

Reactive Power Compensation at the Distribution Feeder:

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Abstract

This paper presents a comprehensive and cost benefit analysis of Reactive Power Compensation provided to the SWIS (South West Interconnected System), and proposes two methods for Reactive Power Compensation using Capacitor Bank arrangement. The first is based on capacitor bank arrangement at the Zone Substation with large MVAR capacitor banks installed at the Zone Substation, and the second is based on providing reactive support to the network near the inductive load at the distribution feeder's using small MVAR capacitor banks mounted on the distribution poles. Also a comparative study of the two cases is presented in order to choose the most technical and cost effective method of reactive power compensation.

Keywords: Reactive Power, Capacitor Banks, Zone Substation and Distribution Feeder.

1.0 Introduction:

Reactive Power Compensation (RPC) in power systems is a very important issue in the expansion planning and operation of power systems because it leads to increased transmission capability, reduced losses and improved power factor using shunt capacitors.

Reactive Compensation generally is needed to reduce MVAR flow via the network to prevent low voltages and also to reduce the resulting real power losses. At the moment there are significant number of capacitor banks installed at the Zone substations to provide Reactive Support to the SWIS (South West Interconnected System); this approach of Reactive Power Compensation has created significant power losses to deliver power from the generating station. Hence an alternative method of Reactive Power support to the SWIS is being considered and analysis is done to determine the most technical and cost effective method of Reactive Support to the SWIS.

1.1 Objective:

The main objective of this project is to explore a method of providing alternate shunt compensation to the SWIS (South West Interconnected System) along the distribution feeders, in order to maintain the reliability, quality, and capacity of power delivery.

The study will include the following.

- Technical analysis and comparison of different methods using the PSSE (Power System Software for Engineering) Load flow analysis package.
- Financial analysis using the Net Present Cost (NPC) method.

On successful completion of the project Western Power may expect to increase the quality of energy delivery to customers and its profitability through improving the voltage profile and power factor, as well as reducing power losses.

2.0 Distribution Capacitor Banks:

Reactive Power support can be provided by a variety of devices including generators, synchronous condensers, shunt capacitors/reactors and static VAR compensators (SVCs) [1]. In this discussion, capacitor banks are used as a source of Reactive Power Compensation.

An alternative solution would be to install capacitor banks along the distribution feeder closer to the load. It is widely recognized that placement of Shunt Capacitors on an electric distribution feeder can lead to reduction in power losses [2]. Distribution Capacitor banks near to the loads were considered due to the following advantages:

- Improved Power Factor.
- Reduced Transmission losses.
- Increased Transmission Capability.
- Improved Voltage Control.
- Improved Power Quality.[3]

The target of reactive power compensation at distribution level is to keep power factor at load buses close to unity. The obligations of transmission companies are to provide the necessary reactive power resources that enhance the capability of transmission network to deliver power from generation sites to load sites and keep system voltages within acceptable range for any kind of load conditions, from very light load to very heavy load, with little help from generation companies during normal operating conditions. [4]

2.1 Background and Theory:

Although real power is the main traded commodity in electricity markets, reactive power plays a crucial role in power systems reliability and security [5]. The current Electric Power systems all over the world are moving towards a deregulated electricity market, and ancillary services are required for transmission and generation of the power network. Reactive power and voltage control is one of the ancillary services used to maintain the voltage profile through injecting or absorbing Reactive Power. [1] Reactive Power services play an important role in the power industry due to the following important roles played by it:

- Satisfy the requirement of reactive power load.
- System wide voltage control.
- Decrease the network loss.
- Relieve the transmission congestion.
- Provide sufficient reactive power reserve to ensure the security of system in emergency [1].

At all times the Power system network voltage and reactive power requirements must be met. If the voltage is not within the specified standard limits, unacceptable voltage profile will interrupt the power supply to the specified network, and loads with under voltage protection will be lost. Power from the generating station is being transmitted to the consumers via the transmission

lines (assets of the power community), which accounts for the losses in the system. As stated above the voltage of the network should be maintained at peak and off peak hours of the load demand.

