CHAPTER 1 THE TRANSMISSION ELECTRICAL NETWORKS

1.1 INTRODUCTION

The author believes that the understanding of forecasting methodologies is important. However, the real test comes in their applicability in practice and their impact on planning and decision-making. The purpose of this thesis is to describe a forecasting methodology for transmission power system planning. The forecasting methodology includes all possible future load growth trends to expand the electrical networks in the most cost-effective manner. The forecast should also give more insight into the electrical industry and therefore reduce the uncertainty in the future expected loads.

This chapter describes the transmission electrical network, the load requirements for network studies and an electrical load model for transmission forecasting.

According to Stevenson power system engineers are interested in studying a power system as it will exist 10 to 20 years into the future. The expansion of a power system requires load studies, fault calculations and stability studies. With load studies, voltage, real power and reactive power are determined at various points in the electrical network under normal operating conditions. [1]

According to Glover et al. power flow programs compute the voltage magnitude and phase angle at each bus for the modelled power system under balanced three-phase steady-state conditions. As a by-product, real power flows (P values) and reactive power flows (Q values) are computed in equipment such as lines and transformers (branches). [2]

The predicting of future P values becomes increasingly more complex and uncertain. Gellings mentions that the roles of forecasters have changed significantly since the 60s. Today's forecasts have to be more accurate and informative. [3]

1.2 TRANSMISSION ELECTRICAL NETWORK

The input into the transmission network comes from electricity generated by the utility's power stations and imported electricity from neighbouring countries. The electricity is then distributed by the transmission network to a number of distribution networks (see Figure 1.2.1). *For this research, all loads are modelled as MW figures at the time of the maximum transmission system load*. The transmission system load (system demand) is the sum of the utility power station's net power outputs and the power imported from neighbouring countries, measured hourly.

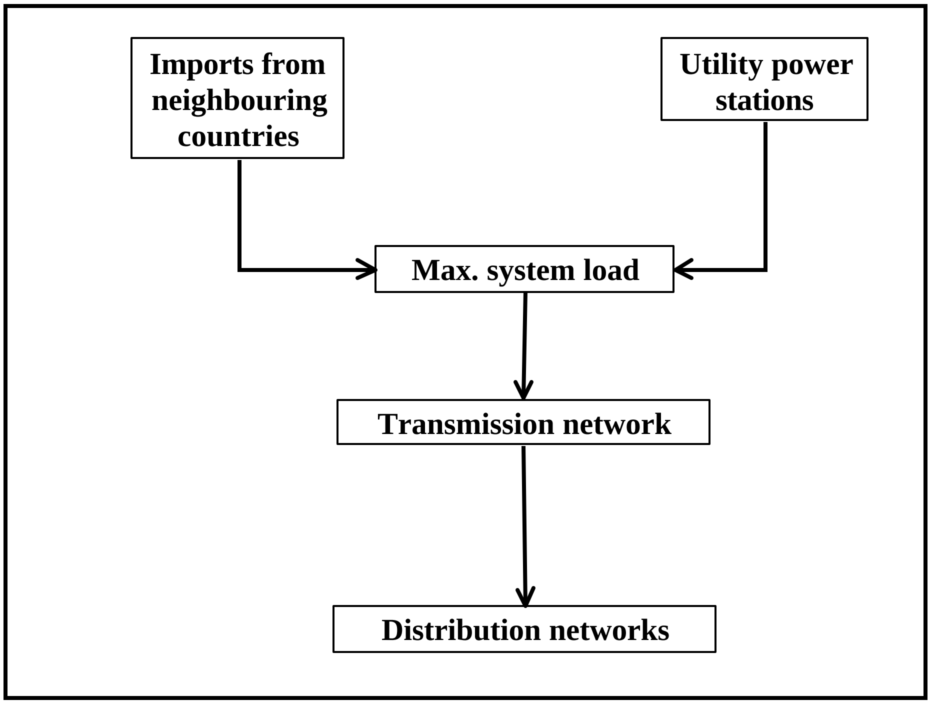

Figure 1.2.1 - A Typical Transmission Electrical Network Layout

By transmission is normally implied the bulk transfer of power by high-voltage links between generation plants and main load centres, and between main load centres. The distribution networks are connected between the transmission network and the end-use customers. However, some authors classify the electrical networks as the transmission system, sub-transmission system and distribution networks.

