Urban Distribution System Planning in India: A Case Study

Anupam Arya, Kalpesh Chauhan, Sunil Verma, Gopal Gajjar

Abstract--**Planned distribution system is still new in India. A scientifically planned system performs better than and costs less than an unplanned or a system that is planned using traditional thumb rules. With large numbers of urban infrastructure projects coming up, demand of better quality and reliable power to such complexes is on rise. The paper presents a case study of urban power delivery infrastructure planning. The project concerns with planning of power delivery system of a vacant area with very little initial power supply installations. The complete planning procedure and the final plan is discussed in the paper.**

I. INTRODUCTION

A metro city urban development corporation is planning to build an area of about 7.5 Km2 into an urban center. The place will be occupied by residential and commercial complexes and other support structures as schools hospitals temples etc. The area does not have any large industries. The planned area is being marketed as an upmarket residential cum commercial district. The aim of the corporation is to provide a highly reliable power at a reasonable cost. It is envisaged that the corporation would build the distribution system and hand over the operation and maintenance responsibility to the state electricity board at the end of construction.

Such an infrastructure project requires a time span of more than a decade. A perfect planning, therefore, is required beforehand to have a smooth co-ordinated project execution and for arranging the required resources.

A distribution system was planned according to the above requirements. Utmost care was taken to incorporate high reliability ease of construction better maintainability and above all least cost. The two major planning criteria were defined as 1) High reliability and 2) Low cost.

The following sections discuss in details the methods employed to reach the final design.

II. METHODLOGY

The basic steps involved in distribution planning are load forecasting, substation planning and feeder layout planning. The substation planning and feeder layout planning are listed separately, but they are more or less interrelated tasks. The whole planning procedure revolves around these two steps.

Anupam Arya , Kalpesh Chauhan , Sunil Verma , Gopal Gajjar
ABB India, Ltd. Maneja, Vadodara 390013
Email- anupam.arya@in.abb.com

Many runs are made through the substation planning and feeder layout planning during the planning procedure. Moving iteratively towards the planning goals like capacity utilization, voltage drop, reliability and the most important of them the cost reduction.

We begin the planning by load forecasting.

A. Load Forecasting

The load forecasting is first and major step towards distribution system planning. The distribution planning require a forecast which gives how much as well as where the load would grow. This is useful in feeder layout and substation locations.

Two type of load forecast was performed for the given area. One method forecast the total expected maximum demand of the whole area. It is known as global load forecast. As the distribution system is to be planned for the area where none existed before, the load trending with help of past load demand cannot be applied. Under this condition the load trends of similar neighbouring areas were used. Consideration was given to the fact that this area is going to reside the people with higher income with larger energy demands. It was estimated that final maximum demand of the area would be 150MW, at 20MW/KM2

Only global load forecast does not serve the purpose of distribution system planning. It only acts as guideline while doing details calculations, to keep the final load in focus.

A better load forecasting can be done using land-use method [1]. The complete area is divided into many small areas, each area being identified from the plot areas given the civil planning maps. These areas are classified according to their land-use into residential, commercial, public utility and social facility. Each customer class differs in how and when they use electricity.

The connected electrical devices of each customer depend on the buildup area of each one. In absence of other details it is reasonable to assume a linear relationship between buildup area and the connected load of each customer. In the present study, the linear coefficient of connected loads are taken is 150 watts/m^2 for commercial customers and 75 watts/m^2 for residential, social facility and public utility customers. These values were reached at by comparison of similar values for neighbouring area.

While there can be large connected loads at each customers, all the connected loads are not switched on at a time, hence the maximum demand of each customer is very small compared to the connected load. A term demand factor is defined as the ratio of actual maximum demand to the connected load. Two demand factors were defined for the study. The demand factor for commercial class customers was taken as 0.6, and that for residential class customers was taken as 0.4. The commercial class customers have a higher demand factor, because they have similar kind of type of demand throughout the day, and they try to utilize most of their connected equipment.

