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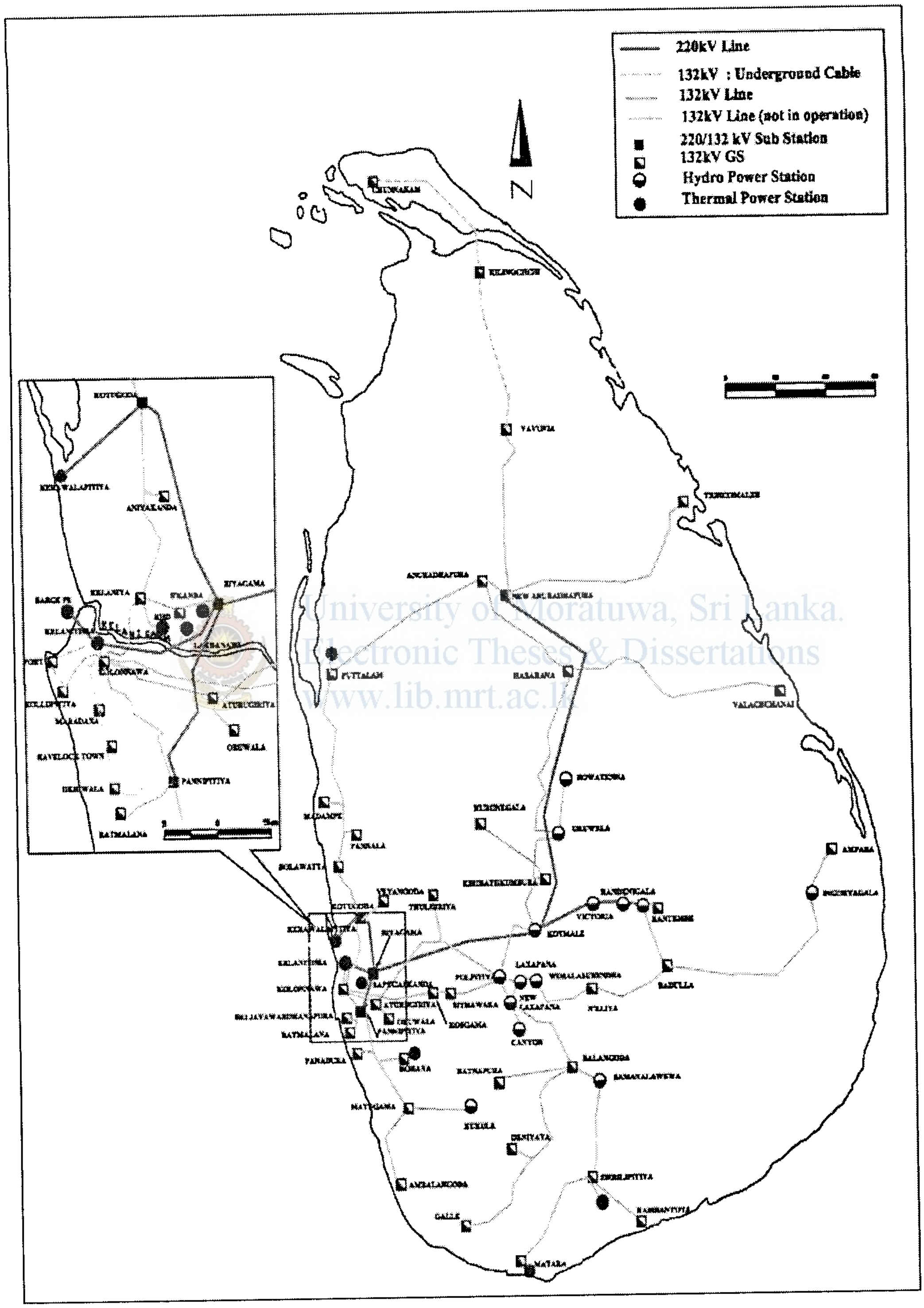
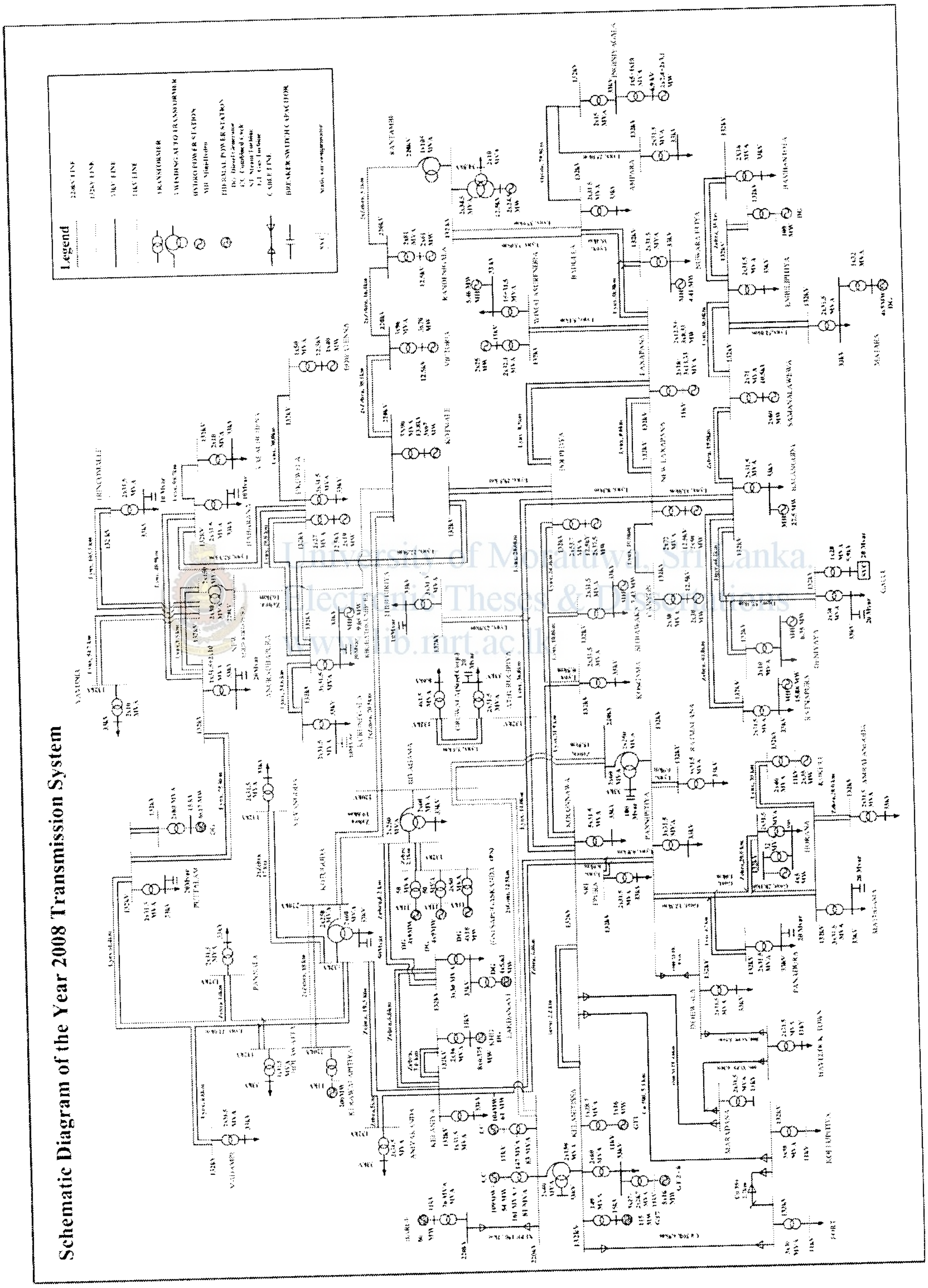
Annex-1 Present Transmission system of Sri Lanka