During the peak hours of the day the transmission lines are heavily loaded due to the rapid increase in load demand and hence the voltage drops in the network and leads to a large inductive reactive power loss, therefore in order to maintain the system voltage, reactive power needs to be supplied into the system, as voltage and reactive power are related commodities. Under these conditions generators produce reactive power and capacitor banks are switched on, to supply the required reactive power, in order to maintain the power balance and maintain the voltage within specified limits. The normal specified voltage limits are 0.95pu to 1.05pu

Similarly during off peak hours of the day the transmission lines are less loaded due to the decrease in load demand, which leads to much less inductive reactive power losses in the network. Under such situations the capacitor banks are switched off to cut down the reactive power supply to the system. So in all circumstances the reactive power and voltage level of the system must be maintained to ensure safe operation of the power system.

3.0 Network Modeling:

Welshpool substation was selected for the case study and comparison of results. Load flow analysis was done for the case of the zone substation capacitor bank. Results obtained are as attached in Appendix 1, Case 1. The same substation network was remodeled with new buses 1161 and 3161 and the line parameters were calculated, power flow studies were done for the same and results obtained are as attached in Appendix 1, Case 2.

Line parameters are calculated for a line length of 2km on a 100MVA base, with the conductor data as specified in PSS/Adept Construction Dictionary of Western Power Corporation. The conductor used is 19/3.25 AAC (All Aluminum Coil).

The calculated values were entered in PSSE and the load flow analysis was carried out.

Results of both the cases were compared and distribution capacitor bank arrangement (case2) had a significant 0.1 MVar saving in each transformer when compared to the substation capacitor bank arrangement, which can be seen from the power flow diagrams in Appendix 1. It can be noticed that 0.1MVar is being saved in the Distribution Capacitor Bank arrangement; this is because the MVar required for the load is being supplied locally at the Distribution feeder. The transmission line losses are also minimized when the load is supplied locally, rather than installing a bulk capacitor bank at the Zone substation and supplying the load demand from the feeder.

Also there is a 0.1MW more losses in the transformer in case 1 when compared to case 2, which indicates active power loss minimization in the Distribution option. 0.1MW represents significant cost saving as there are more than 400 transformers in the network.

Note: The analysis is done for one transformer (T1) in the substation, as the MVar saving and MW losses are consistent for all transformers in the interconnected network.

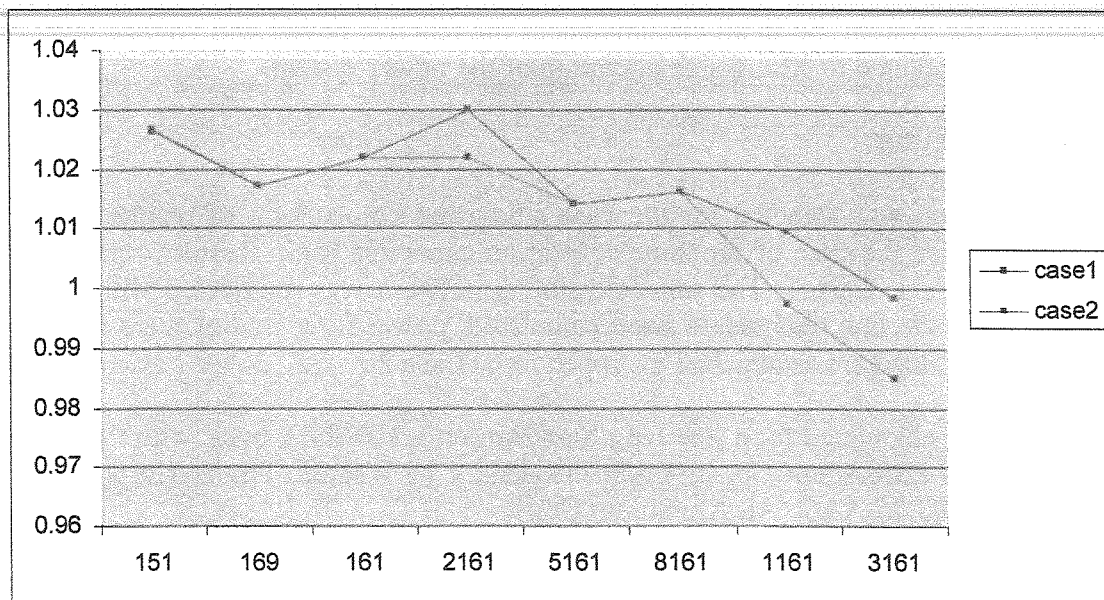
The next consideration is the voltage profile limits in the network which is an important issue in maintaining the quality of power supply and has to be maintained within specified limits of

