Chapter 6

6.0 An Automated Solution

6.1 Introduction

In this chapter I would like to describe an effort by me to develop a solution for a much complicated electrical distribution network suffering from network inefficiencies and losses. The necessity arises as I found a manual phase swapping or load balancing is not practical when it comes to a complicated distribution system like a large installation of the range of 4-5 MVA or above. This type of an installation will have several transformers with several Main Switch Boards making the process complex. The number of feeders incorporated will be high and finding a manual solution will not be the most feasible thing to do.

Another problem I encountered was that most equipment such as power analyzers used for analysis of an electrical network is purely for data collection purposes. There were very few software facilities to analyze the collected data. Therefore I tried to develop a program to get a solution for this problem.

I have used MATLAB as the software for developing this solution as I found it easy to develop a solution using matrix operations. A 'm file' is developed for each and every feature of the program and is available for further development on the same platform.

I intend this software to be used by operations and maintenance managers for the process of load balancing and harmonic detection in an electrical network. The system will give suggestions for phase swapping on a instantaneous or long term basis. The recommendations can be incorporated at the next maintenance program as these require power interruptions.

Objective of the program

- Reduce neutral current by reducing phase current unbalance
- Reduce network losses over a period of operation

Input to the system

- Average current readings of the feeders to find out best combination to reduce neutral current and voltage unbalance
- Current logs over period to find out best solution to reduce neutral current losses and reduce voltage unbalance

Output of the system

- Best combination of feeder phase arrangement to reduce the losses and improve efficiency.

6.2 Phase combinations

If you are trying to connect up a feeder to a main or sub panel, there are several combinations of connection. It is not necessary on technical terms to connect phase 1 of the feeder to phase 1 of the incomer. But depending on the types of machines on the load side like three phase machines, it is important to connect up so that the phase rotation is not changed. Given that the incoming is L1, L2 and L3, and if the feeder to be connected is L4, L5 and L6 the following combinations are possible.

If load includes 3phase loads

- L1-L4, L2-L5, L3-L6
- L1-L5, L2-L6, L3-L4
- L1-L6, L2-L4, L3-L5

However we will not consider a feeder to be connected in a reverse phase rotation due to safety regulations and compatibility to standards.

6.3 Logical processes of the system

6.3.1 Solving current unbalance problem

The idea of this feature is to make sure the phase currents of a distribution system is balanced and hence the voltage unbalance problem is sorted to a certain extent. The program will consider how the phases can be swapped to arrive at the minimum neutral current and minimum phase unbalance level.

For the phase swapping option feeders are considered from each panel. Say panel no. 1 is taken first and the outgoing feeders of the panel to the load side are identified. Feeder data of each feeder is inserted to the software first. Then this will do a load flow analysis for all combinations of the connections. Then the best combination to reduce the resultant neutral current is selected. This is a very basic process where the current of each phase of each feeder is input manually to the system and the system will advise on the best combination for that feeder.

User will need to identify the rms currents of the 3 phases and the power factors to input to the system. Harmonics currents need to be eliminated first and only the fundamental is to be inserted for calculations. High harmonics will reduce the accuracy of the output.

Input to the system

Feeder No.	Feeder Name	Phase 1 current (A)	PF	Phase 2 current (A)	PF	Phase 3 current (A)	PF	3 phase
1								
2								
3								
...								

Table 5 : Sample data entry table

Phase unbalance

$$\text{Current Unbalance Ratio} = \frac{\text{Maximum difference of a phase current to average}}{\text{Average phase current}}$$

$$= \frac{\text{Max}\{\,|Ia - Iavg|,\ |Ib - Iavg|,\ |Ic - Iavg|\,\}}{Iavg}$$

Where

$$I_{avg} = (I_a + I_b + I_c) / 3$$

Where Ia, Ib and Ic are fundamental phase rms currents.

Neutral current is estimated assuming the fundamental phase currents are balanced with equal phasor differences of 120°.

$$\text{Neutral current } I_n = \sqrt{2}\, I_a \sin \omega t + \sqrt{2}\, I_b \sin(\omega t + 2\Pi/3) + \sqrt{2}\, I_a \sin(\omega t + 4\,\Pi/3)$$

This feature will require only the instantaneous values of the phases, which can be easily measured using a clip on meter. It is important that a true rms value ammeter is used to measure as other meters will not give the correct value. The power factor level will need a power factor meter or a power analyzer to be used for measurement. If PF cannot be measured it is recommended to insert average assumed power factors to enable calculations.