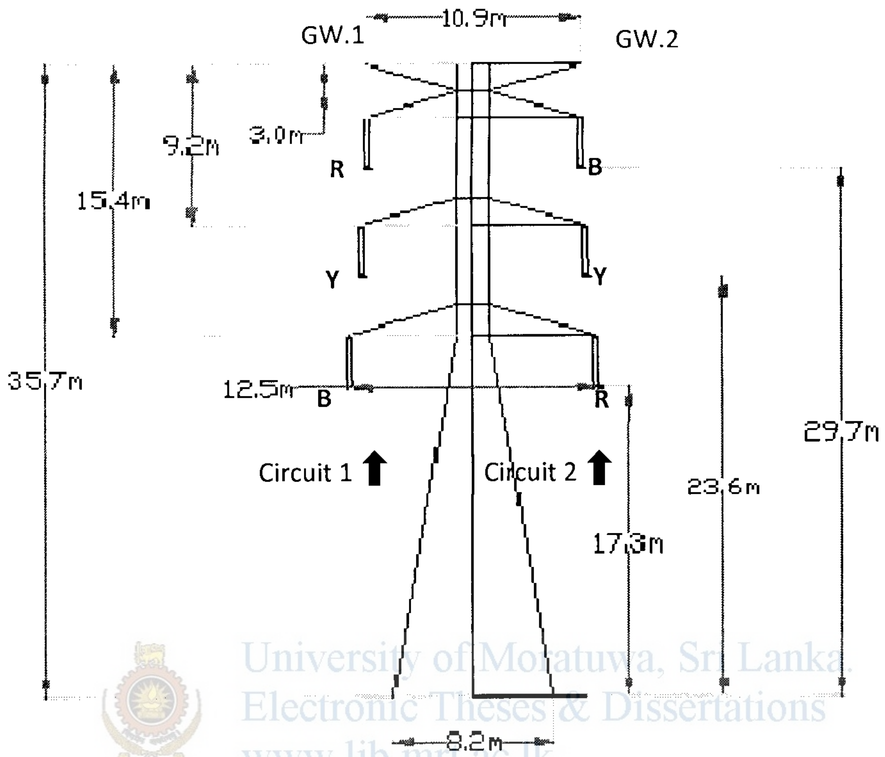
Annex-2 Transmission system of Sri Lanka (Single line diagram)



