

## Distribution Network Planning for Mumbai



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### Introduction

The Indian utility Reliance Energy Ltd. (REL) operates the power supply for its Mumbai supply area with 1200 MW peak load by 220/33/22/11 kV networks. On the distribution level with more than 4000 distribution substations medium to low voltage the supply situation was characterized by high losses and frequent interruptions. The network had grown over years and some replacement works as well as expansion work to meet the load growth were urgently necessary.

At this stage in 2003 the management decided to carry out a major system study for network optimisation, distribution automation and automatic meter reading together with Siemens in order to optimise the upcoming investments and to define the priorities.

The paper shows the approach of network optimization with the identification of weak points in the existing network as well as the selection of the target network structure and its verification with principle networks and concrete modeling in Mumbai area.

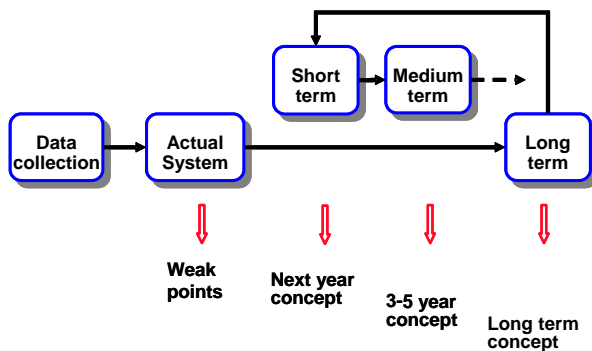


Figure 1 - Planning Procedure Loop

suitable measures for short term and medium term development are influenced by the long term concept. Therefore the general long term concept is setting the course and gives the basis for detailed next year decisions.

### Data Collection and System Modeling

For a huge grown network like Mumbai distribution network the data has to be taken in the format as they are and from the sources available. Target for this project was to fill the common database of the network planning tool SINICAL® (figure 2). Data collection and data input for network analysis of a large network in a short period of time is a challenge which can not be done without automatic routines.

### Network Planning

One main task of a utility is to operate the network economically. Key targets from the technical side are low operational costs, reliable supply and a low level of losses.

From the given situation (e.g. type and age of equipment, location and size of load, configuration of network) it is essential to develop a strategic plan how the network should look like in the future and how this goal can be achieved including the required amount of investment.

The principle procedure for long term planning is given in figure 1. The key point is the fact that

One main data source was the geographical information system (GIS). The electrical and geographical data was automatically transferred into SINCAL®.

Existing AutoCAD drawings showed the connectivity of the network whenever GIS data did not contain this information. Additionally some open points of the system had been taken manually out of these drawings.

Peak loads of the distribution substations and transformer loads of receiving stations had been provided in MS Excel sheets. Routines for an automatic transfer into the distribution network model had been developed. For this purpose unique names were essential.

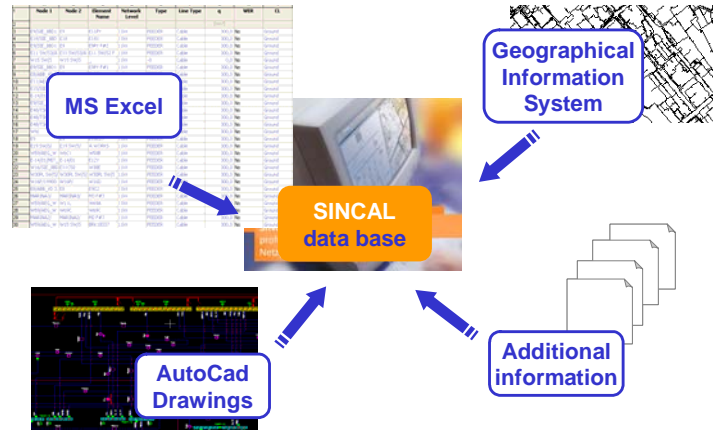


Figure 2 - Data Collection

The transmission and sub-transmission network (220 kV / 33 kV) were modeled manually as schematic diagrams with geographic orientation and linked via macros to the distribution network. Finally a single database for the network from 220 kV down to 11 kV was available.

### Weak Point Analysis

Weak point analysis of the existing network delivers information on structural deficiencies, violation of electrical limits, bottlenecks and operational trouble zones.

For this purpose a colored diagram giving the routing of supply cables per receiving substations (R/S) was created and load flow as well as short circuit calculations were carried out.