The individual maximum demands of each customer on plot wise basis are determined by this method. The load details once obtained are reviewed for any discrepancy, like any plot giving unrealistic load levels. The method based purely on buildup area is gives higher loads on social facilities like schools and hospitals, the load levels of such plots has to be rationalized based on practically observed levels.

The total maximum demand of the area was calculated from the individual maximum demand by applying the diversity factor. The diversity factor is the sum of individual maximum demands of a group to the observed peak demand of the group. The diversity for different levels considered here are [2], between individual users: 2.0, between transformers: 1.4 and between substations: 1.1. Hence, the global diversity factor, product of above three, comes out to be 3.08.

Using the 'bottom up' approach the expected maximum demand is calculated using the demand factor and the diversity factor as above. This forecast is then compared to the earlier estimate made through global load forecast. The total maximum demand forecasted through this method comes out to be 136 MW, at 18.13 MW/Km^2. This forecast is used for all the further studies.

B. Substation planning

A good distribution system plan rests of shoulder of a perfect substation planning. The substation planning starts from selection of voltage levels for secondary and primary distributions. The voltage selection was made with consideration of factors like load density, load reach required, type of substations required and the general practice of the state electricity board. The higher load density requires that higher secondary distribution voltage like 66 kV is preferred, to reduce the long-term distribution losses. But as, it was required to have indoor substations and the normal practice of the state electricity was to have secondary distribution of 33 kV, it was decided that secondary distribution level would be 33 kV. The primary voltage levels of 11 kV and the utilization voltage of 415 V were selected.

So, two types of substations are required to be planned 1) secondary distribution substation of 33 kV/ 11 kV. and 2) primary distribution substations of 11 kV/ 440 V.

The substation planning includes decision on 1) the number of substation required, 2) the MVA capacity of each substation, 3) the number as capacity of transformers at each substation and 4) the location of each substation.

Determination of number of substations is an economic conflict between substation size and feeder layout. A large size substation would require lesser numbers of substations, and hence less space. But at the same time it would mean long lower voltage feeder runs. In underground cable networks the long feeder length prove very costly, from point of view of initial investments as well as long term electrical losses.

The load density map as prepared during load forecasting was used to determine the number, size and locations of the substations. Many different options for numbers of substations were tested on the load density plots, for demand satisfaction, contingency support, reliability, load reach and feeder layouts. For example say option one is to have three substations to cover whole area, next option is to have five substations, and another option is to have seven substations. Then the size and number of transformers for each option are selected. Now each option is tested for the above mentioned criteria. The best among all the tested options was selected in the final plan. Total five numbers of substations were decided. The service area of each substation was selected based on perpendicular bisector rules given in [1].

The size and number of transformers are selected as follows. A small numbers of large size transformers do not provide good flexibility in initial building and future expansion, and large numbers of small size transformers reduces reliability and increases complexities in substation engineering and operations. It was decided that 16 MVA capacity transformers are to be used for 33 kV/11 kV substations. The number of transformers per substation is decided based on load density.

The primary substations have somewhat different planning criteria. The practice in overhead distribution system is to design with smaller capacity of transformer in range of 100 KVA and 200 KVA, and single transformer (usually pole mounted) per substation. But in underground system, due to unavailability of space to build indoor substations, larger capacity transformers are utilized and many times a substation have more than one transformer. 630 KVA and 500 KVA transformers were selected for 11 kV/440 V substations. The primary substations are designed to be very simple in construction, and operation. So the primary transformers don't have any tap changers for secondary voltage regulation. The voltage rating of 11 kV/440 Volts was selected so that the customer at the farthest end also receives power within the standard declared voltage range. Most of the design was made with two transformers per substations, for economic and reliability reasons.

The procedure for substation design is difficult to describe in formal mathematical way. Many similar designs can be found out which satisfy most of the design criteria, the selection of best design is more of an art then science. The method progresses in iterative manner. A given design is checked for all the criteria one by one and the design is improved in steps.