For the purpose of this thesis the *transmission network* is defined as the electrical network connected between the generation plants and the distribution networks. The *backbone of the transmission network* is the electrical network not directly connected to the distribution networks, but supplying a number of transmission substations. The transmission backbone substations have the following voltage transformations:

1) 765/400 kV
2) 400/275 kV
3) 400/220 kV

The next three figures give typical layouts of backbone substations. The backbone substation forecasts are determined differently from those transmission substations directly connected to the distribution networks (see Chapter 3).

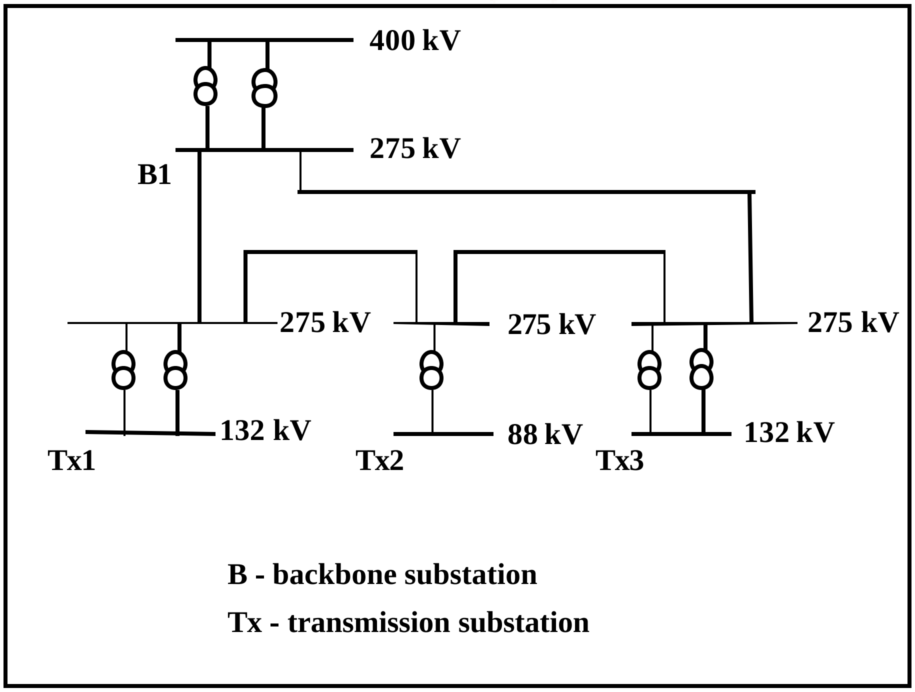

Figure 1.2.2 – Single Backbone Substation Arrangement

In some cases, transmission backbone substations have more than one voltage transformation. One example is a substation with three different voltage transformations (see Figure 1.2.3):