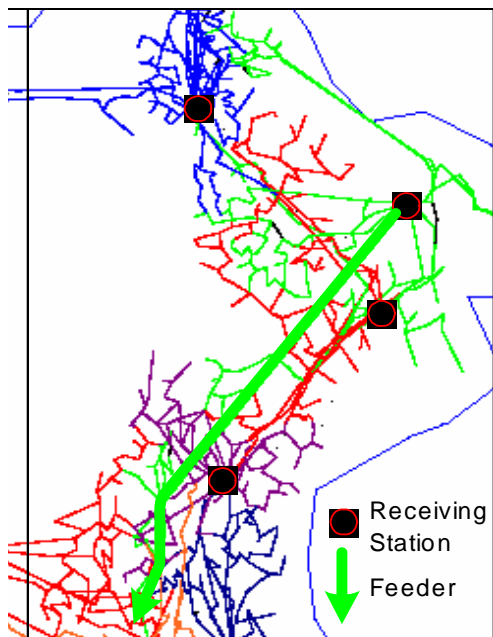


Figure 3 - Structure Analysis

### Structure

The investigation of the network structure mainly shows the location of the R/S and its supplied area. Whenever an R/S supplies loads which are closer to another R/S the reason why has to be questioned. In most cases this configuration is likely to have problems of long feeders leading to unnecessary losses, and voltage drops.

Figure 3 shows a part of the total network. It can be shown that R/S in the north supply loads in the south. One reason is that overload in the south was solved by "transmission cable" instead of new R/S. This is a typical situation resulting from "operative planning".

### Electrical and Operational Weak Points

Basically the bottlenecks in the medium voltage system were high loading of cables and transformers as well as voltage violations. All electrical bottlenecks were presented in the geographical drawing of the 11 kV network by coloring the weak elements of the system like shown in figure 4. This figure can also be looked at as the artery for the electricity supply.

With the same method it is possible to identify weak cable cross sections, transformer sizes or age of equipment etc.

Contingency analysis showed that in some cases the re-supply after a failure can only be done by shifting several open points.

**Assessment**

The analysis of the existing system with geographic representation shows that the existing 11 kV system is of meshed structure and operated in radial. There are many cross connections giving switching options.

Based on the results of weak point analysis immediate measures had been proposed, like open point shifting and network enhancement.

The last reserves have been bailed out to fulfill the basic requirements of electrical power supply. The proposed measures from weak point analysis could not guarantee the future supply of Mumbai distribution network. It was strongly needed to simplify the network structure.

**Principles and Options**

Option	Transmission	Sub transmission	Distribution	
			Voltage Level	Structure
1	220 kV	33 kV	11 kV	open ring
2	220 kV	33 kV	11 kV	open line to R/S
3	220 kV	66 kV	11 kV	open ring
4	220 kV	66 kV	11 kV	open line to R/S
5	220 kV	110 kV	11 kV	open ring
6	220 kV	110 kV	11 kV	open line to R/S
7	220 kV		22 kV	open ring

Table 1 - Options



Figure 4 - Total Network - Load Flow

In order to select a suitable structure for the future, seven options were developed and applied to principal networks. The seven options vary in voltage levels of sub-transmission and distribution and in the structure of the distribution network (table 1).

One standard structure is an open ring starting and ending at the same R/S. Another standard structure has an open line which starts and ends at different R/S. For option 7 a configuration without a sub-transmission level was selected. The principle networks are based on characteristic network parameters such as total load, load density and size of the area. Figure 5 gives as an example the principle structure for option 1.

All options were modeled and analyzed regarding:

- Losses
- Reliability
- Feasibility
- Investment costs

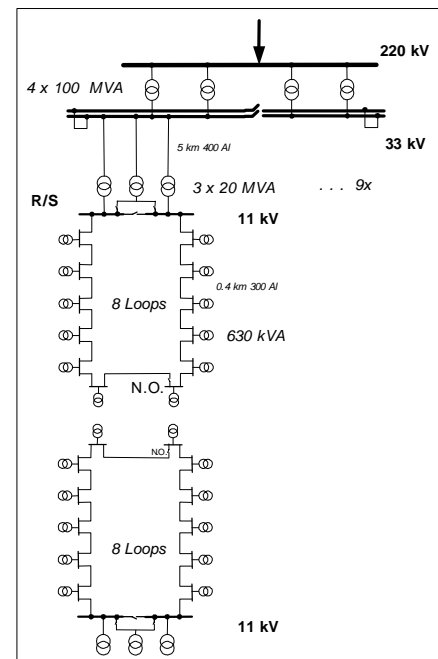


Figure 5 - Principle Structure for Option 1

Figure 6 shows the result of the comparison of all seven options. For ease of comparison, the highest values of the investment costs, the non availability and the losses are referred to as 100%.