The final accepted design is with five secondary substations with total installed capacity of 224 MVA, with total of 14 numbers of 16 MVA transformers.

The electrical layout and transformer connections were selected so as to provide good balance between flexibility of operation and cost of installation. Fig. 1 gives electrical layout of 33 kV/11 kV substation.

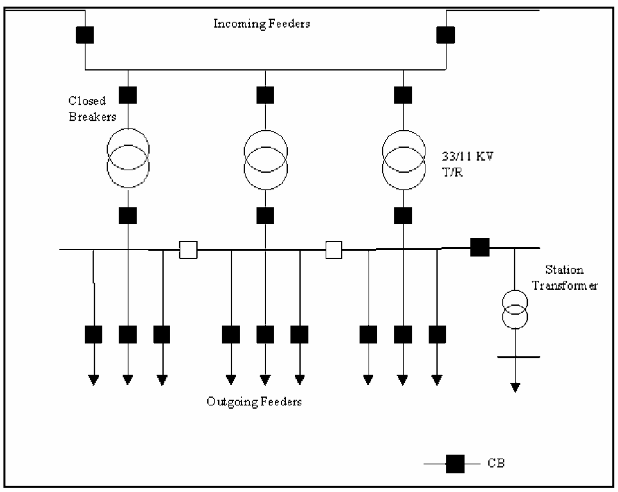

Fig. 1. Electrical Layout of 33 kV/11KV Substation

C. Feeder Planning

The feeder design involves, decision on type of construction, topology, size of conductors and routing of the conductors. The feeder design is highly influenced by size and locations of substation. Feeder design in turn influence operation, maintenance and reliability of the system. Most of the system losses occur in the feeder system, hence there is a great opportunity to control and reduce, within economically possible level, the electrical losses.

Underground cable distribution was selected, considering higher reliability requirements. Moreover, Hume pipes and underground cable trenches were selected for 33 kV and 11 kV cable. The 415 V primary distribution was done through direct buried underground cable. Cable trenches give better esthetics and reduces possibility of dig-in faults.

The 33 kV and 11 kV secondary distribution is done through loop feeder topology, as shown in Fig. 2. 33 kV cables form a ring that loops over all the secondary substations. Similar rings were adopted for 11 kV cables also. Each primary substation is feed from two independent cables running on different paths. The operation of these 11 kV rings is in open condition. At any given time all the primary substation receive power from a single feeder, but in case of contingency there is provision of receiving power from alternate feed. The switching operation required for rerouting the power from alternate paths are quite simple and fast, hence customer outage time is very small. It can be said that secondary feeders are built as rings but operated as radial feeders.

SF_6 insulated Ring Main Units (RMU) specially designed for protection and switching operations of underground cable rings are used for protection of 11 kV rings. The RMUs are used for terminating 11 kV cables to provide tapping for 11 kV/ 440 V transformers. Compact size, safety and modular design makes RMU ideally suited for indoor type primary substations. Its communication capability helps for SCADA installations in the distribution system, for remote monitoring and control.