The following process flow diagram is what will be used in the logical components in finding a solution for this problem.

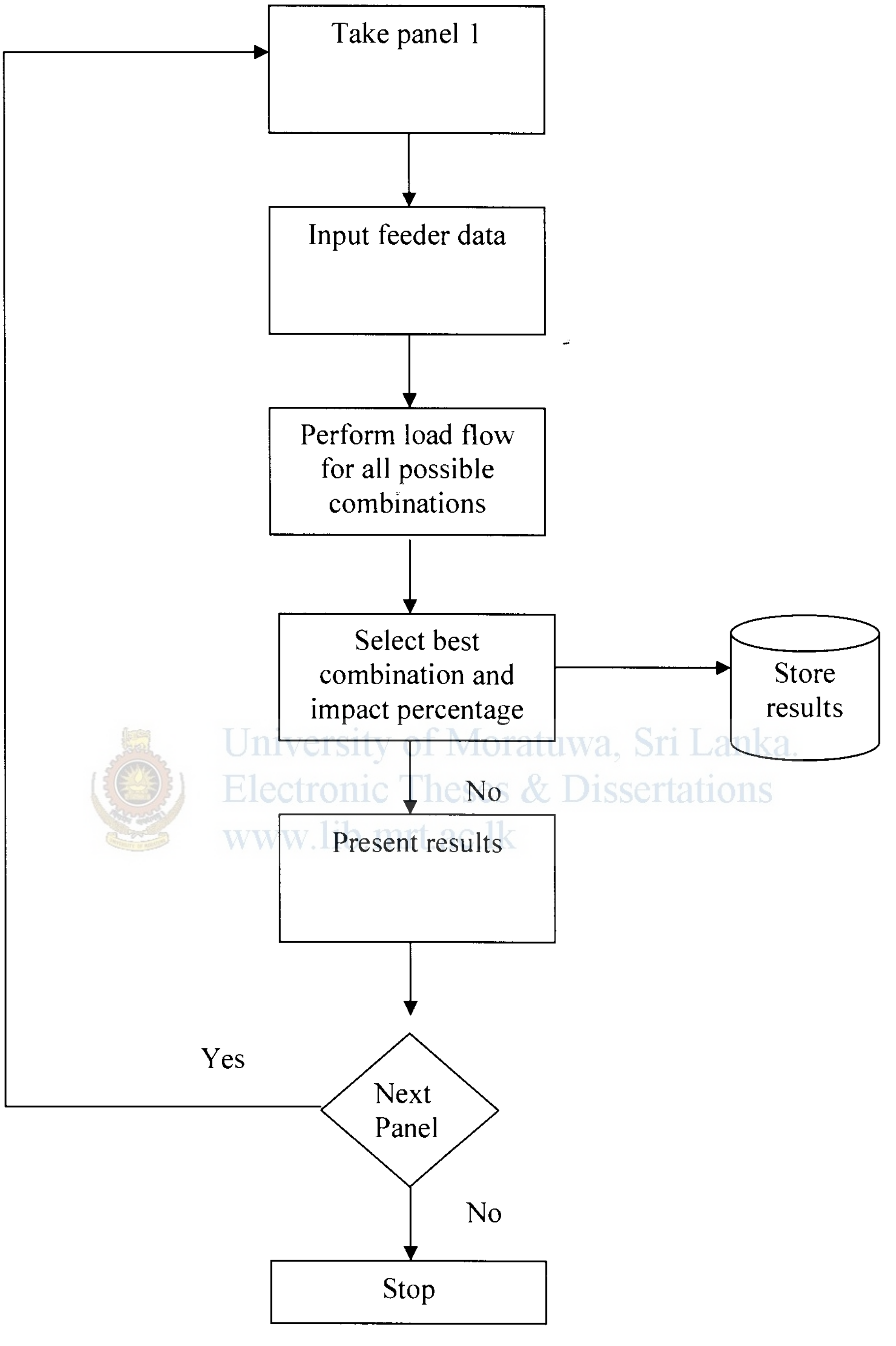

Figure 23 : Flow chart for instantaneous phase balancing

Matrix operation description

If feeder 1 currents a, b & c and if feeder 2 currents are d, e & f, where currents are written in complex numbers for active and reactive components in the form of x + jy. The following combinations can be achieved as the resultant.