It appears that the capital cost vary from 100% down to 65% for the cheapest one. The non availability of the most reliable option is reduced by 25%. The distribution losses of the best performing option are only 18% of reference option.

Option 1 and 2 are the lowest in investment cost but they have the highest level of losses. Option 7 offers the minimum of losses.

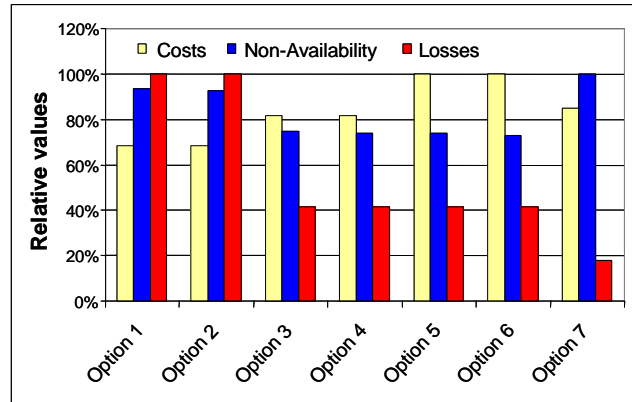


Figure 6 - Comparison of Options

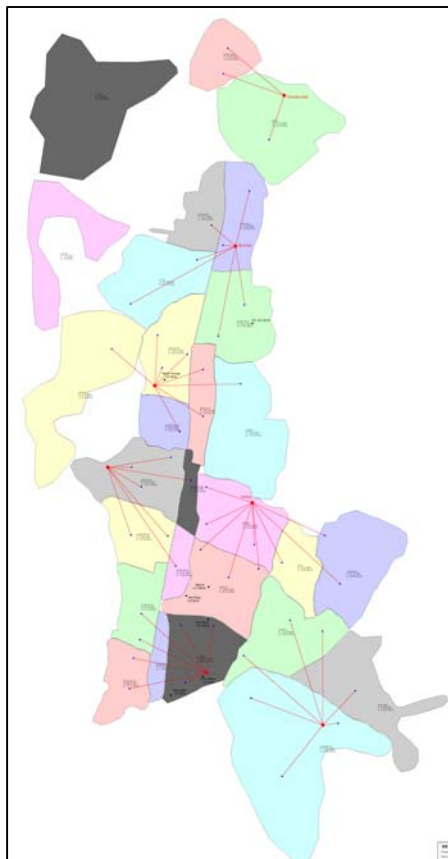


Figure 7 - Reliance Energy Mumbai Supply Areas

### Greenfield Planning Approach

Based on the information of distribution transformer location, distribution transformer load and existing infeeds from 220 kV network an optimum network has been developed in theory, as if the project starts on a green field. The Greenfield analysis has been done for a 50% increased load which is expected within the next 10 years.

For the investigation the total REL distribution area in Mumbai had been divided into supply areas as shown by the colored areas in figure 7. The borders of each supply area are mainly defined by natural barriers.

Each receiving substation should only supply loads within its supply area.

The arrangement of the total supply area into several smaller areas has got the following benefits for network planning:

- Reduction and splitting of network planning activities to several areas
- Short feeder length
- Low losses
- Low cost