Annex-3 220kV Biyagama – Kotmale transmission line parameters

#	Line parameters' description	Value	Unit	Comment
1	Voltage	220	kV	
2	Steady state Frequency	50	Hz	
3	Line/Span length	As per the tower schedule (Annex 5)	Km	
4	Line shunt conductance	$1x10^{-11}$	mΩ/m	
5	No. of circuits	02	Nos.	
6	Conductor Type/Name	ACSR "ZEBRA"		
7	Conductor size	428.9	mm^2	
8	Conductor radius	0.01431	m	
9	Conductor DC resistance	0.0674	Ω/km	
10	Sag of all phase conductors	9.56	m	
11	No. of sub conductors per phase	02	Nos.	
12	Bundle configuration	Symmetrical		
13	Sub conductor spacing	0.4	m	
14	Earth wire Type/Name	GS 7/3.25		
15	Earth wire size	58.07	mm^2	
16	No. of Earth wires	02	Nos.	
17	Earth wire radius	0.0049	m	
18	Earth wire DC resistance	3.1	Ω/km	
19	Sag of Earth wire	6.41	m	
20	Ground resistivity	1000	Ωm	
21	Relative ground permeability	1.0		
Other parameters used in the Transmission line model				
22	Conductor coordinates reference to the center of the tower base			
23	Phase/nodal connection information of line interface			
24	Ideally transposed line?			YES

Annex-4: A typical transmission tower used in the selected transmission line



Annex-5: Tower schedule

Tower number	Span/Line Section length (m)	Tower type	Tower height(m)
1 to 32	12,088		
33	333	1D1	34.885
34	458	1D3	34.710
35	285	1DL	35.741
36	174	1DL	35.741
37	488	1DL	35.741
38	232	1D1	34.885
39	258	1D1	34.885
40	438	1D6+6	40.710
41	287	1D6+6	40.710
42	506	1DL+9	44.741
43	297	1D3+3	37.710
44	186	1DL+6	41.741
45	376	1DL	35.741
46	568	1D1+6	40.885
47	239	1DL+3	38.741
48	261	1D6	34.710
49	329	1DL+6	41.741
50	261	1DL+9	44.741
50 to 84	11,999		
85	181	1D6	34.710
86	682	1D1	34.885
87	474	1D1	34.885
88	422	1D1+3	37.885
89	356	1D1	34.885
90	513	1DL	35.741
91	281	1D3	34.710
92	692	1D1	34.885
93	397	1D1	34.885
94	477	1D1	34.885
95	477	1D1	34.885
95 to 206	35,525		