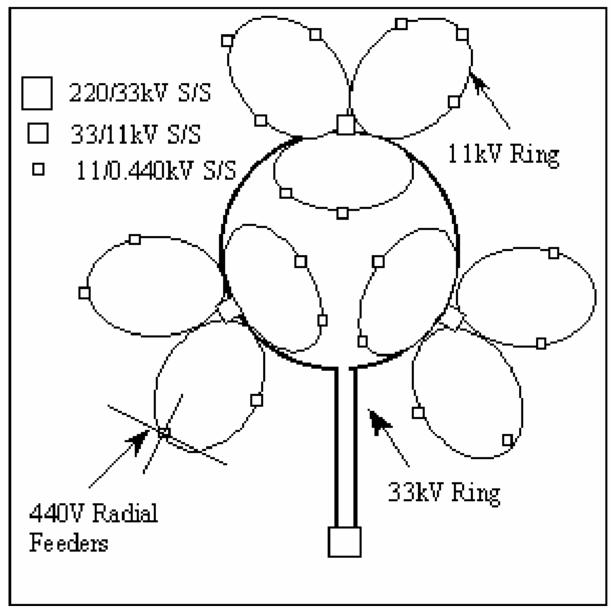

Fig. 2. 33 kV and 11 kV rings

The conductor selection was based on cost economics and losses. It was tried to balance the cost of cables against the long-term profit that can be obtained form low feeder losses. The cable size was also selected such that full utilization of ring topology can be made. A cable should be able to feed the total load of a ring even when it is supplied from a single side. The voltage drop in the cable should also be maintained within limit even under the contingency conditions.

The primary feeders of 415 V levels are arranged in radial topology, with many interconnection points between neighbouring feeders at different locations. This gives meshed topology nature, even though the supply at any time is through single path only. The supply restoration time during 415 V cable faults can be reduced to just the time taken for couple of switching operations. Once the faulty cable is located, this time can be as small as ten minutes.

Finally the cable routing was done based on the civil layout maps. Complete network was planned along roads and pathways. Such routes were selected for each cable, such that the trench length required for the system is minimized.

With this the basic planning of the distribution is over, the measures taken for having higher reliability are discussed in the next section.

III. CONTINGENCY PLANNING

The aim of contingency planning is to prevent consumers from affects of electrical equipment failures. Electrical outages occur due to various reasons including planned maintenance. The electricity supply of the end consumer should not be cut by any of the electrical outages.

Having cable trenches and ducts helps in preventing the usual dig-in faults in the cable networks. Most of the contingency problems of substation can be solved by having spare capacities in transformers and good circuit breaker arrangements. A regular maintenance reduces possibilities of surprise faults in substation equipment. A design with enough contingency support simplifies the maintenance procedures. The above steps only reduce number of outages. Inclusion of proper automation in substation and feeders reduce the customer outage duration. The communicable RMUs used in feeders and SCADA for all secondary and primary substations are suggested for complete automations.

IV. DESIGN VALIDATION

The basic system once designed has to be validated through power system analysis. The usual distribution system analyses include load flow, short circuit, and contingency analysis. All the above analyses were performed on the system using software designed by ABB, CALPOS. The software facilitates distribution system analysis through useful GUI that allows a background map. Exact representation of network with line lengths, and accurate line impedance can be made on the map. The load flow analysis and other analyses can be performed, with geographical context. CALPOS also have special facility for clubbing loads in different network groups. Each network group can be assigned different diversity factor. This gives the user huge flexibility to run the load flow under various scenarios, to check the design thoroughly.

For load flow analysis, individual consumers at each plot were modeled and constant power load model was considered. The individual constant power factor was taken as 0.85 lagging. It was assumed that all the 33 kV/11 kV transformers were operated at their nominal tap ratio. Appropriate maximum current rating for cables were taken as per general practice recommended by cable manufacturers. The ONAN transformer MVA rating was considered.

The global diversity factor of three was applied to the system while analyzing for the base case. The base condition describe the system with all the load connected and all equipment in service is healthy condition. The analysis was performed at peak load condition, when there is highest possibility of equipment load going beyond limit, and high voltage drop in feeders.

The result obtained shows that, under base condition, every equipment i.e. transformer and cable is loaded below 80 % of its rated capacity. The worst voltage drop is 4.5 % of the declared voltage to consumer 415 V. This is within the limits prescribed in the Indian electricity rules, 1956.