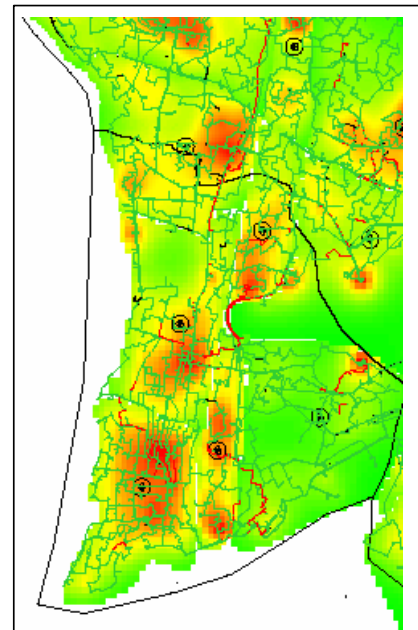


Figure 8 - Load Density

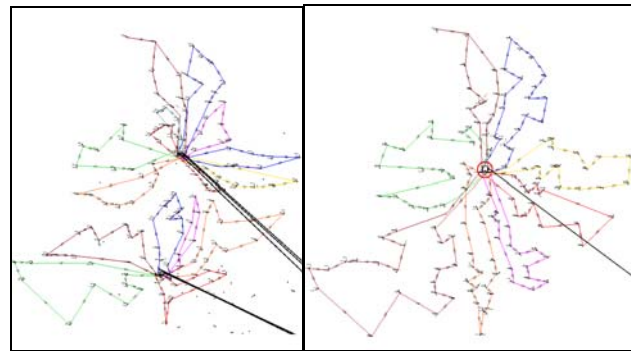
The optimal locations for receiving substations have been identified by load density analysis.

Figure 8 shows the diagram of load density from low load areas in green color to high load areas in red color. Same colored areas have got the same load density. The load center of each area is marked with a circle.

Three pre-selected options have been modeled for three supply areas in the network planning software tool to verify the optimum network structure in real distribution network and carry out detailed network calculations. These three supply areas are called pilot areas.

Figure 9 shows one pilot area for two different options as an example. In figure 9a the option 1 having 11 kV with open ring structure requires two R/S. For the option 7 based on 22 kV with open ring structure only one R/S is necessary as shown in figure 9b.

Load flow, short-circuit and reliability analysis have been carried out for each option and each pilot area. Based on the bill of quantity the investment cost as well as the operation and maintenance cost have been evaluated.



a) 11 kV Network; Open Ring Structure  
b) 22 kV Network; Open Ring Structure

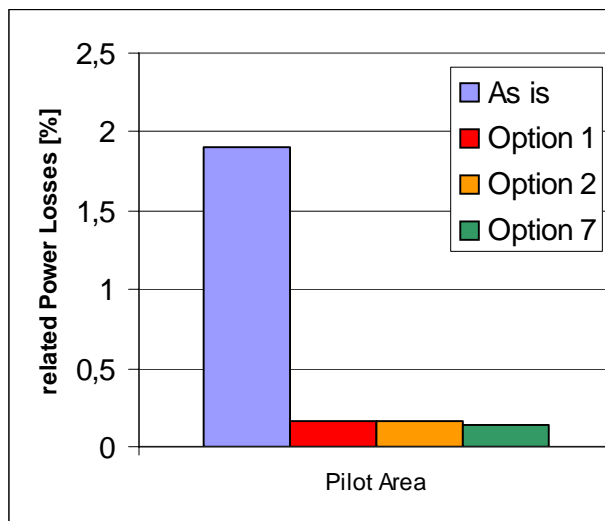


Figure 10 - Comparison of Power Losses related to Maximum Load of the Pilot Area

The results of Greenfield planning were compared with the existing network (As Is). Figure 10 shows for a pilot area the peak power losses of the distribution referred to the total load in the area. The figure indicates clearly that any of the new distribution network structures leads to much lower losses than the existing network structure.

In the pilot area the actual peak power losses are 1.9% of peak load and can be compared to the Greenfield proposals where the losses reach only 0.2%. In other areas the peak power losses of the existing system were between 1.2% and 2.5%. The savings in losses with the restructured network are in the same range as for the given example.

Additionally the reliability of the three investigated options has been analysed. The comparison of non availability in a pilot area has

shown that a reduction to 40 % of the actual level could be achieved. The non availability of 22 kV network is higher in comparison to 11 kV networks in fact of longer feeders.

All proposed long term target structures are technically feasible and the results show benefits to the existing grown network structure. The main statement is that there is an urgent requirement to simplify the network and to apply standard structures. The proposed options guarantee a large degree of flexibility to react to local developments in the future and adjust investment accordingly.

Finally option 2 with 11 kV open lines to R/S has been chosen. Greenfield planning has been applied for the whole REL distribution network. The majority could be handled by the standard structure. In special cases ring structures and remote switching stations have been used for distribution.

Even with a load increase of 50 % to the existing situation the 11 kV cable length could be reduced from 2170 km to 1260 km.

