0.30	0.30	0.20
02.02.2009	01:40:00	1.90	1.40	2.10	0.50	0.30	0.60	1.70	1.00	1.70	0.40	0.40	0.60	0.30	0.10	0.10	0.50	0.50	0.60	0.20	0.30	0.20
02.02.2009	01:50:00	2.00	1.40	2.10	0.50	0.40	0.70	1.70	1.00	1.80	0.40	0.40	0.60	0.30	0.10	0.20	0.60	0.50	0.70	0.30	0.40	0.30
02.02.2009	02:00:00	2.00	1.40	2.10	0.40	0.30	0.60	1.70	1.00	1.80	0.40	0.50	0.50	0.30	0.10	0.20	0.60	0.50	0.70	0.30	0.30	0.30
02.02.2009	02:10:00	2.00	1.50	2.20	0.50	0.40	0.80	1.80	1.20	1.90	0.40	0.50	0.50	0.30	0.10	0.20	0.60	0.40	0.70	0.30	0.30	0.30
02.02.2009	02:20:00	1.90	1.50	2.10	0.40	0.40	0.80	1.70	1.10	1.80	0.40	0.50	0.60	0.30	0.10	0.20	0.60	0.40	0.60	0.30	0.30	0.20
02.02.2009	02:30:00	1.90	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.10	1.80	0.50	0.50	0.50	0.20	0.10	0.10	0.60	0.40	0.60	0.30	0.30	0.20
02.02.2009	02:40:00	2.00	1.50	2.10	0.50	0.40	0.50	1.80	1.50	1.80	0.40	0.50	0.50	0.20	0.10	0.20	0.60	0.40	0.70	0.30	0.30	0.30
02.02.2009	02:50:00	1.90	1.50	2.10	0.40	0.40	0.80	1.70	1.10	1.80	0.40	0.50	0.50	0.20	0.10	0.20	0.60	0.40	0.60	0.30	0.30	0.20
02.02.2009	03:00:00	1.90	1.50	2.10	0.40	0.40	0.80	1.70	1.10	1.80	0.30	0.50	0.60	0.20	0.10	0.20	0.70	0.40	0.70	0.30	0.40	0.30
02.02.2009	03:10:00	1.80	1.50	2.10	0.40	0.40	0.80	1.50	1.10	1.70	0.30	0.50	0.50	0.20	0.10	0.20	0.60	0.40	0.70	0.30	0.40	0.30
02.02.2009	03:20:00	2.60	2.10	2.80	0.50	0.70	1.00	2.10	1.20	2.00	0.30	0.50	0.50	0.30	0.20	0.20	0.60	0.40	0.60	0.20	0.40	0.20
02.02.2009	03:30:00	1.70	1.40	2.00	0.40	0.40	0.80	1.40	1.00	1.60	0.30	0.50	0.50	0.20	0.10	0.20	0.50	0.30	0.60	0.30	0.30	0.20
02.02.2009	03:40:00	1.70	1.50	1.90	0.40	0.30	0.80	1.40	1.00	1.60	0.30	0.50	0.50	0.20	0.10	0.10	0.60	0.40	0.70	0.30	0.40	0.30
02.02.2009	03:50:00	1.80	1.40	2.00	0.50	0.30	0.80	1.50	1.00	1.60	0.40	0.50	0.50	0.30	0.10	0.10	0.60	0.30	0.70	0.30	0.40	0.30
02.02.2009	04:00:00	1.80	1.20	1.90	0.50	0.30	0.70	1.40	0.80	1.50	0.40	0.50	0.60	0.30	0.10	0.10	0.60	0.40	0.70	0.30	0.30	0.30
02.02.2009	04:10:00	1.90	1.40	2.00	0.50	0.30	0.60	1.60	0.90	1.70	0.40	0.40	0.50	0.30	0.10	0.10	0.60	0.50	0.70	0.30	0.30	0.30
02.02.2009	04:20:00	2.10	4.10	4.00	1.00	0.70	0.60	1.40	0.80	1.60	0.40	0.40	0.60	0.30	0.10	0.10	0.50	0.40	0.60	0.30	0.20	0.30
02.02.2009	04:30:00	1.70	1.20	1.80	0.60	0.30	0.70	1.30	0.70	1.50	0.40	0.50	0.50	0.30	0.20	0.10	0.50	0.50	0.60	0.30	0.20	0.30
02.02.2009	04:40:00	1.70	1.50	1.90	0.50	0.30	0.70	1.50	0.90	1.50	0.40	0.60	0.60	0.20	0.20	0.30	0.40	0.50	0.50	0.30	0.30	0.30

APPENDIX 7(a) - Format for results - Reactive power control switching points for 21st January 2009

Multiple Run Output Fil 21_0000 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9850000000	77.25789239	33.60726631	3.339223622	20.92905232	1.221310032	.6591664180E-01
3	1.000000000	77.25750360	33.10557628	-3.337917828	20.30879510	1.184935209	.6397523240E-01