0.95pu to 1.05pu. The voltage profile in the network in both the cases is as tabulated below in Table 1.

Table: 1 Voltage Profile in the network system

Bus	151	169	161	2161	5161	8161	1161	3161
Voltage in pu (Case 1)	1.0263	1.0172	1.0218	1.0220	1.0140	1.0160	0.9973	0.9850
Voltage in pu (Case 2)	1.0264	1.0172	1.0218	1.0299	1.0141	1.0161	1.0093	0.9984

Figure: 1 Comparison of voltage profile in the two cases.



From the above table and graph it can be identified that the voltage profile has increased in the Distribution capacitor bank option when compared to the Zone substation arrangement and the voltage levels are within specified limits of the standards.

Hence the technical aspects are in support to the Distribution Capacitor Bank option as the active power losses are minimized and a considerable amount of MVar saving. Technically it can be concluded saying that installing capacitor banks along the Distribution feeder is the best option of Reactive Power Compensation to the SWIS when compared to the existing method.

3.1 Load Factor Calculation:

Load Factor is a ratio of the average load supplied during a designated period to the peak load occurring in that period, in kilowatts. Simply, the load factor is the actual amount of kilowatt-hours delivered on a system in a designated period of time as opposed to the total possible kilowatt-hours that could be delivered on a system in a designated period of time. [6]

Utilities are generally interested in increasing load factors on their systems. A high load factor indicates high usage of the system's equipment and is a measure of efficiency. High load factor

customers are normally very desirable from a utility's point of view. Using a year as the designated period, the load factor is calculated by dividing the kilowatt-hours delivered during the year by the peak load for the year times the total number of hours during the year. [6]

Load factor of Welshpool substation is calculated over a one-year period from 10/07/2006 to 09/07/2007 and the value is found. Load factor in this analysis is used to calculate the dollar value for the MW losses in the system, which is as calculated in the NPC analysis (4.2).