Fig. 3 shows the voltage at each 11 kV bus, under base condition. There are 304 busses of 11kV level. The busses are arranged in descending order of the voltage as reported in load flow studies. The upper line shows voltage during 90 % peak load and the lower line shows the voltage during 110 %

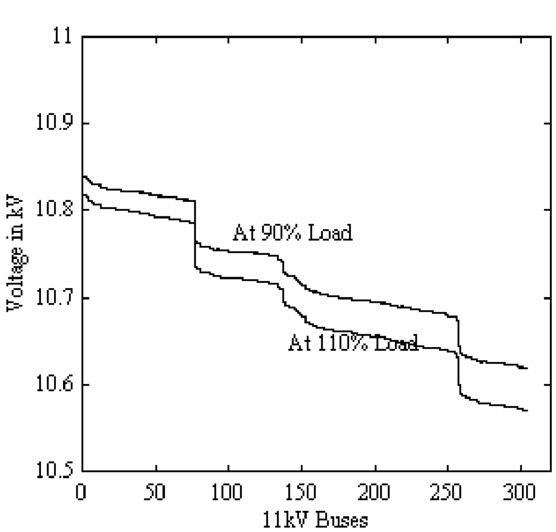

Fig. 3 Voltage profile of 11 kV buses

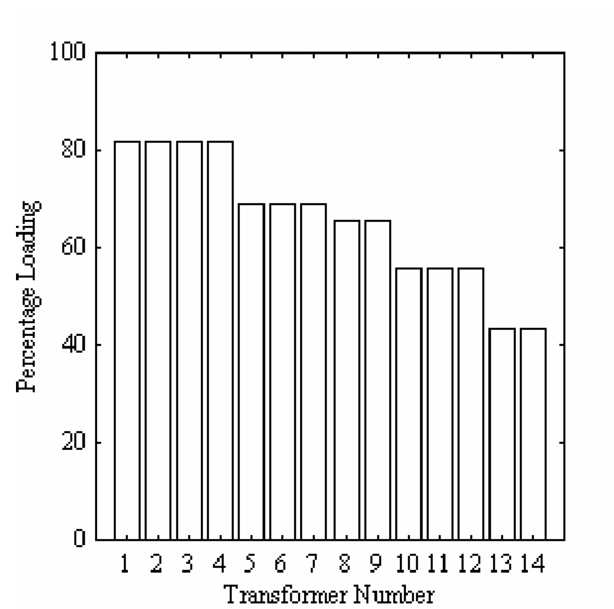

Fig. 4 33 kV/11 kV transformer loading

of peak load condition. The voltage fluctuations between peak load and off peak load is below 0.45 %, i.e. 50 V. The steps in the voltage profile are due to groups of busses under different 33 kV/11 kV substations. All the 11 kV buses falling under a single substation will have only small difference in their voltage, corresponding to the drop in 11 kV cables. But the primary voltage i.e. at 33 kV side of the transformers at different substation is not same, thus forming groups of 11 kV busses according to their corresponding substations. The loading condition of 33 kV/11 kV transformers under peak demand condition is shown in Fig. 4. It is a bar chart showing the loading of each of 14 transformer in descending order. It can be seen that the peak loading is about 80 %, providing ample spare capacity for contingency condition. The system losses under base case condition were about 3 % of the load served.

The system was tested for various contingencies like failure of a transformer in a substation, or breakdown of a 33 kV and 11 kV cable. It was found that the worst case overloading of a transformer was 110 %. The maximum cable loading was 98.5 %.

The short circuit studies were also performed to check the short circuit ratings of cables and substation equipment.

The accuracy of load flow result depends on the details up to which the system is modeled. It was not considered prudent that we model the system up to level of service main. Yet with modeling of 415 V level up to each load group of 20 KW, the results can be considered as benchmarks against which the actual system performance should be judged.

V. CONCLUSION

A state of the art system has been designed to provide the consumers good quality and highly reliable power supply. The system has been planned systematically taking into consideration the electricity consumption pattern of the consumers it serves. The design is fully validated using sophisticated tools like CALPOS. Finally it can be said that the planned system provide for low system losses, good voltage profile and high reliability at reasonable cost, through proper planning.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

[1] H.L.Willis, “Power distribution planning reference book”, Marcel Dekker, Inc. 1997.

[2] Donald G. Fink and H. Wayne Beaty, “Standard handbook for electrical engineers”, McGraw-Hill, Inc. 1987