Multiple Run Output Fil 21_0030 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.39278847	33.27852734	2.670006829	19.63244992	.9154634266	.6338808721E-01
2	.9850000000	75.39223421	32.77409036	-2.669217346	19.04162845	.8876354555	.6149058731E-01
3	1.000000000	75.39170317	32.[illegible]8464290	2.668665422	18.4769[illegible]173	.8608543472	.5967500481E-01

Multiple Run Output Fil 21_0100 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9700000000	75.46793688	33.[illegible]6939903	2.284357610	19.07324084	.7608382043	.6141779392E-01
3	.9850000000	75.46730237	32.86344795	-2.2[illegible]185610	18.49891342	.7371398615	.5957242630E-01
4	1.000000000	75.4666[illegible]	[illegible]261095	[illegible]934835	[illegible]	.7154926927	.5782700675E-01

Multiple Run Output Fil 21_0130 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9700000000	75.671098[illegible]	33.[illegible]774535	2.185507709	18.60565[illegible]15	.7117664066	.5992480987E-01
3	.9850000000	75.67042557	32.87167540	-2.194311045	18.04624136	.6914587221	.5813194118E-01
4	1.000000000	75.66982506	32.[illegible]062[illegible]36	[illegible]56177	17.51062265	.6699229319	.5640926343E-01

Multiple Run Output Fil 21_0200 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9700000000	75.13258021	33.32240301	1.491547255	18.2447[illegible]439	.475088[illegible]129	.5883156739E-01
3	.9850000000	75.13175016	32.81697058	-1.491074325	17.69533951	.4605672132	.5706494611E-01
4	1.000000000	75.13096374	32.[illegible]663446	1.49[illegible]894850	17.[illegible]7067669	.4472664155	.5538266170E-01

Multiple Run Output Fil 21_0230 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9700000000	76.0302[illegible]	[illegible]123547	[illegible]163995	18.20876990	.3637463861	.5816494075E-01
3	.9850000000	76.02930456	33.13094928	-1.145354050	17.66054318	.3529189207	.5642341477E-01
4	1.000000000	76.02846[illegible]	32.[illegible]685444	[illegible]	[illegible]13553960	.3419591506	.5476474791E-01

Multiple Run Output Fil 21_0300 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
2	.9700000000	75.997501[illegible]98	33.63192165	.4771497592	17.82998698	.1484689181	.5696165755E-01
3	.9850000000	75.99647648	33.12166281	-.4766275306	17.29328716	.1445156249	.5525616543E-01
4	1.000000000	75.9955[illegible]609	32.6[illegible]660762	.4[illegible]231865	16.77970102	.1389829183	.5362764849E-01

Multiple Run Output Fil 21_0330 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.96128000	33.[illegible]088601	1.[illegible]0258303	18.21530451	.3533095388	.5798921353E-01
2	.9850000000	75.95985[illegible]	33.[illegible]9827249	1.111587682	17.66641203	-.3431785373	.5624632253E-01
3	1.000000000	75.9584[illegible]	[illegible]6545	[illegible]	[illegible]	.332629[illegible]961	.5459170525E-01

Multiple Run Output Fil 21_0400 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	76.0525[illegible]	[illegible]4952562	[illegible]	[illegible]	.2946154579	.6138959634E-01
2	.9850000000	76.05109236	33.13904477	.875[illegible]73751	18.68700094	-.2855331168	.5955239841E-01
3	1.000000000	76.049[illegible]	[illegible]939940	[illegible]	[illegible]6946	.2778106598	.5779814243E-01

Multiple Run Output Fil 21_0430 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.86770321	33.49241035	.3649[illegible]3300	21.86493186	.1391959334	.6986667544E-01
2	.9850000000	75.86624429	32.98457691	.3644523671	21.20691163	-.1349760304	.6776956533E-01
3	1.000000000	75.86483[illegible]	32.[illegible]91311	.3639863899	20.57[illegible]98564	-.1312098863	.6576558878E-01

Multiple Run Output Fil 21_0500 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.69830974	33.42472361	.9050[illegible]00950	25.81[illegible]52915	.4094363603	.8250018366E-01
2	.9850000000	75.69704143	32.91852787	-.9091597869	25.03545218	.3968076921	.8002632280E-01
3	1.000000000	75.6958[illegible]	[illegible]743003	.905[illegible]58[illegible]	24.2942[illegible]625	.3852304086	.7766844077E-01

Multiple Run Output Fil 21_0530 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.046[illegible]	33.[illegible]557185	2.61[illegible]1566	28.92370518	1.319655005	.9346826979E-01
2	.9850000000	75.04579644	32.55610247	-2.610[illegible]71523	28.05559340	1.280047088	.9066751470E-01
3	1.000000000	75.0451[illegible]	[illegible]107022	[illegible]1509	27.22[illegible]	1.242191805	.8799125308E-01

Multiple Run Output Fil 21_0600 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	74.99777[illegible]	33.0[illegible]051170	3.181504168	30.52001494	1.696788084	.9858560644E-01
2	.9850000000	74.99731664	33.57070298	-3.181063677	29.60419055	1.645718554	.9563326860E-01
3	1.000000000	74.9968[illegible]	[illegible]0570367	3.18[illegible]11949	28.72900199	1.596986854	.9281148317E-01