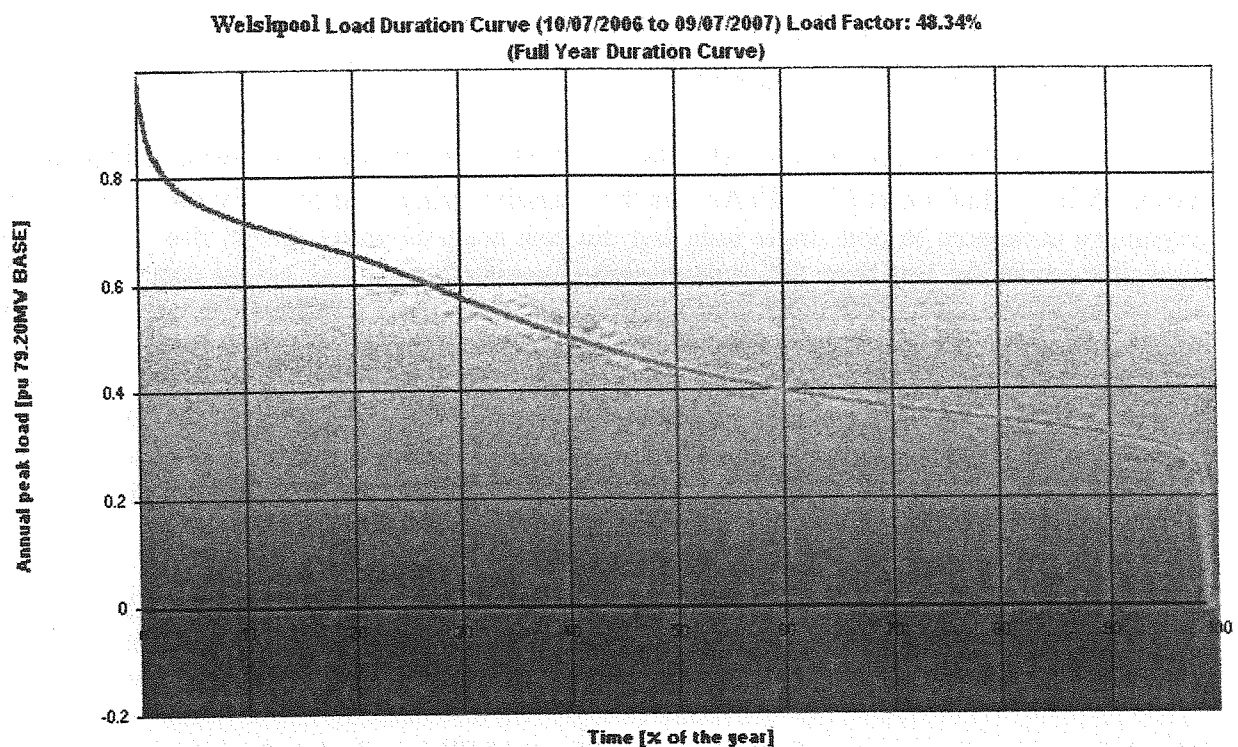
The average load in the substation = 38.29MW

The Peak load in the Substation = 79.2MW

$$\text{LoadFactor} = \frac{\text{AverageLoad}}{\text{PeakLoad}} = \frac{38.29}{79.20} = 0.48.$$

The full year load duration curve for Welshpool substation is as plotted below:

Figure 2: Welshpool Load Factor Curve



The most important consideration in the industry is the Cost benefit, which can be arrived in comparison of the two cases. The Net Present Cost Analysis is as discussed below.

4.0 Financial Evaluation of the Project:

Financial evaluation of the project is done based on the Net Present Cost (NPC).

4.1 Net Present Cost (NPC):

Net Present Cost method represents the cost of the project in today's dollars after taking into account the time dependent value of money.

This economic analysis has been conducted over a 20-year period with a discount rate of 10.05 %, (Refer calculation sheet in Appendix 2) for the two test cases with 5MVAR capacitor bank required. These cases require compensation of 5MVAR to be installed either in the form of one capacitor bank at the Zone substation or equivalent multiple units of 1MVAR distribution capacitors on distribution feeders. NPC is done taking into account the MVAR saving in case 2 and the MW losses in case 1.

4.2 NPC Analysis:

Cost of a 22kv 5MVAR transmission Capacitor Bank with Circuit Breaker including Labor and Material cost is \$440k/unit.

Cost of a 22kv 1MVAR Distribution Capacitor Bank including Labor and Material cost is \$55k/unit

Therefore cost of 5*1MVAR cost is \$275k.

It is widely considered that the cost of a single unit (5MVAR Capacitor Bank) should be less than having 5 individual units (5*1MVAR), as the manufacturing cost of individuals units is more expensive compared to one single unit, but the cost analysis above shows that the distribution capacitor banks are less than the transmission capacitor banks. The actual cost of the 5MVAR transmission capacitor banks is around \$200k; the remaining \$240k is the cost of the circuit breaker. Overall the cost of the distribution capacitor banks is cheaper.

It is obvious that instead of one capacitor bank at transmission level (i.e. 5MVAR) there will be installed 5 distribution units (i.e. 1MVAR). Therefore, there could be at total a higher maintenance cost for the distribution capacitor banks option, and the life time is also shorter when compared to the Transmission Zone substation capacitor bank.

From the power flow diagram in Appendix 1, it can be noticed that there is a 0.1MW more losses in the Zone Substation capacitor bank arrangement when compared to the Distribution Capacitor bank arrangement. Converting 0.1MW into dollar value will result in a massive saving.