	Phases		
Combinations	a + d	b + e	c + f
	a + e	b + f	c + d
	a + f	b + d	c + e

Table 6 : Matrix after the first step

If another feeder is to be added as feeder 3 of currents g, h & l, the resultant will be increased to 9 * 3 matrix as below.

	Phases		
Combinations	a + d + g	b + e + h	c + f + i
	a + d + h	b + e + i	c + f + g
	a + d + i	b + e + g	c + f + h
	a + e + g	b + f + h	c + d + i
	a + e + h	b + f + i	c + d + g
	a + e + i	b + f + g	c + d + h
	a + f + g	b + d + h	c + e + i
	a + f + h	b + d + i	c + e + g
	a + f + i	b + d + g	c + e + h

Table 7 : matrix after the second step

The diagram above is the matrix operation for the current phase unbalance solution finder. The process is iterative in finding the best combination for the network. Higher the number of feeders, higher will be the size of the matrix. However for panel with a large number of feeders, the process time will be considerably longer.

The graphical user interface for entering the data of each feeder of each panel is given below. Entry to the system is manual and results will be shown at the end of the process.

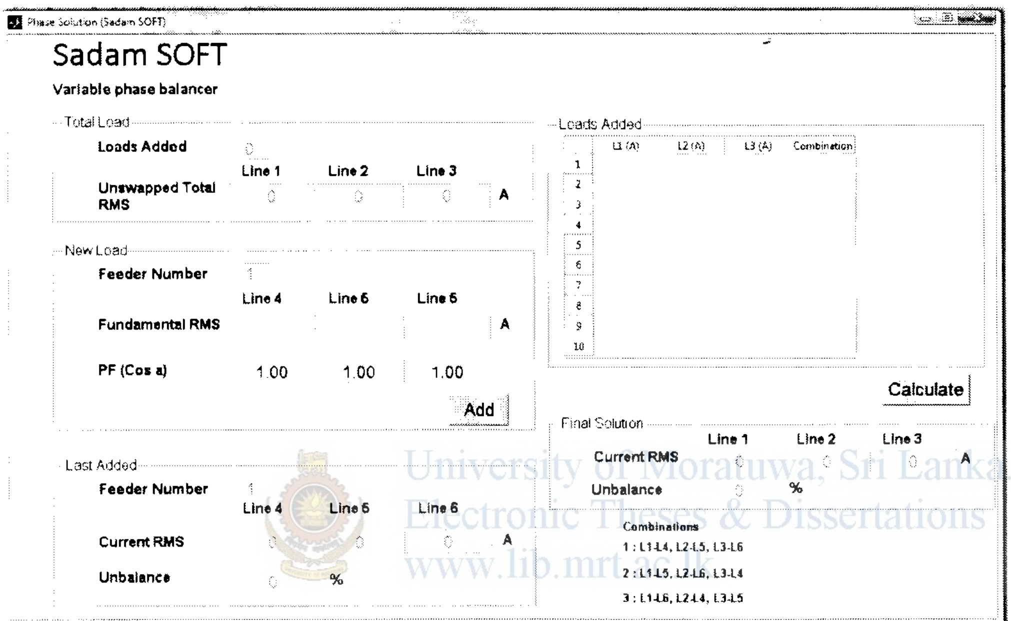

Figure 24 : User interface for data entry for instantaneous phase balancing

In the first frame of "Total Load" displays the present status of the iterative load addition process. This will get updated when each feeder is added to the system. The second frame of "New Load" is where the user enters the next feeder and adds it up to the existing system. The button "Add" will convert phase currents to complex numbers using the power factor and store it for calculations.

The frame "Last Added" will display the feeder added last to the system. It will display the unbalance of the last added feeder.

Once the additions of the feeders are done, next step is to calculate the load flows for each combination. This will be done by clicking the "Calculate" button. This will calculate the maximum unbalances of each combination first. Then it will select the minimum unbalance combination as the best solution.

The results will be displayed on the "Loads Added" frame under combination column. The table will display recommended combination for each feeder. The combinations are given at the bottom of the panel. The frame "Final Solution" will display final phase currents after phase swapping and the respective unbalance level. The user can decide whether the required level of unbalance is reached.