Multiple Run Output Fil 21_0630 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.3438[illegible]	[illegible]3343345	2.81[illegible]409575	27.38916608	1.348083358	.8788404974E-01
2	.9850000000	75.3432174[illegible]	32.81023333	-2.818307693	26.5664[illegible]013	1.307354319	.8525485992E-01
3	1.000000000	75.3425[illegible]	[illegible]011751	[illegible]	[illegible]	1.269218183	.8274387452E-01

Multiple Run Output Fil 21_0700 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	75.85386[illegible]	[illegible]4794741	3.54[illegible]0408	22.[illegible]403	1.565581332	.7286512791E-01
2	.9850000000	75.853630[illegible]1	32.97285386	-3.54[illegible]0522	22.0295[illegible]071	1.518090516	.7069071807E-01
3	1.000000000	75.85335[illegible]	[illegible]64	[illegible]	[illegible]	1.473079056	.6860083134E-01

Multiple Run Output Fil 21_0730 2banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	76.74923[illegible]97	33.[illegible]767573	3.4847[illegible]0683	22.72839936	2.583984272	.7262296257E-01
2	.9850000000	76.74971983	33.26008988	-3.485206025	22.04569053	2.506351016	.7044981655E-01
3	1.000000000	76.7502[illegible]	[illegible]3568979	3.48[illegible]037063	21.39291135	2.431536437	.6837062729E-01

Multiple Run Output Fil 21_0800 4banks

Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang LV	LV MW	LV MVar	TF_HV_Current
1	.9700000000	77.13938[illegible]	33.[illegible]309697	1.093052009	31.2180[illegible]907	.5957551823	.9891653868E-01
2	.9850000000	77.13732[illegible]7	33.1422138	1.091447353	30.28036703	-.5769829591	.9594725862E-01
3	1.000000000	77.1353[illegible]	32.[illegible]51098	1.09[illegible]63702	29.3842[illegible]773	.5594605672	.9314084246E-01

APPENDIX 7(b) - Format for Summary of results- Comparison of simulation data - Present, Optimum & reactive power control schemes for 21st January 2009