The dollar value for one transformer per year for 0.1MW is calculated taking into account the load factor as calculated in section 3.1, and a cost of 5cents per KWh, which is 50\$/MWh

Cost of 0.1MW/ per year = $24 \times 365 \times 0.48 \times 0.1 \times 50 = \$21,024$

With more than 400 transformers in the system, this dollar saving represents a considerable cost saving if the Distribution Capacitor Bank option were adopted.

The maintenance cost for the distribution capacitor bank is around \$130.00 per year and the Transmission capacitor banks are checked once in every four years, which costs around \$1262.00. Overall the maintenance cost is a minimal value and does not make much of a

difference in the NPC analysis. The data sheet used for the NPC analysis is as attached in Appendix 2.

From the Cost analysis (as in Appendix 2) it can be noted that for a 20year period the total cost of distribution capacitor banks is \$258,700, when compared to \$634,300 for transmission capacitor bank, which is a difference of about \$375,600, so about \$375k is being saved in the distribution capacitor bank option.

So the cost analysis is in favor of distribution capacitor bank, as the cost benefit is an important factor.

5.0 Conclusions and Recommendation.

This paper presented a comprehensive and cost efficient analysis of Reactive Power Compensation provided to the SWIS (South West Interconnected System), analysis and discussion were done for two methods of Reactive Power Compensation and a best method of Reactive Power Compensation is being recommended to the SWIS.

Results found in this study shows that both Zone substation capacitor banks and distribution capacitor banks provide the same level of reactive support in terms of voltage profile. Taking into account the Real and Reactive power losses in the network, the distribution capacitor banks were found to be more efficient. Financial analysis (NPC) discussed in section 4.2 shows that the distribution capacitor bank is a more superior option when compared to the Zone substation capacitor banks.

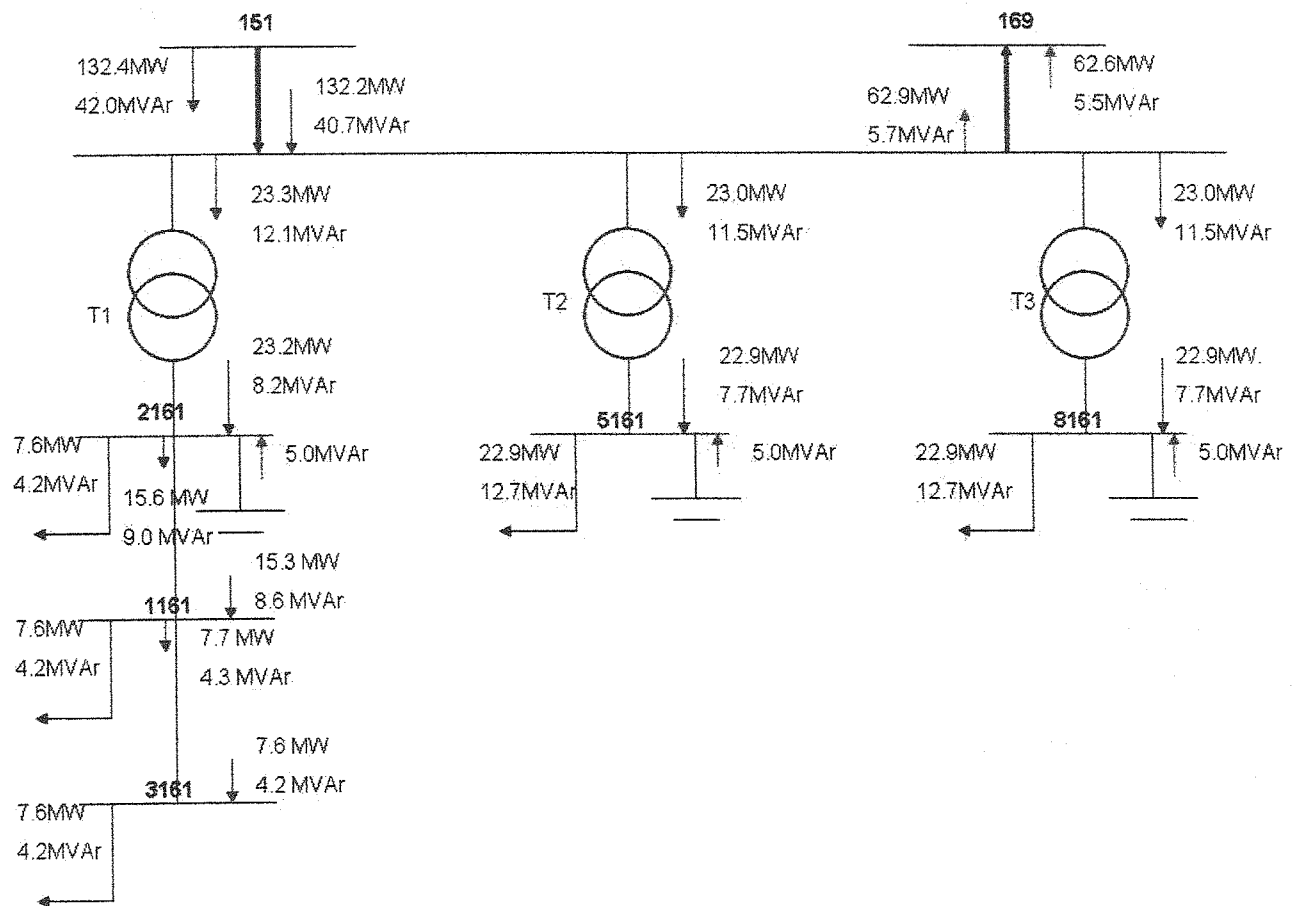
It is therefore recommended that distribution capacitor banks should be installed in place of Zone substation Capacitor banks where practically possible.