1) 400/220 kV
2) 220/132 kV
3) 220/66 kV

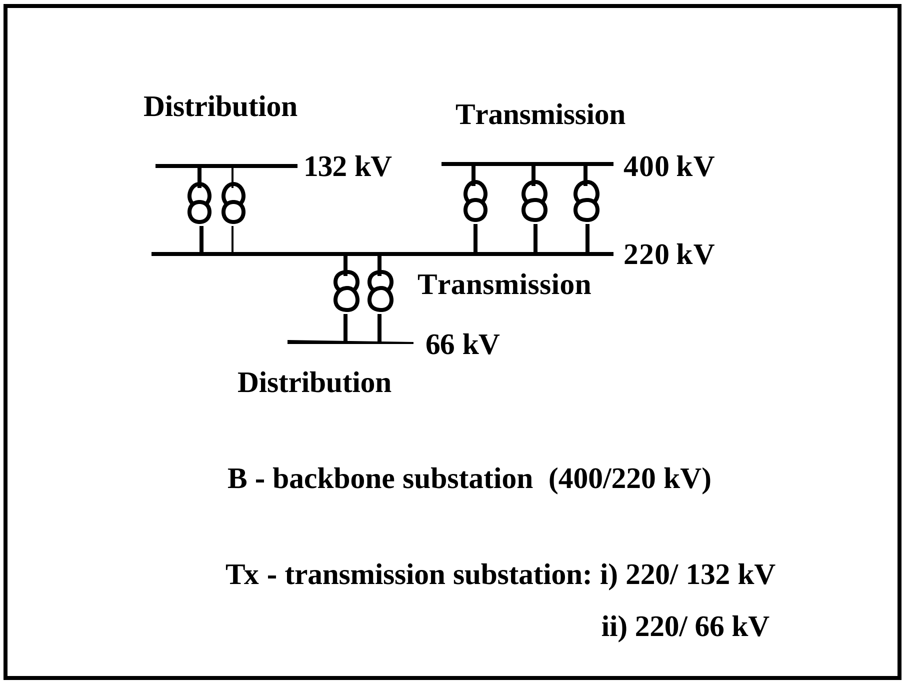

Figure 1.2.3 – A Backbone Substation with Multi-Voltage Arrangement

Figure 1.2.4 shows a more complicated arrangement of backbone substations.

The utility power station generator voltages are normally in the range of 11 – 25 kV. Thereafter the voltage is increased by transformers (generation transformers) to the main transmission voltages (400 kV, 275 kV, 220 kV & 132 kV). The net power output is thus the gross power output minus the auxiliary unit loads and is measured at the generation transformers. The imports from neighbouring countries are measured at the transmission substation between the utility and the neighbouring networks.

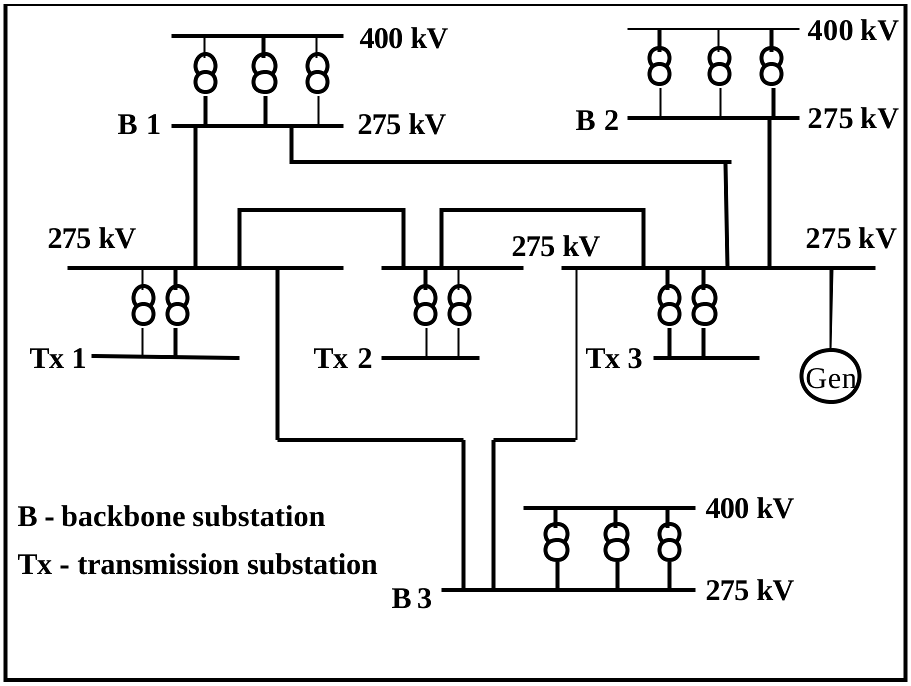

Figure 1.2.4 – Multi-Backbone Substation Arrangement

Substations play an important role in the transmission network. A substation has a number of buses and a bus can be described as an electrical connection of "zero impedance" joining several items such as lines, transformers, loads, etc. A transformer can either increase (step up) or decrease (step down) the voltage.