6.3.2 Solving minimum network losses over a period of time

This feature was introduced to the process to overcome some problems in the above system. The previous system can receive only instantaneous data. In a practical load flow the currents in each phase will not be constant. It can even be the case that the overloaded phase at one time is a minimum loaded at another time. Therefore the requirement arises to find a solution for a whole period of time. This could be a day or week as appropriate to the load centre.

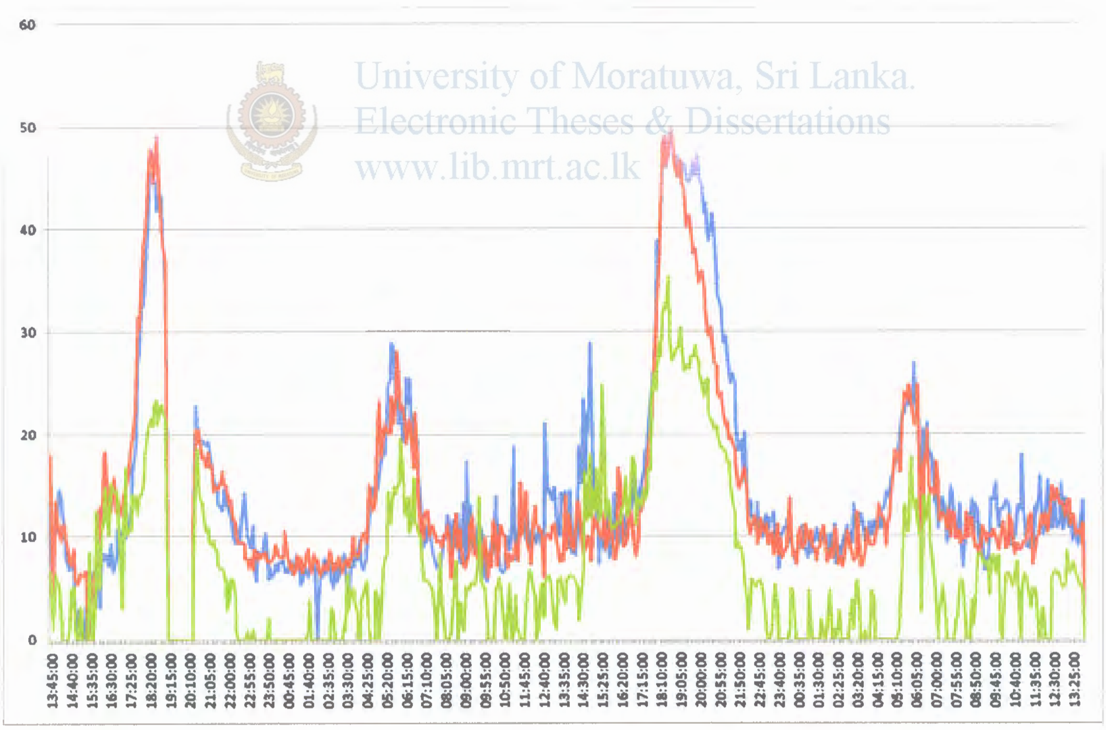

Figure 25 : Logged data with high current variations

System will receive data as logged data over the period as averaged decided by the user. The logged data will be in a table format with the time and average current as columns. Each nodes data will be added to the system and at the end of the input the system will start processing the data to find out the best solution for the load flow.