6.0 References:

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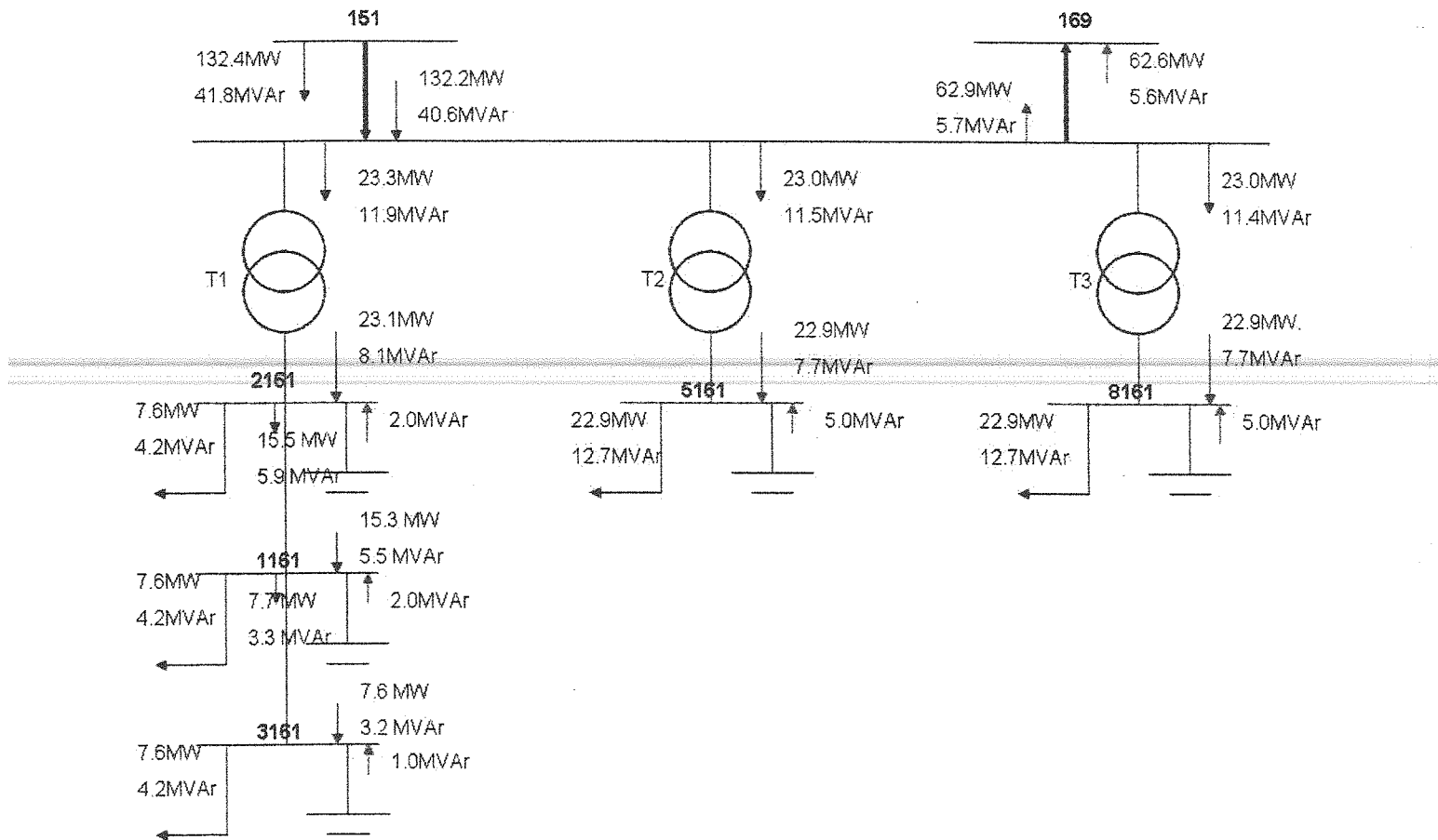
Appendix 1: Power Flow Diagrams