The utility main power pool (where most of the power stations are located) and the load centres are connected with a 400 kV system. A 765 kV system exists to supply a remote load centre from the main power pool. The utility has at this time two 765/ 400 kV substations (2 X 2000 MVA transformers per substation). The 275 kV and 220 kV systems are located closer to the main load centres and are connected to the 400 kV system.

The distribution networks are fed from transmission substations that are either directly connected to the 400 kV system, or to a 275 kV (or 220 kV) system. In general the distribution substations connected to the transmission substation feeders are included in the electrical forecasts.

To develop the balancing algorithm (Chapter 4), Figure 1.2.1 has been modified to cater for the transmission electrical losses, power station loads, export to neighbouring countries and (geographical) area loads. Privately owned power stations are some future developments to consider under the proposed restructured electrical industry. Those power stations can either supply some end-use customers directly (the maximum transmission system load will reduce) or else be connected to the transmission network (the net power output is then added to the maximum transmission system load). Furthermore, some end-use customers have their own power stations (see Figure 1.2.5). [1, 2, 4 – 7]

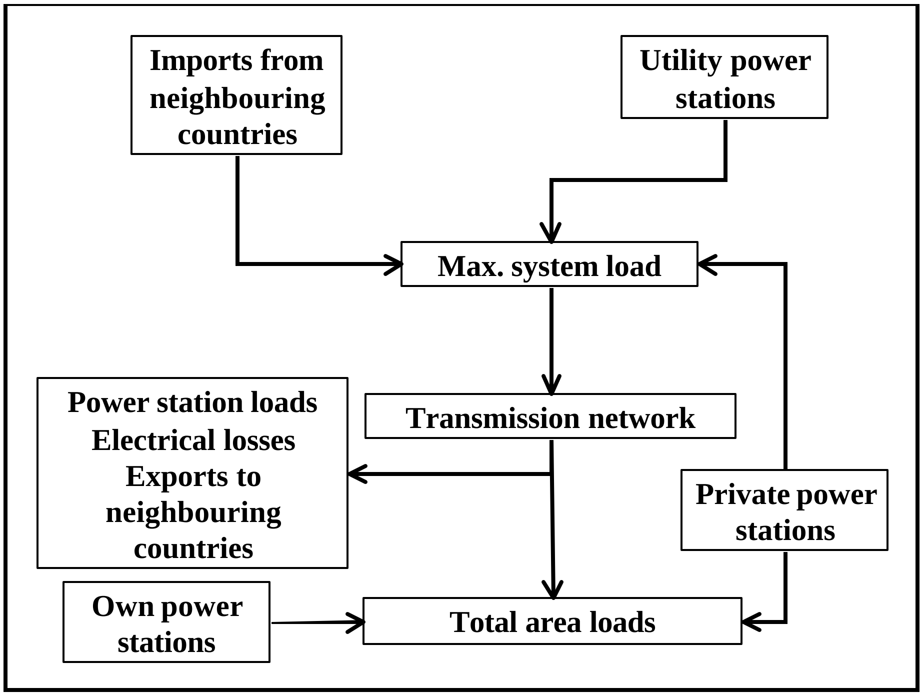

Figure 1.2.5 - A Typical Transmission Electrical Network

1.3 ELECTRICAL NETWORK LOAD REQUIREMENTS

For power flow studies, each bus is categorised into one of the following three bus types:

1) Swing bus – the reference bus
2) Load bus – requires a P (MW) and Q (MVAR) value

3) Voltage Control bus – model generators, switched shunt capacitors and reactors and static var systems [2]

The first requirement is to produce P and Q values for each load bus (point load). The modelled P and Q values are the expected values *(single values not between ranges, or between confidence levels)* on the load bus when the transmission network reaches its annual maximum load. The load buses are mainly the distribution substations. Although mentioned as a requirement, the *predicting of Q values are excluded from the thesis*.

The maximum transmission system load is used as a benchmark figure to reconcile the different forecasts and is therefore a very important input into the transmission forecast process (see Chapter 5).

The term "generation pattern" defines the set of figures representing the utility power station net power outputs and imports from neighbouring countries. Generation patterns are important for load flow studies, and should therefore include all possible expected inputs into the transmission networks (see Chapter 3).