Date & Time	Under Present criteria									Optimum control scheme									Proposed var control scheme								
	MW	Mvar	33 Volt	132 Volt	No of Banks	Ph angle	Utilization	HV A	Tap	MW	Mvar	33 Volt	132 Volt	No of Banks	Ph angle	Utilization	HV A	Tap	MW	Mvar	33 Volt	132 Volt	No of Banks	Ph angle	Utilization	HV A	Tap
21.01.2009 00:00:00	20.31	1.19	33.11	77.26	2	-3.338	5.00	45.24	8	20.309	1.18	33.106	77.258	2	-3.338	5.00	45.24	8	20.309	1.1849	33.106	77.258	2	-3.338	5.00	45.237	8
21.01.2009 00:30:00	19.63	0.92	33.28	75.39	2	-2.670	5.00	44.82	10	18.477	0.86	32.285	75.392	2	-2.669	5.00	42.20	8	19.042	0.8876	32.774	75.392	2	-2.669	5.00	43.48	9
21.01.2009 01:00:00	19.07	0.76	33.37	75.47	2	2.280	5.00	43.43	10	18.499	0.74	32.863	75.467	2	-2.282	5.00	42.12	9	18.499	0.7371	32.863	75.467	2	-2.282	5.00	42.124	9
21.01.2009 01:30:00	18.61	0.71	33.38	75.67	2	-2.190	5.00	42.37	10	18.046	0.69	32.872	75.67	2	2.194	5.00	41.10	9	18.046	0.6915	32.872	75.67	2	-2.194	5.00	41.105	9
21.01.2009 02:00:00	18.24	0.48	33.32	75.13	2	[illegible]	5.00	41.60	10	17.695	0.40	32.817	75.132	2	[illegible]	5.00	40.35	9	17.695	0.4606	32.817	75.132	2	[illegible]	5.00	40.351	9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible]	[illegible]	[illegible]	76.029	[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible]	[illegible]	[illegible]	76.029	2	[illegible]	[illegible]	[illegible]	9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	75.886	[illegible]	[illegible]	[illegible]	41.82	9	[illegible]	[illegible]	[illegible]	75.886	2	[illegible]	[illegible]	41.82	9
[illegible]	[illegible]	[illegible]	33.48	75.75	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	32.973	75.854	2	[illegible]	[illegible]	49.98	9	[illegible]	[illegible]	32.973	75.854	2	[illegible]	5.00	49.989	9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]	74.72	4	[illegible]	[illegible]	[illegible]	10
21.01.2009 10:00:00	[illegible]	4.64	33.28	74.58	4	[illegible]	10.00	[illegible]	[illegible]	[illegible]	[illegible]	32.775	74.583	4	[illegible]	10.00	[illegible]	10	[illegible]	4.7876	32.775	74.583	4	7.492	10.00	[illegible]	10
21.01.2009 10:30:00	38.88	5.75	33.09	74.68	4	-8.410	10.00	90.88	11	37.7	5.57	32.582	74.678	4	-8.411	10.00	88.12	10	37.7	5.5749	32.582	74.678	4	-8.411	10.00	88.115	10
21.01.2009 11:00:00	39.50	6.24	33.02	74.63	4	-8.980	10.00	92.62	11	38.298	6.05	32.518	74.628	4	-8.977	10.00	89.82	10	38.298	6.0501	32.518	74.628	4	-8.977	10.00	89.82	10
21.01.2009 11:30:00	41.64	7.20	33.43	74.31	4	-9.810	10.00	98.24	11	40.364	6.98	32.91	74.31	4	-9.803	10.00	95.22	11	40.364	6.9755	32.91	74.31	4	-9.803	10.00	95.219	11
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21.01.2009 12:30:00	[illegible]	[illegible]	33.43	[illegible]	[illegible]	[illegible]	10.00	[illegible]	[illegible]	[illegible]	[illegible]	33.428	74.776	4	[illegible]	10.00	[illegible]	[illegible]	[illegible]	[illegible]	33.428	74.776	4	-6.620	10.00	[illegible]	[illegible]
21.01.2009 13:00:00	38.30	4.24	33.43	75.12	4	-6.310	10.00	88.16	11	38.296	4.24	33.431	75.115	4	-6.312	10.00	88.16	11	38.296	4.2358	33.431	75.115	4	-6.312	10.00	88.158	11
21.01.2009 13:30:00	36.06	3.25	33.11	75.14	4	-5.150	10.00	82.36	10	36.057	3.25	33.115	75.14	4	-5.150	10.00	82.36	10	36.057	3.2501	33.115	75.14	4	-5.150	10.00	82.355	10
21.01.2009 14:00:00	36.65	3.55	33.30	74.89	4	-5.530	10.00	84.59	11	35.54	3.44	32.796	74.888	4	-5.529	10.00	82.02	10	35.54	3.4405	32.796	74.888	4	-5.529	10.00	82.023	10
21.01.2009 14:30:00	42.06	6.43	33.45	74.25	4	-8.690	10.00	98.88	12	40.791	6.23	32.927	74.251	4	-8.684	10.00	95.83	11	39.555	6.0412	32.425	74.254	4	-8.683	10.00	92.917	10
21.01.2009 15:00:00	40.13	5.79	33.04	74.23	4	-8.210	10.00	93.85	11	40.132	5.79	33.042	74.234	4	-8.209	10.00	93.85	11	38.916	5.6131	32.537	74.237	4	-8.207	10.00	90.985	10
21.01.2009 15:30:00	39.20	5.06	33.11	74.46	4	-7.360	10.00	91.29	11	39.198	5.06	33.114	74.463	4	-7.362	10.00	91.29	11	38.01	4.9116	32.608	74.465	4	-7.362	10.00	88.512	10
21.01.2009 16:00:00	40.40	5.89	33.14	74.42	4	-8.300	10.00	94.20	11	40.395	5.89	33.14	74.422	4	-8.302	10.00	94.20	11	39.172	5.7174	32.634	74.425	4	-8.303	10.00	91.346	10
21.01.2009 16:30:00	39.27	5.90	33.34	74.76	4	-8.540	10.00	91.12	11	39.27	5.90	33.338	74.765	4	-8.539	10.00	91.12	11	38.079	5.7166	32.829	74.767	4	-8.538	10.00	88.364	10
21.01.2009 17:00:00	37.68	3.87	33.42	75.37	4	-5.860	10.00	85.33	10	37.677	3.87	33.419	75.373	4	-5.858	10.00	85.33	10	37.677	3.866	33.419	75.373	4	-5.858	10.00	85.333	10
21.01.2009 17:30:00	30.24	-1.76	33.07	76.46	4	3.340	10.00	67.88	9	30.239	-1.76	33.069	76.456	4	3.339	10.00	67.88	9	30.239	-1.765	33.069	76.456	4	3.339	10.00	67.884	9
21.01.2009 18:00:00	33.59	-0.07	33.39	76.63	4	0.120	10.00	74.59	9	33.592	-0.07	33.389	76.626	4	0.124	10.00	74.59	9	33.592	-0.072	33.389	76.626	4	0.124	10.00	74.589	9
21.01.2009 18:30:00	37.84	-1.09	33.13	76.55	4	1.650	10.00	84.56	9	37.836	-1.09	33.133	76.551	4	1.645	10.00	84.56	9	37.836	-1.087	33.133	76.551	4	1.645	10.00	84.563	9
21.01.2009 19:00:00	44.21	-0.56	33.02	75.07	4	0.730	10.00	100.56	10	42.888	-0.54	32.518	75.065	4	0.727	10.00	97.54	9	42.888	-0.544	32.518	75.065	4	0.727	10.00	97.542	9
21.01.2009 19:30:00	44.17	-0.77	33.12	75.01	4	1.000	10.00	100.15	10	42.851	-0.75	32.62	75.009	4	1.004	10.00	97.14	9	42.851	-0.751	32.62	75.009	4	1.004	10.00	97.145	9
21.01.2009 20:00:00	43.38	-1.12	33.28	75.21	4	1.480	10.00	97.90	10	42.083	-1.09	32.778	75.204	4	1.482	10.00	94.96	9	42.083	-1.089	32.778	75.204	4	1.482	10.00	94.965	9
21.01.2009 20:30:00	42.46	-1.55	33.49	75.58	4	2.090	10.00	95.26	10	41.187	-1.50	32.981	75.578	4	2.087	10.00	92.41	9	41.187	-1.501	32.981	75.578	4	2.087	10.00	92.413	9