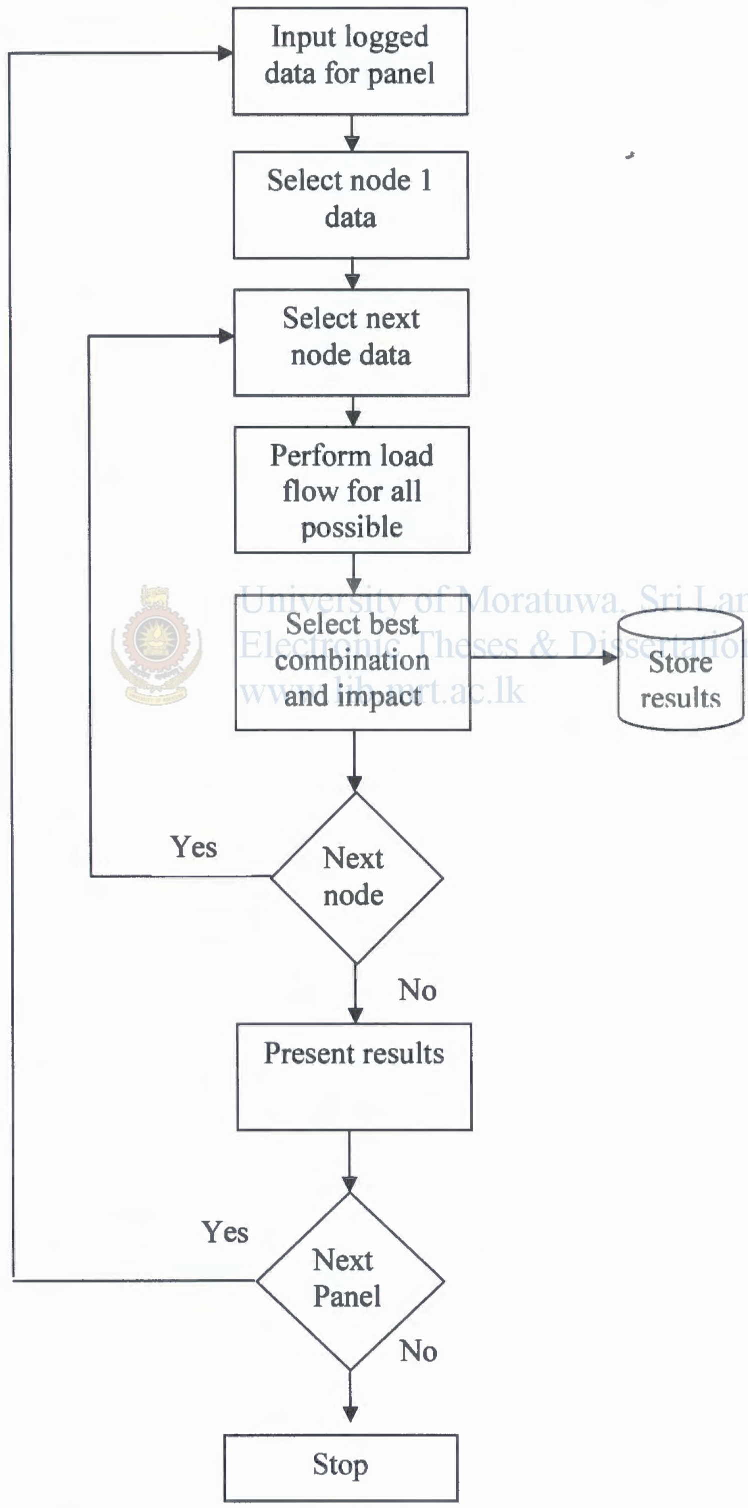

Figure 24 : Flow chart for phase balancing over a period

An example table of a logged data is given below.

Record	Chan 1
End Time	Avg. Amp
13:45:00	13.04
13:50:00	4.52
13:55:00	3.2
14:00:00	13.56
14:05:00	10.53
14:10:00	14.59
14:15:00	13.73
14:20:00	12.59
14:25:00	10.81
14:30:00	7.84
14:35:00	7.38
14:40:00	6.75
14:45:00	7.95
14:50:00	6.64
14:55:00	1.32
15:00:00	0
15:05:00	2.92
15:10:00	1.89
15:15:00	0
15:20:00	0
15:25:00	3.32
15:30:00	4.75
15:35:00	5.84
15:40:00	6.46
15:45:00	5.84

Table 8 : Sample data entry format for phase balancing over a period

The above table is only for Line 1, which is tabulated as "chan 1" as downloaded from common power data loggers. Therefore it is convenient to transfer downloaded data directly to the program for finding a solution. Similarly the data for "Line 2" and "Line 3" need to be inserted for the calculation.

The report generated from the input will be displayed in the same format as of the above computation.

6.4 Case study done using the program

The program was executed for a few sample data collected at different facilities. These data was collected by measurement of existing load flow in the particular installation.

Case study

Data was collected from a main distribution panel of a hospital facility which was also used for the previous unbalance analysis. The outgoing breakers were measured for phase currents and tabulated as below.