Area forecasts play an important role in the transmission forecasts. The area loads assist the transmission power system planning engineers to determine the bulk power transfer between generation plants and main load centres, and between the different main load centres. Long-term planning deals with the acquisition of lands and rights for new substations and electrical lines. The area loads help to identify electrical network constraints that require network expansions such as new overhead lines and substations.

The firm capacity of a substation is defined as the available capacity for that substation, given the transformer with the highest MVA rating has been switched out. The expected substation loads should not exceed the substation's firm capacity.

The last requirement is to assist the planning engineer to determine the line loadability. The modelled point loads (at time of maximum system load) are scaled to determine the expected minimum and maximum loads for line loadability. The three major line-loading limits are:

1) Thermal limits – Normally for lines up to 80 km to determine whether thermal limits are not exceeded and, therefore, the conductor-to-ground clearances are met.
2) Voltage drop limits – Normally for medium length lines, 80 to 300 km, to ensure prescribed voltage limits are met.
3) Steady-state stability limits – Normally longer lines, more than 300 km, to ensure stability is maintained (Synchronous machines on either end of the line remain in synchronism). [2]

1.4 ELECTRICAL LOAD MODEL

The objective of the electrical load model is to structure the transmission network so that a number of expert views in the South African electrical industry can be modelled mathematically for network studies. The different forecasts vary from the maximum transmission system load, sector, area and substation loads. The outputs (point loads) should include all future load growth trends in order to expand the electrical networks in the most cost-effective manner. The modelling of different expert views gives more insight into the electrical industry and therefore reduces the uncertainty in the future expected loads.

The electrical load model is explained in three phases. Phase one looks at the transmission network inputs, phase two at the outputs and the last phase at how to incorporate the sector forecasts.

The hourly system load is the sum of the total load imported from neigbouring countries and the net output from the utility power stations (*generation pattern*). According to latest plans, it will be possible for privately owned power stations to be connected to the transmission network. The *maximum transmission system demand* is the maximum load into the transmission network. As mentioned earlier, the load modelling is done at the time when the transmission network reaches its maximum expected load. Phase one is summarised in Figure 1.4.1.

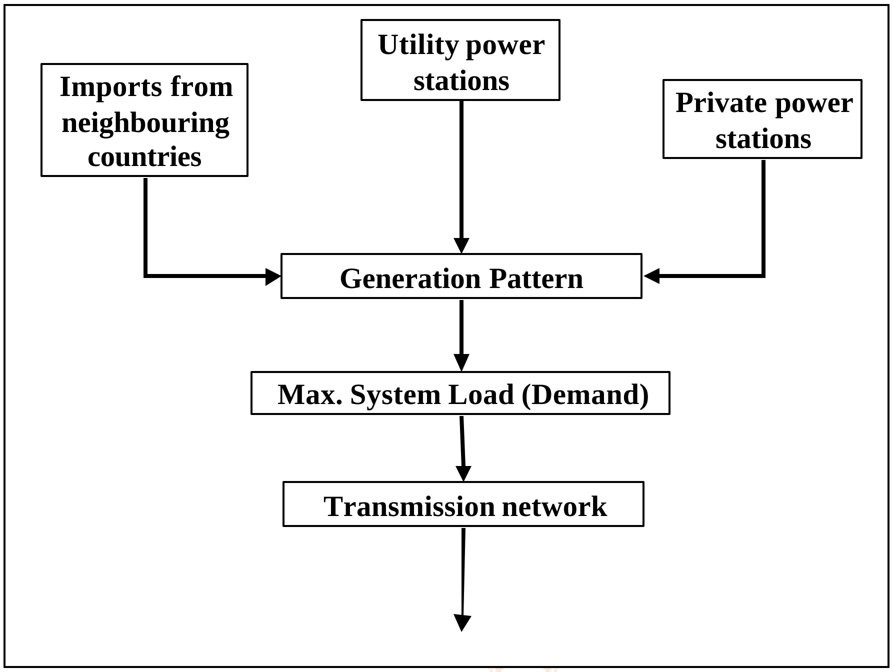

Figure 1.4.1 – Electrical Load Model: Phase One

Phase two looks at the outputs. The total *transmission substations* directly connected to the distribution networks are just more than one hundred substations. A supply area is allocated to each transmission substation. It is possible that load can be transferred between supply areas (exports or imports). The distribution substations (approximately 1100 substations in total) in a transmission supply area are linked to that transmission substation.