APPENDIX 8(a) - Format for results – Voltage control switching points for 21st January 2009

Multiple Run Output File 21_0000_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
2	.9700000000	75.32032959	32.95212067	-16.97142769	20.12217291	6.141043122	.1047113926
Multiple Run Output File 21_0030_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.21847399	33.47533637	-16.94190492	19.86611170	6.051709766	.6802097942E-01
2	.9700000000	75.22181367	32.96183462	-16.94190555	19.26131684	5.867473396	.6595553861E-01
3	.9850000000	75.22500001	32.46378621	-16.94190212	18.68365389	5.691501514	.6398320272E-01
Multiple Run Output File 21_0100_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.26806369	32.96479330	-16.94190500	19.26428507	5.868377580	.6596144284E-01
Multiple Run Output File 21_0130_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.33975274	33.56966090	-17.06118669	19.30291751	5.924090953	.6600264148E-01
2	.9700000000	75.34301194	33.05457463	-17.06118815	18.71512794	5.743697131	.6399891474E-01
3	.9850000000	75.34612162	32.55499576	-17.06118760	18.15371636	5.571397652	.6208551477E-01
Multiple Run Output File 21_0200_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.54250393	33.57812582	-17.33496814	18.83022689	5.877619917	.6451673569E-01
2	.9700000000	75.54578537	33.06285366	-17.33497183	18.25675767	5.698618796	.6255815411E-01
3	.9850000000	75.54891640	32.56309713	-17.33497103	17.70902881	5.527650678	.6068787675E-01
Multiple Run Output File 21_0230_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.00497902	33.52216989	-16.93347210	18.46439190	5.622082896	.6324867465E-01
2	.9700000000	75.00804202	33.00761454	-16.93347404	17.90194482	5.450827972	.6132872243E-01
3	.9850000000	75.01096455	32.50855941	-16.93347556	17.36475026	5.287260902	.5949536663E-01
Multiple Run Output File 21_0300_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.90109064	33.84294285	-16.92201339	18.42760865	5.606849017	.6255860327E-01
2	.9700000000	75.90414073	33.32339579	-16.92201635	17.86619611	5.436032398	.6065976283E-01
3	.9850000000	75.90705096	32.81950240	-16.92201786	17.32999512	5.272885465	.5884658142E-01
Multiple Run Output File 21_0330_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9550000000	75.86849210	33.83353801	-16.61935838	18.04434053	5.386254666	.6120434150E-01
2	.9700000000	75.87140424	33.31403313	-16.61936219	17.49449001	5.222124801	.5934668393E-01
3	.9850000000	75.87418280	32.81018523	-16.61936621	16.96933888	5.065366413	.5757284996E-01
Multiple Run Output File 21_0400_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.92617638	33.33151717	-14.22361782	18.90438914	4.792162635	.6318681102E-01
Multiple Run Output File 21_0430_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.74177229	33.17630620	-12.85747252	21.45423309	4.897249474	.7138815892E-01
Multiple Run Output File 21_0500_1banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.57298566	33.11012492	-12.06841827	25.32822954	5.415673900	.8390037060E-01
Multiple Run Output File 21_0530_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.04648866	33.05597185	-2.612171566	28.92370518	1.319655005	.9346826979E-01
Multiple Run Output File 21_0600_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	74.99777837	33.07051170	-3.181594168	30.52001494	1.696788084	.9858560644E-01
Multiple Run Output File 21_0630_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.34385170	33.32343345	-2.817409575	27.38916608	1.348083358	.8788404974E-01
Multiple Run Output File 21_0700_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	75.85386478	33.47984741	-3.943799468	22.71247403	1.565581332	.7286512791E-01
Multiple Run Output File 21_0730_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	76.74923297	33.80167573	-6.484790683	22.72838986	2.583984272	.7262296257E-01
Multiple Run Output File 21_0800_2banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
1	.9700000000	76.88595292	32.99659032	-17.34466904	30.06451995	9.389611834	.1022231954
Multiple Run Output File 21_0830_4banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
2	.9550000000	75.58171719	33.51361661	-5.052056071	35.44088816	3.134357449	.1149228845
3	.9700000000	75.58218932	33.00049060	-5.058583212	34.36479316	3.041532095	.1114264387
4	.9850000000	75.58274682	32.50264486	-5.056520483	33.33562303	2.949488175	.1080882473
Multiple Run Output File 21_0900_4banks							
Run #	Tap Position	HV Voltage	LV Voltage	Ph Ang_LV	LV_MW	LV_MVar	TF_HV_Current
2	.9550000000	74.71888288	33.42002071	-6.985022028	36.06457014	4.417823240	.1177050762
3	.9700000000	74.72026921	32.90868176	-6.985290101	34.96952537	4.284032841	.1141195589
4	.9850000000	74.72163075	32.41267731	-6.981955176	33.92328505	4.155193095	.1107202854