Annex-6 Grounding Resistance variation of towers due to soil ionization effect

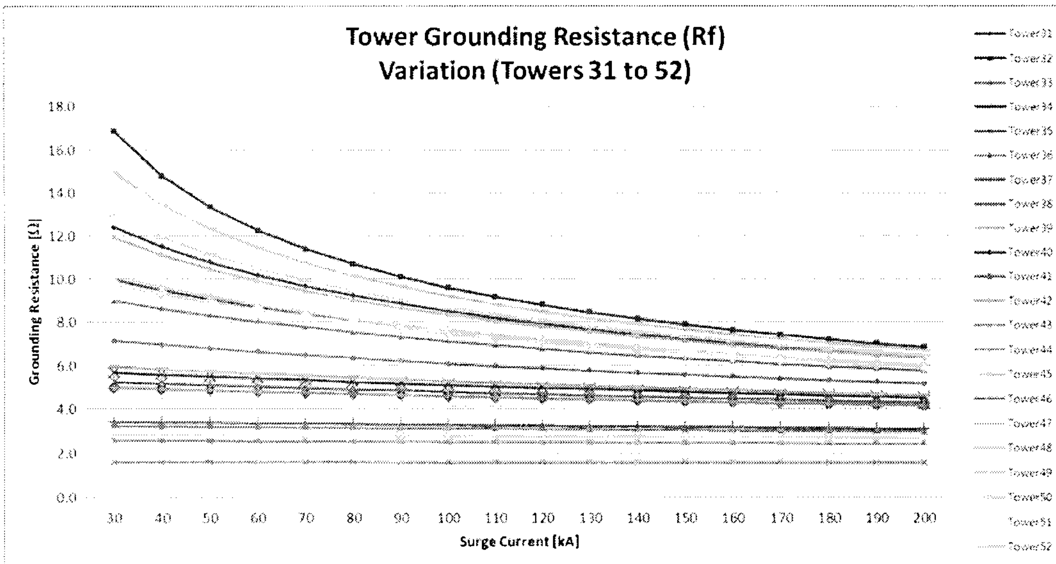


Figure A6-1: Grounding resistance variation of towers 31 to 52

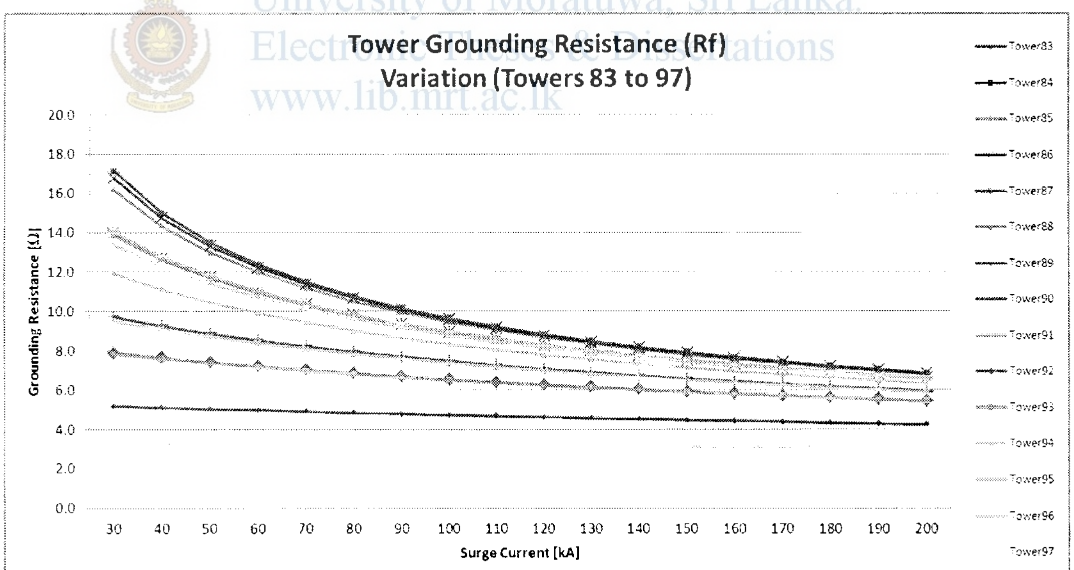


Figure A6-2: Grounding resistance variation of towers 83 to 97

Annex-7 Simplified selection procedure of an ABB surge arrester

Selection of electrical parameters as per the selection procedure shown in Figure 3.12:

Product range

Product family	Arrester classification [1]	Type	Max. system voltage [2] U_m kV_{rms}	Rated voltage [2] U_r kV_{rms}	Energy requirement/ Lightning intensity	Mechanical strength [3] Nm
PEXLIM — Silicone polymer-housed arresters. Superior where low weight, reduced clearances, flexible mounting, non-fragility and additional personnel safety is required. Major component for PEXLINK™ concept for transmission line protection.	10 kA, IEC class 2	PEXLIM R	24 - 170	18 - 144	Moderate	1 600
	10 kA, IEC class 3	PEXLIM Q	52 - 420	42 - 360	High	4 000
	20 kA, IEC class 4	PEXLIM P	52 - 420	42 - 360	Very high	4 000
HS PEXLIM - High strength silicone polymer-housed arresters. Specially suited to extreme seismic zones.	20 kA, IEC class 4	HS PEXLIM P	245 - 550	180 - 444	Very high	28 000
	20 kA, IEC class 5	HS PEXLIM T	245 - 800	180 - 612	Very high	28 000
EXLIM — Porcelain-housed arrester	10 kA, IEC class 2	EXLIM R	52 - 170	42 - 168	Moderate	7 500
	10 kA, IEC class 3	EXLIM Q-E	52 - 245	42 - 228	High	7 500
	10 kA, IEC class 3	EXLIM Q-D	170 - 420	132 - 420	High	18 000
	20 kA, IEC class 4	EXLIM P	52 - 550	42 - 444	Very high	18 000
	20 kA, IEC class 5	EXLIM T	245 - 800	180 - 624	Very high	18 000

[1] Arrester classification according to IEC 60099-4 (nominal discharge current, line discharge class).
[2] Arresters with lower or higher voltages may be available on request for special applications.
[3] Specified short-term service load (SSL).

Table A7-1: Product range of ABB Surge arresters [13]

Step 1: Selection of rated voltage (U_r)

System voltage (U_m) = 245kV, System earthing = effectively earthed, Earth fault duration ≤ 1s (Maximum 1.5s for backup protection) Therefore from Table A7-3,

Rated voltage, $U_r \geq 0.72 * U_m$

$U_r \geq 176.4kV$

The Table A7-3 gives a minimum value of the arrester rated voltage (U_r). In each case, choose the next higher standard rating as given in the catalogue (Table A7-2). ABB Transmission Line Arresters (TLA) uses PEXLIM-Q Metal Oxide Surge Arresters as the arrester component. Table A7-2 gives the protective data of PEXLIM Q type arresters.

Therefore, $U_r = 180kV$ from table 2 (for PEXLIM Q arrester type)

Step 2: Selection of line discharge class and energy capability

From Table A7-4, for PEXLIM Q type arresters

Line Discharge Class = 3 and Energy capability = 7.8kJ/kV (U_r) for U_m = 170-420kV range

Max. System Voltage	Rated Voltage	Max. continuous operating voltage 1)		TOV capability 2)		Max. residual voltage with current wave						
		as per IEC	as per ANSI/IEEE			30/60 μs			8/20 μs			
U_m	U_r	U_c	MCOV	1 s	10 s	0.5 kA	1 kA	2 kA	5 kA	10 kA	20 kA	40 kA
kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}
170	132	106	106	151	145	254	262	272	295	311	342	382
	144	108	115	165	158	277	286	297	322	339	373	417
	150	108	121	172	165	288	298	309	335	353	388	434
	162	108	131	186	178	312	321	334	362	381	419	469
	168	108	131	193	184	323	333	346	376	395	435	486
	192	108	152	220	211	369	381	396	429	452	497	555
245	180	144	144	207	198	346	357	371	402	423	466	521
	192	154	154	220	211	369	381	396	429	452	497	555
	198	156	160	227	217	381	393	408	443	466	512	573
	210	156	170	241	231	404	417	433	469	494	543	608
	216	156	175	248	237	415	428	445	483	508	559	625
	219	156	177	251	240	421	434	451	489	515	567	634
	222	156	179	255	244	427	440	458	496	522	574	642
	228	156	180	262	250	438	452	470	510	536	590	660
300	216	173	175	248	237	415	428	445	483	508	559	625
	240	191	191	276	264	461	476	495	536	564	621	694
	258	191	209	296	283	496	512	532	576	607	667	746
	264	191	212	303	290	507	523	544	590	621	683	764
	276	191	220	317	303	530	547	569	617	649	714	798
362	258	206	209	296	283	496	512	532	576	607	667	746
	264	211	212	303	290	507	523	544	590	621	683	764
	276	221	221	317	303	530	547	569	617	649	714	798
	288	230	230	331	316	553	571	593	643	677	745	833

Table A7-2: Guaranteed protective data for ABB PEXLIM Q surge arresters [13]

Step 3: Selection of Lightning and Switching protection levels (U_{pl} and U_{ps})