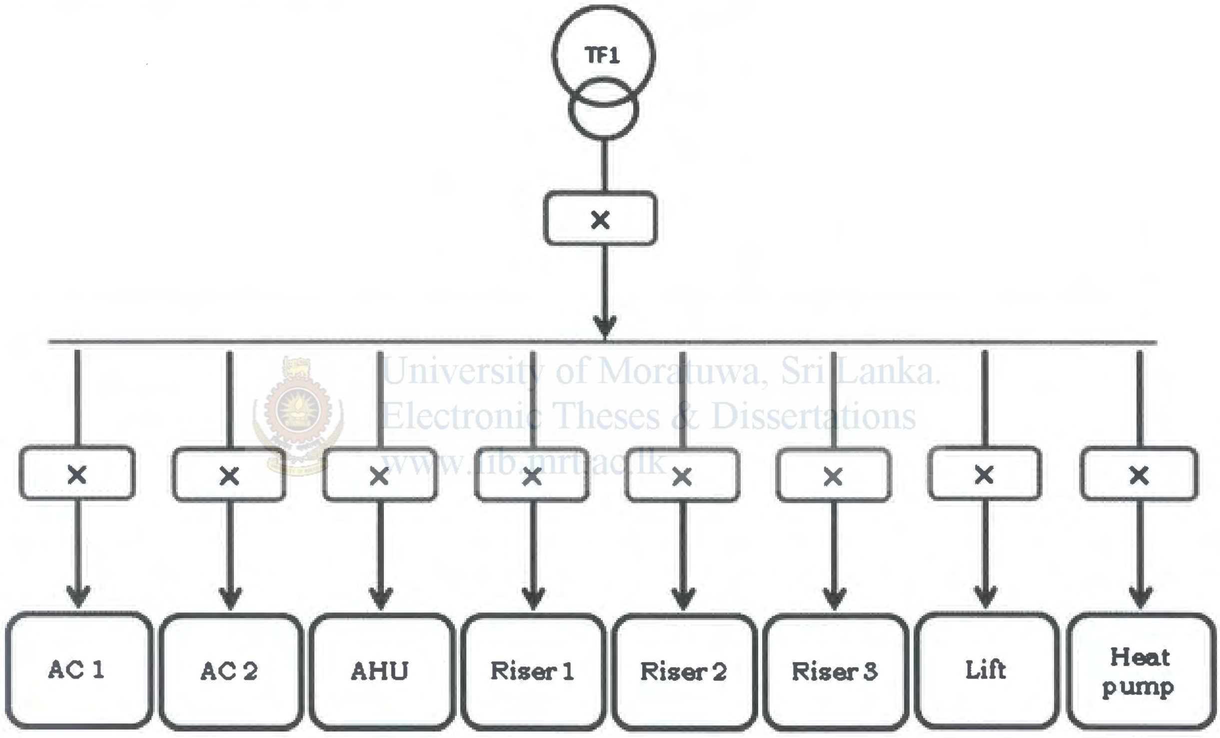

Figure 25 : Sample network configuration

Feeder No.	Feeder Name	Phase 1 current (A)	PF	Phase 2 current (A)	PF	Phase 3 current (A)	PF
1	AC 1	165	0.74	120	0.73	130	0.75
2	AC 2	125	0.68	130	0.68	92	0.69
3	AHU	175	0.80	140	0.79	150	0.81

4	Riser 1	130	0.85	120	0.86	130	0.85
5	Riser 2	140	0.65	120	0.67	120	.60
6	Riser 3	111	0.78	110	0.75	107	0.77
7	Lift	115	0.68	115	0.68	116	0.69
8	Heat pump	54	0.93	53	0.92	54	0.94