APPENDIX 8(b) Format for Summary of results- Comparison of simulation Present, & voltage control schemes for 21st 22nd 24th January 2009

Date & Time	Under Present criteria									Proposed voltage control scheme								
	MW	Mvar	33 Volt	132 Volt	No of Bank	Ph angle	Utilization	HV A	Tap	MW	Mvar	33 Volt	132 Volt	No of Bank	Ph angle	Utilization	HV A	Tap
21.01.2009 00:00:00	20.31	1.19	33.11	77.26	2	-3.338	5.00	45.24	8	20.12	6.14	32.95	75.32	1	-16.971	2.50	74.04	10
21.01.2009 00:30:00	19.63	0.92	33.28	75.39	2	-2.670	5.00	44.82	10	19.26	5.87	32.96	75.22	1	-16.942	2.50	46.64	10
21.01.2009 01:00:00	19.07	0.76	33.37	75.47	2	-2.280	5.00	43.43	10	19.26	5.87	32.96	75.27	1	16.942	2.50	46.64	10
21.01.2009 01:30:00	18.61	0.71	33.38	75.67	2	-2.190	5.00	42.37	10	18.72	5.74	33.05	75.34	1	-17.061	2.50	45.25	10
21.01.2009 02:00:00	18.24	0.48	33.32	75.13	2	-1.490	5.00	41.60	10	18.26	5.70	33.06	75.55	1	-17.335	2.50	44.24	10
21.01.2009 02:30:00	17.66	0.35	33.13	76.03	2	-1.140	5.00	39.89	9	17.90	5.45	33.01	75.01	1	16.933	2.50	43.37	10
21.01.2009 03:00:00	17.29	0.14	33.12	75.10	2	-0.490	5.00	39.07	9	17.87	5.44	33.32	75.90	1	-16.922	2.50	42.89	10
21.01.2009 03:30:00	17.67	0.34	33.20	75.96	2	-1.110	5.00	39.77	9	17.49	5.22	33.31	75.87	1	-16.619	2.50	41.96	10
21.01.2009 04:00:00	18.69	-0.29	33.14	76.05	2	0.880	5.00	42.11	9	18.90	4.79	33.33	75.93	1	-14.224	2.50	44.68	10
21.01.2009 04:30:00	21.86	-0.14	33.49	75.87	2	0.360	5.00	49.41	10	21.45	4.90	33.18	75.74	1	-12.857	2.50	50.48	10
21.01.2009 05:00:00	25.81	0.41	33.42	75.70	2	-0.910	5.00	58.34	10	25.33	5.42	33.11	75.57	1	-12.068	2.50	59.33	10
21.01.2009 05:30:00	28.92	1.32	33.06	75.05	2	-2.610	5.00	66.09	10	28.92	1.32	33.06	75.05	2	-2.612	5.00	66.09	10
21.01.2009 06:00:00	30.52	1.70	33.07	75.00	2	-3.180	5.00	69.69	10	30.52	1.70	33.07	75.00	2	-3.182	5.00	69.71	10
21.01.2009 06:30:00	27.39	1.35	33.32	75.34	2	-2.820	5.00	62.14	10	27.39	1.35	33.32	75.34	2	-2.817	5.00	62.14	10
21.01.2009 07:00:00	22.71	1.57	33.48	75.85	2	-3.940	5.00	51.53	10	22.71	1.57	33.48	75.85	2	3.944	5.00	51.52	10
21.01.2009 07:30:00	22.05	2.51	33.29	76.75	2	-6.490	5.00	49.82	9	22.73	2.58	33.80	76.75	2	-6.485	5.00	51.35	10
21.01.2009 08:00:00	30.63	4.49	33.31	77.01	3	-8.340	7.50	70.24	10	30.06	9.39	33.00	76.89	2	17.345	5.00	72.28	10
21.01.2009 08:30:00	34.36	3.04	33.00	75.58	4	-5.060	10.00	8.08	10	34.36	3.04	33.00	75.58	4	-5.059	10.00	78.79	10
21.01.2009 09:00:00	36.06	4.42	33.42	74.72	4	-6.990	10.00	83.23	11	34.97	4.28	32.91	74.72	4	-6.985	10.00	80.69	10
21.01.2009 09:30:00	37.23	4.76	33.21	74.84	4	-7.280	10.00	86.51	11	36.10	4.61	32.70	74.84	4	-7.279	10.00	83.88	10
21.01.2009 10:00:00	37.55	4.94	33.28	74.58	4	-7.490	10.00	87.07	11	36.41	4.79	32.78	74.58	4	-7.492	10.00	84.43	10
21.01.2009 10:30:00	38.88	5.75	33.09	74.68	4	-8.410	10.00	90.88	11	37.70	5.57	32.58	74.68	4	-8.411	10.00	88.12	10