The distribution substations for transmission load modelling are selected according to the following criteria:

1) All distribution substations connected to the interconnections between transmission substations are modelled (Tx1, Dx3, Dx4, Tx2).

2) If the interconnections between distribution substations have significant impacts on transmission substation loads, then the distribution substations connected to the interconnection are also modelled (Dx3 & Dx4 – secondary side).
3) For radial feeders, the first two distribution substations are modelled (Dx1 & Dx2).

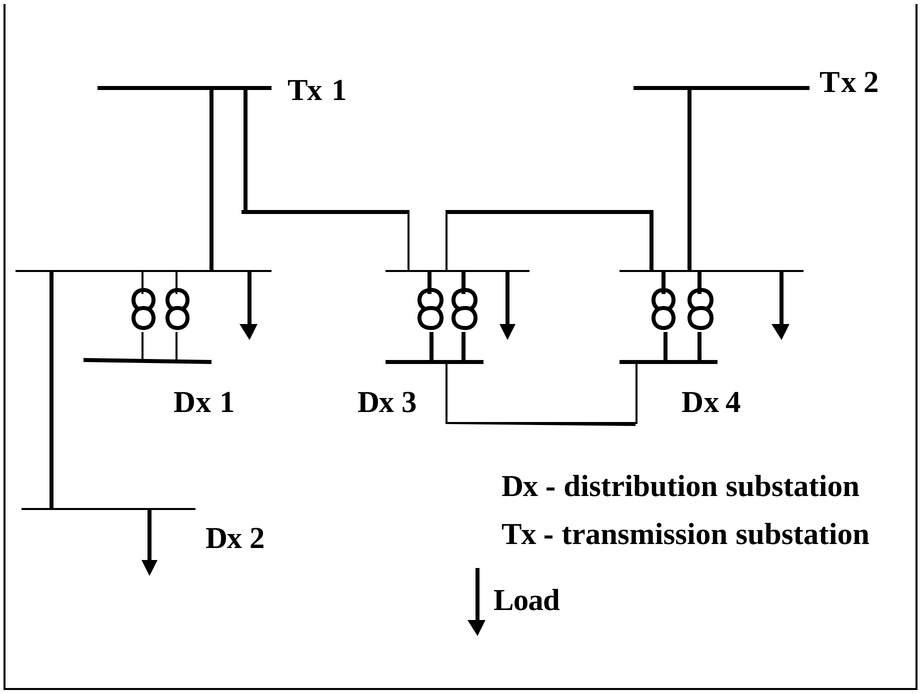

Figure 1.4.2 – Distribution Substation Selection Criteria

For the study of this thesis, South Africa has been divided into twenty-seven geographical areas. Based on the transmission and distribution electrical network layout (topology), a geographical area is selected according to the following three criteria:

- Load transfers (due to different network operations) between areas are minimised.
- A geographical area is selected in such a way that there are no overlaps between areas, but that the entire South Africa is included.
- No area should be surrounded by only one area.

The transmission electrical losses, the total power station loads and total load exported are modelled each as an output (see Chapter 3).