Main figures of the target Greenfield network are:

- No. of Supply Areas 28
- 11 kV Cable Length 1260 km
- 33 kV Cable Length 790 km
- No. of 220/33kV R/S 7
- No. of 33/11kV R/S 51
- No. of 33/11kV Transformers 142
- No. of Ring Main Units 5650

### Superimposition

After the Greenfield investigation the question has to be answered how the existing system can be transformed to the target structure and how much of the existing equipment can be used also in the future. For this purpose a Superimposition has been carried out.

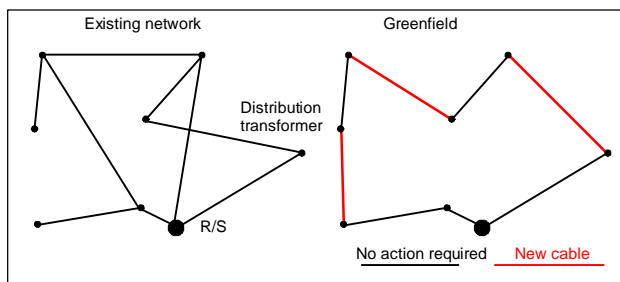


Figure 11 - Principle of Superimposition

For Superimposition a method has been developed to determine those cables which can still be used in the target network structure. For Superimposition only those cables out of existing distribution networks have been taken which interconnect the same nodes directly (see figure 11). In praxis it can be expected that more than these cables can be used due to cables or cable sections which are close to the required route. The determination of optimal routing has to be

done by detailed cable planning including existing equipment as well as age and condition of existing equipment.

As a result of superimposition it can be stated that at least 25% of the existing cables of the 11 kV network can be used for the target structure.

### Cost / Benefit

In comparison to Greenfield analysis the implementation costs have been decreased by taking existing equipment into consideration.

For a cost benefit analysis the investment costs, costs for operation and maintenance and costs for losses have been taken into account. For the continuation of the existing network as well as for the modifications towards Greenfield approach these costs have been evaluated for the next ten years. It can be shown that the curves of the existing network structure and the modifications towards Greenfield approach have a break even point after less then three years.

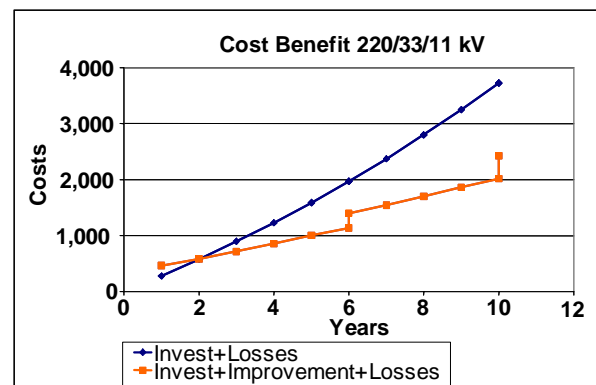


Figure 12 - Cost comparison of As-Is and Proposal

### Conclusion

The existing 220/33/11 kV networks were modeled, calculated with SINCAL® and analyzed. An automatic data transfer from different data sources has been successfully executed. Manual data input has been reduced to a minimum.

The weak point analysis shows bottlenecks of the existing network and immediate measures were derived from load flow and short circuit calculation.

For long term network concept Greenfield and Superimposition analysis offer the possibility to compare different network structures and their effective measures to identify measures to improve system.

The analysis of the existing system with geographic representation showed that the grown 11 kV system is of meshed structure and operated in radial. The losses of the existing distribution system reach 1.5% of the distributed power. In the pilot areas the actual peak power losses are up to 2.5% compared to the Greenfield proposals where the losses reach only 0.2%. The comparison of non availability in a pilot area has shown that a reduction to 40 % could be achieved.

The distribution network with high load growth needs standard structures and the network has to be simplified. Part of the modernization has to be distribution network automation as this will improve operation, network control and respond time to events. On the whole these measures can contribute to ease operation and increase supply reliability, they will reduce losses and assure investment.

The proposed options guarantee a large degree of flexibility to react on local developments in future time and adjust investment accordingly.

Based on the results of the pilot areas and the presented options it will be possible together with directing decisions from REL to provide proposals for one standard solution for the remaining supply areas.

The joint work with external partner guarantees keeping of tight time frame, overcomes problem of manpower involved in daily work and gives critical question and new ideas.