21.01.2009 11:00:00	39.50	6.24	33.02	74.63	4	-8.980	10.00	92.62	11	38.30	6.05	32.52	74.63	4	-8.977	10.00	89.82	10
21.01.2009 11:30:00	41.64	7.20	33.43	74.31	4	-9.810	10.00	98.24	11	40.36	6.98	32.91	74.31	4	-9.803	10.00	95.22	11
21.01.2009 12:00:00	40.10	6.02	33.24	74.61	4	-8.540	10.00	93.30	11	40.10	6.02	33.24	74.61	4	-8.540	10.00	93.30	11
21.01.2009 12:30:00	39.03	4.53	33.43	74.78	4	-6.620	10.00	89.88	11	39.03	4.53	33.43	74.78	4	6.620	10.00	89.88	11
21.01.2009 13:00:00	38.30	4.24	33.43	75.12	4	-6.310	10.00	88.16	11	38.30	4.24	33.43	75.12	4	-6.312	10.00	88.16	11
21.01.2009 13:30:00	36.06	3.25	33.11	75.14	4	-5.150	10.00	82.36	10	37.19	3.35	33.63	75.14	4	-5.149	10.00	84.93	11
21.01.2009 14:00:00	36.65	3.55	33.30	74.89	4	-5.530	10.00	84.59	11	36.65	3.55	33.31	74.89	4	-5.528	10.00	84.59	11
21.01.2009 14:30:00	42.08	6.43	33.45	74.25	4	-8.690	10.00	98.88	12	40.79	6.23	32.93	74.25	4	-8.684	10.00	95.83	11
21.01.2009 15:00:00	40.13	5.79	33.04	74.23	4	-8.210	10.00	93.85	11	40.13	5.79	33.04	74.23	4	-8.209	10.00	93.85	11
21.01.2009 15:30:00	39.20	5.06	33.11	74.46	4	-7.360	10.00	91.29	11	39.20	5.06	33.11	74.46	4	-7.362	10.00	91.29	11
21.01.2009 16:00:00	40.40	5.89	33.14	74.42	4	-8.300	10.00	94.20	11	40.40	5.89	33.14	74.42	4	-8.302	10.00	94.20	11
21.01.2009 16:30:00	39.27	5.90	33.34	74.76	4	-8.540	10.00	91.12	11	39.27	5.90	33.34	74.76	4	-8.539	10.00	91.13	11
21.01.2009 17:00:00	37.68	3.87	33.42	75.37	4	-5.860	10.00	85.33	10	37.43	14.00	33.31	75.12	2	-20.509	5.00	92.01	11
21.01.2009 17:30:00	30.24	-1.76	33.07	76.46	4	3.340	10.00	67.88	9	30.96	8.44	33.46	76.20	2	-15.244	5.00	73.71	11
21.01.2009 18:00:00	33.59	-0.07	33.39	76.63	4	0.120	10.00	74.59	9	33.76	15.31	33.47	76.24	1	-24.388	2.50	85.13	11
21.01.2009 18:30:00	37.84	-1.09	33.13	76.55	4	1.650	10.00	84.56	9	38.03	14.05	33.22	76.17	1	-20.277	2.50	93.61	11
21.01.2009 19:00:00	44.21	-0.56	33.02	75.07	4	0.730	10.00	100.56	10	43.92	9.35	32.91	74.82	2	-12.019	5.00	104.34	11
21.01.2009 19:30:00	44.17	-0.77	33.12	75.01	4	1.000	10.00	100.15	10	43.88	9.20	33.01	74.76	2	-11.845	5.00	103.85	11
21.01.2009 20:00:00	43.38	-1.12	33.28	75.21	4	1.480	10.00	97.90	10	42.76	8.88	33.04	74.77	2	-11.738	5.00	101.09	11
21.01.2009 20:30:00	42.46	-1.55	33.49	75.58	4	2.090	10.00	95.26	10	42.17	8.66	33.37	75.33	2	-11.597	5.00	98.69	11
21.01.2009 21:00:00	39.36	-2.41	33.21	75.79	4	3.510	10.00	87.80	9	39.56	12.79	33.29	75.41	1	-17.919	2.50	95.69	11
21.01.2009 21:30:00	36.88	-3.90	33.47	76.20	4	6.030	10.00	81.93	9	36.38	16.38	33.24	75.70	0	-24.240	0.00	92.15	11
21.01.2009 22:00:00	31.26	-2.95	33.00	76.65	3	0.540	7.50	69.20	8	31.40	14.73	33.08	76.28	0	-25.129	0.00	79.42	10
21.01.2009 22:30:00	26.93	-1.91	33.16	77.34	3	4.050	7.50	59.50	8	27.07	13.26	33.24	77.00	0	-26.095	0.00	68.87	10
21.01.2009 23:00:00	23.37	-2.85	33.31	77.45	3	6.950	7.50	51.67	8	23.47	12.44	33.38	77.08	0	27.922	0.00	60.63	10
21.01.2009 23:30:00	21.30	-3.30	33.38	77.46	3	8.790	7.50	47.21	8	21.39	12.05	33.45	77.08	0	-29.404	0.00	56.06	10