Case 1: Power Flow Diagram: Zone Substation Capacitor Bank.



Appendix 1: Power Flow Diagrams

Case 2: Power Flow Diagram: Distribution Capacitor Bank



Appendix 2: Net Present Cost Analysis Data Sheet

NPC Analysis		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
YEAR: 2007																							
Option 1 Zone Substation Capacitor Banks																							
Cost of 5MVAr Capacitor Bank			0.400																				
Transmission Losses Cost (\$/MVA)			0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210
Maintenance Cost			0.0013				0.0013								0.0013				0.0013				0.0013
Sub-total (\$M)		0	0.462862	0.021	0.021	0.021	0.022262	0.021	0.021	0.021	0.022262	0.021	0.021	0.021	0.022262	0.021	0.021	0.021	0.022262	0.021	0.021	0.021	0.022262
Inflation rate WA (%) (as per August 2006)		0.0%	3.0%	2.5%	2.5%	2.5%	2.4%	2.4%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%
Inflation rate multiplier		1.00	1.03	1.06	1.08	1.11	1.14	1.16	1.19	1.21	1.24	1.26	1.29	1.32	1.35	1.37	1.40	1.43	1.46	1.49	1.52	1.56	1.59
Escalated Total (\$M)		0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Discount rate for capital cost		1.00	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.46	0.42	0.38	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.13
Present Base Cost (\$M)		0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Present Cost (\$M)		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
YEAR: 2007																							
Option 2 Distribution Feeder Capacitor Banks																							
Cost of 5.1 MVAr Capacitor Banks			0.275																				
Maintenance Cost			0.0001				0.0001								0.0001				0.0001				0.0001
Sub-total (\$M)		0	0.27513	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013
Inflation rate WA (%) (as per August 2006)		0.0%	3.0%	2.5%	2.5%	2.5%	2.4%	2.4%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%	2.1%
Inflation rate multiplier		1.00	1.03	1.06	1.08	1.11	1.14	1.16	1.19	1.21	1.24	1.26	1.29	1.32	1.35	1.37	1.40	1.43	1.46	1.49	1.52	1.56	1.59
Escalated Total (\$M)		0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Discount rate for capital cost		1.00	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.46	0.42	0.38	0.35	0.32	0.29	0.26	0.24	0.22	0.20	0.18	0.16	0.15	0.13
Present Base Cost (\$M)		0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Present Cost (\$M)		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