System Earthing	Fault Duration	System Voltage U_m (kV)	Min. Rated Voltage, U_r (kV)
Effective	≤ 1 s	≤ 100	≥ 0.8 x U_m
Effective	≤ 1 s	≥ 123	≥ 0.72 x U_m
Non-effective	≤ 10 s	≤ 170	≥ 0.91 x U_m ≥ 0.93 x U_m (EXLIM T)
Non-effective	≤ 2 h	≤ 170	≥ 1.11 x U_m
Non-effective	> 2 h	≤ 170	≥ 1.25 x U_m

Table A7-3: Minimum arrester rated voltages [13]

System parameters for U_{wl} and U_{ws},

Lightning withstand voltage of the line U_{wl} = 1,050kV

Switching withstand voltage of the line U_{ws} = 460kV

For insulation co-ordination purposes, consider the lightning impulse protection level (U_{pl}) at 10 kA for U_m ≤362 kV and at 20 kA for higher voltages. Similarly, the switching impulse protection levels (U_{ps}) for co-ordination purposes range from 0.5kA (for U_m ≤170 kV) to 2 kA (for U_m ≥362kV).

From Table A7-5, for PEXLIM Q arresters at Nominal Discharge Current I_n = 10kA

U_{pl}/U_r = 2.350 and U_{ps}/U_r = 1.981

Therefore arrester parameters for U_{pl} and U_{ps}

U_{pl} = 2.350*180kV = 423kV

U_{ps} = 1.981*180kV = 357kV

Arrester Type	Line discharge class	Energy capability (2 impulses) kJ/kV (U_r)	Normal application range (U_m)
EXLIM R	2	5.0	≤ 170 kV
PEXLIM R	2	5.1	≤ 170 kV
EXLIM Q	3	7.8	170 - 420 kV
PEXLIM Q	3	7.8	170 - 420 kV
EXLIM P	4	10.8	362 - 550 kV
PEXLIM P	4	12	362 - 550 kV
HS PEXLIM P	4	10.5	362 - 550 kV
EXLIM T	5	15.4	420 - 800 kV
HS PEXLIM T	5	15.4	420 - 800 kV

Table A7-4: Energy capability of arresters [13]

Step 4: Calculation of protection margins

Protection margin for lightning impulses = {(Uwl/Upl) – 1}*100%

= {(1050/423) – 1}*100%

= 148%

Protection margin for switching impulses = {(Uws/Ups) – 1}*100%

= {(460/357) – 1}*100%

Arrester Type	Nom. Dis-charge current (I_n)	U_{pl}/U_r at 10 kA_p	U_{pl}/U_r at 20 kA_p	U_{ps}/U_r
EXLIM R	10	2.590		2.060 at 0.5 kAp
PEXLIM R	10	2.590		2.060 at 0.5 kAp
EXLIM Q	10	2.350		1.981 at 1.0 kAp
PEXLIM Q	10	2.350		1.981 at 1.0 kAp
EXLIM P	20	2.275	2.5	2.020 at 2.0 kAp
PEXLIM P	20	2.275	2.5	2.020 at 2.0 kAp
HS PEXLIM P	20	2.275	2.5	2.020 at 2.0kAp
EXLIM T	20	2.200	2.4	1.976 at 2.0 kAp

Table A7-5: U_{pl} and U_{ps} ratios for ABB arresters [13]

= 29%

Summary of system and arrester electrical parameters

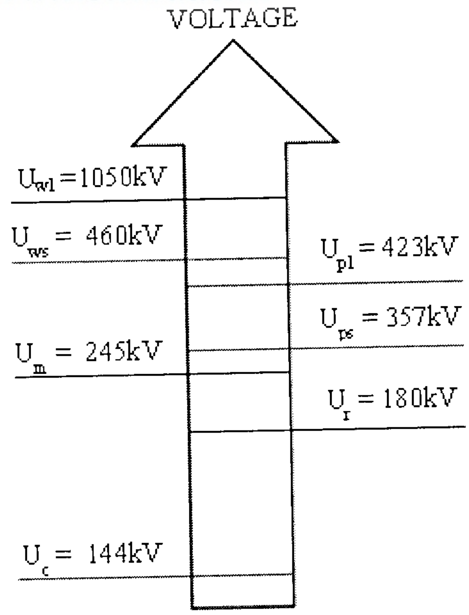


Table A7-6: Summary of system and arrester electrical parameters