							0.81									0.55		
22.01.2009 00:00:00	19.27	-4.21	33.01	77.68	3	12.337	7.50	42.99	7.00	19.33	10.78	33.06	77.32	0	-29.143	0.00	51.23	10
22.01.2009 00:30:00	18.60	-4.56	33.36	75.98	3	13.789	7.50	42.51	9.00	18.12	10.44	32.93	75.61	0	-29.961	0.00	48.66	10
22.01.2009 01:00:00	18.15	-4.75	33.37	76.12	3	14.676	7.50	41.63	9.00	17.68	10.26	32.93	75.75	0	-30.128	0.00	47.60	10
22.01.2009 01:30:00	17.47	-4.67	33.15	76.60	3	14.961	7.50	39.79	8.00	17.54	10.46	33.21	76.23	0	-30.820	0.00	47.18	10
22.01.2009 02:00:00	17.37	-4.77	33.28	76.95	3	15.351	7.50	39.48	8.00	17.44	10.48	33.34	76.57	0	-30.994	0.00	46.85	10
22.01.2009 02:30:00	17.14	-4.83	33.30	77.08	3	15.733	7.50	39.00	8.00	17.21	10.43	33.36	76.70	0	-31.234	0.00	46.33	10
22.01.2009 03:00:00	17.10	-4.86	33.33	77.03	3	15.866	7.50	38.90	8.00	17.17	10.43	33.39	76.66	0	-31.280	0.00	46.21	10
22.01.2009 03:30:00	17.15	-4.94	33.33	77.03	3	16.075	7.50	39.05	8.00	17.22	10.35	33.39	76.65	0	-31.004	0.00	46.21	10
22.01.2009 04:00:00	18.18	-4.84	33.31	77.01	3	14.894	7.50	41.20	8.00	18.25	10.44	33.37	76.63	0	-29.763	0.00	48.31	10
22.01.2009 04:30:00	20.99	-4.59	33.24	77.00	3	12.328	7.50	47.15	8.00	21.07	10.63	33.31	76.63	0	-26.767	0.00	54.11	10
22.01.2009 05:00:00	24.53	-4.19	33.05	76.55	3	9.698	7.50	54.93	8.00	24.63	10.85	33.11	76.18	0	-23.770	0.00	61.82	10
22.01.2009 05:30:00	28.95	-3.91	33.34	76.26	3	7.689	7.50	64.85	9.00	28.20	11.06	32.91	75.89	0	-21.416	0.00	69.81	10
22.01.2009 06:00:00	30.57	-3.39	33.31	76.12	3	6.320	7.50	68.36	9.00	29.79	11.55	32.88	75.75	0	-21.186	0.00	73.62	10
22.01.2009 06:30:00	27.68	-3.82	33.49	76.43	3	7.858	7.50	61.79	9.00	26.97	11.28	33.06	76.06	0	-22.700	0.00	67.14	10
22.01.2009 07:00:00	22.33	-3.85	33.19	76.99	2	9.787	5.00	49.85	8.00	22.42	11.32	33.26	76.62	0	-26.789	0.00	57.59	10
22.01.2009 07:30:00	22.73	-2.40	33.42	76.66	3	6.017	7.50	50.78	9.00	22.14	12.61	32.99	76.28	1	-29.654	2.50	58.91	10
22.01.2009 08:00:00	26.24	-2.01	33.38	75.88	3	-2.005	7.50	59.42	10.00	25.27	10.70	32.75	75.63	3	-22.953	7.50	63.67	10
22.01.2009 08:30:00	28.90	3.31	33.36	74.79	3	-6.528	7.50	66.93	11.00	28.02	3.21	32.84	74.79	3	-6.526	7.50	64.89	10
22.01.2009 09:00:00	30.44	4.41	33.26	74.51	3	-8.248	7.50	70.94	11.00	29.51	4.28	32.75	74.51	3	-8.247	7.50	68.78	10
22.01.2009 09:30:00	31.37	4.94	33.46	75.24	3	-8.957	7.50	72.80	11.00	30.42	4.79	32.95	75.24	3	-8.959	7.50	70.59	10
22.01.2009 10:00:00	30.59	4.66	33.05	75.23	3	-8.657	7.50	70.73	10.00	30.59	4.66	33.05	75.23	3	-8.657	7.50	70.73	10
22.01.2009 10:30:00	32.24	5.99	33.28	74.96	3	-10.526	7.50	75.59	11.00	31.26	5.81	32.77	74.97	4	-10.522	10.00	73.29	10
22.01.2009 11:00:00	33.10	6.21	33.22	74.83	3	-10.626	7.50	77.75	11.00	32.70	1.15	33.02	74.95	4	-2.011	10.00	74.65	10
22.01.2009 11:30:00	33.73	6.71	33.13	74.67	3	-11.258	7.50	79.60	11.00	33.33	1.67	32.93	74.80	4	2.876	10.00	76.35	10