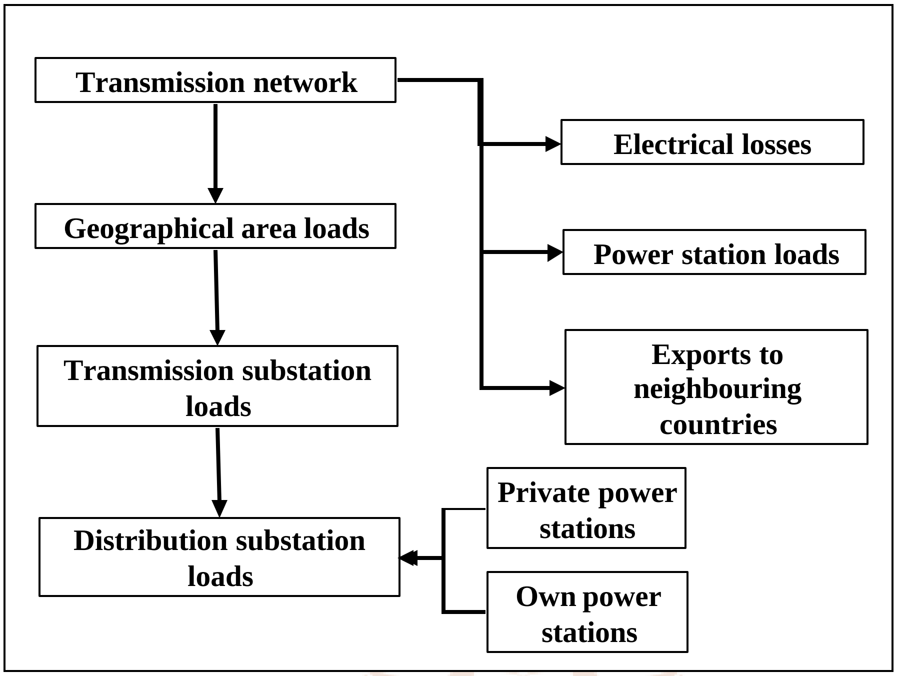

Figure 1.4.3 – Electrical Load Model: Phase Two

The last phase is excluded from the balancing algorithm (Chapter 4). The capital investment software requires that the load at each transmission substation is divided into pre-defined sector loads. To determine those sector loads, each distribution substation load is divided into sector loads in accordance to the investment criteria. Those individual sector loads are then summated per sector and per transmission substation to determine the required capital investment criteria loads. The sector loads are also added per area to determine the area per sector load. The area loads for each sector are summated and compared with the corresponding expected national sector load.

The component-based approach (for load modelling) was developed by EPRI in 1976. The load supplied in bulk is sub-divided into load classes such as residential, commercial, industrial, agricultural and mining. Each category of load class is represented in terms of load components such as lighting, space heating, water heating, etc. Static load models (polynomial models) are commonly referred to as ZIP models. ZIP models are composed of constant impedance (Z), constant current (I), and constant power (P). The distribution substation sector loads can play a major role to assist load modelling for more accurate representation of the real conditions.[4]