Table 9 : Input data to the software

Input to the system

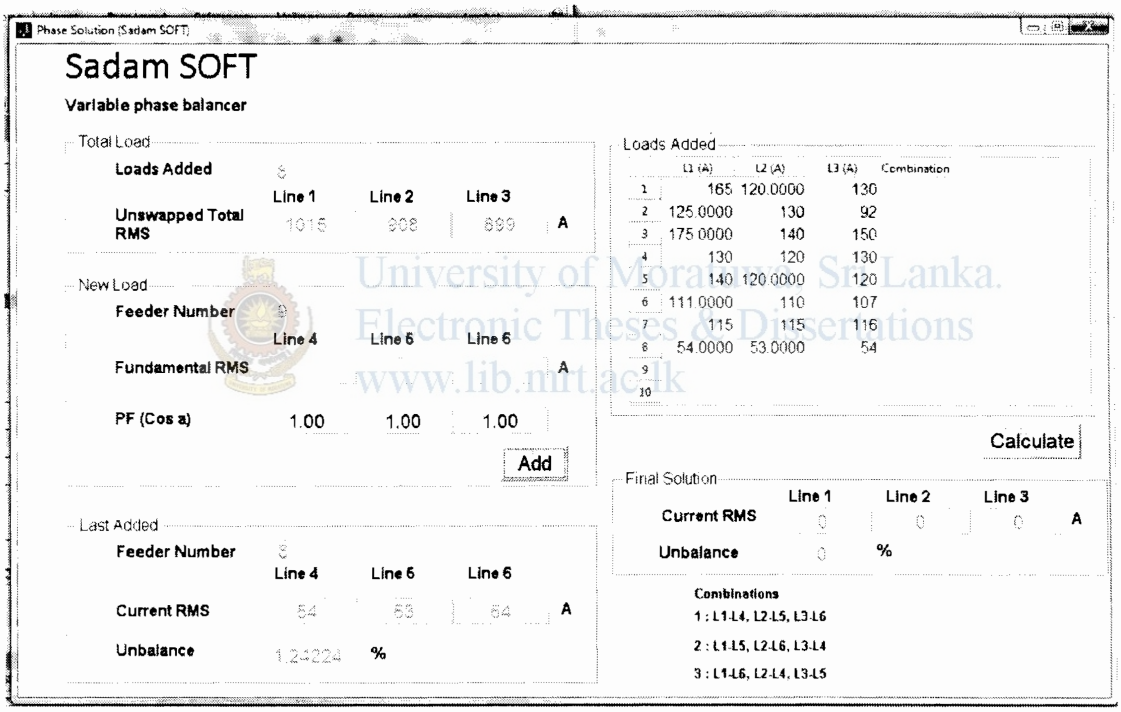

Figure 26 : Screen after data entry

Output of the system

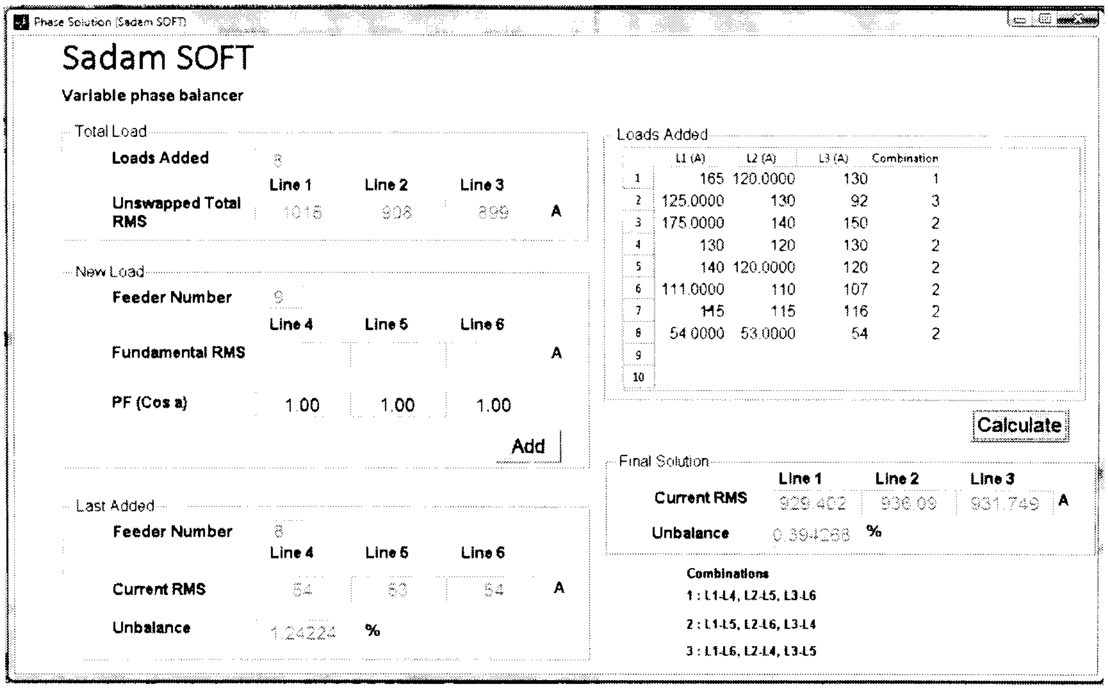

Figure 27 : Output screen