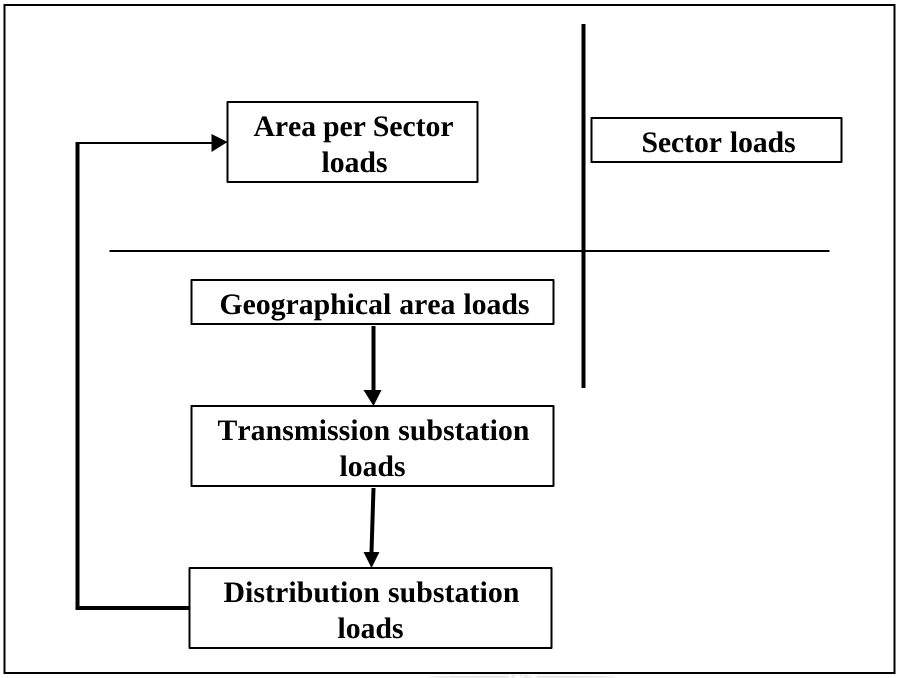

Figure 1.4.4 – Electrical Load Model: Phase Three

1.5 LITERATURE SURVEY

Consensus forecasts are used to combine historical demand and the views of everybody in the company "on the same page". Babson Brothers uses it as a top-down approach (company revenues) and a bottom-up basis for production levels. With this approach, both viewpoints are included. The electrical load model uses a similar approach - the transmission system load and the distribution substation loads are checked for consensus. [8]

The importance of energy demand forecasts is well-explained by an energy analysis and policy document (no reference for the document). The timely availability of energy is vital for the functioning of a modern economy.

Secondly, expansions to energy supply systems usually require many years. Lastly, such capital investments are costly. It is this important that the transmission load forecast must be informative and include, as far as possible, all new developments in the electrical industry in South Africa.

The electrical load model defines expert views as variables between lower- and upper ranges. Lootsma used variables for his long-term planning perspectives. These variables were allowed to vary over a continuous range of values, between a lower "bound" where production is just technically and economically feasible, and an upper "bound" such as the total factory capacity. The selection of variables for the electrical load model and individual ranges (lower and upper "bounds") is discussed in Chapter 4. [9]

Broehl et al. mentioned that it is insufficient to estimate only the total system loadshape. What is required are the various contributions of the major end-uses of electricity. Battelle has developed an integrated energy-and demand forecasting model that builds up the demand and energy projections from the major end-use components. This very similar to the sector load forecasts that are used for the transmission load forecast. [10]

The report by the independent electricity market operator includes forecasts done by areas. Demand for electricity differs across different areas in the province. Therefore, for the purpose of the forecast, the province is divided into six different load forecast areas. [11]

Goh et al. also wrote that accurate load forecasting of energy and peak power demand has become increasingly crucial for effective system planning. Forecasting is extending patterns of past data into the future with effective projection. Annual data has no seasonal component but weather cycles are important to consider. [12]

The success of the research is to provide a process to compare a number of different forecasts where each forecast is based on well-defined assumptions and scenarios (factors). The load forecast has to be supported by a knowledge-based system, appropriate forecasting techniques and computer models. Any knowledge-based system (referred to as an expert system) essentially emulates the acquired knowledge and thought processes of an expert in arriving at decisions concerning a problem, according Bhatnagar et al. [13 – 17]

An article of Romero and Monticelli, with the objective to plan transmission network expansions more optimally, also structures the networks as a hierarchical structure. The initial solution is obtained from a simple model (transportation model) and more advanced models are used later.

The major difference is that the expansion algorithm add new branches (lines) and the balancing algorithm reconciles different forecasts at different levels of the hierarchical structure with one another. The expansion algorithm minimises the network expansion cost and the balancing algorithm "minimises" the differences between the different forecasts. [18]

In Chapter 4 the electrical load model provides a basis to evaluate a number of different forecasts (Chapter 3). The different forecasts are "balanced" to ensure that the different forecasts interpret different factors that have a significance on the transmission loads correctly (Chapter 2) and provide forecasting results that are more informative and provide more confidence in the expected load growths.

1.6 CONCLUSION

The number of transmission and distribution substations and the different factors that have an impact on the expected loads make transmission load forecast complex and difficult. A holistic approach is required to evaluate the maximum transmission system load, but also an end-use approach to evaluate the different distribution substation forecasts. Furthermore, a top-down and bottom-up approach is required to compare those different forecasts.

The electrical load model provides such a structure. Expert knowledge (knowledge-based system) can be entered in the model (Chapters 2 and 3) and compared whether consensus exists about future load growths (Chapter 4). The balancing algorithm has been developed to balance the loads year after year, depending on the modeled hierarchical system. It is therefore possible to accommodate network topology changes between years.

1.7 REFERENCE

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