A PLANNING APPROACH FOR URBAN DISTRIBUTION NETWORKS IN BAHRAIN

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SUMMARY

Electricity consumption in Bahrain has experienced growth in excess of 100% over the past decade. This, along with forecasted continued development, has led to the necessity for a strategic, long term distribution network plan. The primarily urbanised distribution system in Bahrain must be able to provide for rapid future expansion periods, as well as cater for load growth in established, mature areas. This paper focuses on the planning approach taken to ensure the Distribution System Development Plan meets rising energy demands, supports economic and land development strategies in Bahrain and optimises existing infrastructure. Challenges facing network planners in Bahrain are also highlighted. The Plan is intended to guide short term developments to be in line with the strategic long term ultimate network, while maintaining appropriate standards at least economic cost.

Keywords: Distribution Planning - Spatial load forecast - PSS®Sincal

1. INTRODUCTION

Bahrain has experienced high socio-economic growth over the past decade with GDP increase in excess of 6% per annum in the past five years. An Economic Vision for 2030 [1] and an associated land development strategy [2] for Bahrain have been established, to ensure continued progress and rate of growth. In Bahrain, there are currently five generation stations with a total installed capacity of approximately 2.9 GW. As a result of economic and population increase, electricity consumption has also experienced continuous growth over the past decade from an annual peak load of 1,216 MW in 1999 to 2,438 MW in 2009, as shown in Figure 1 [3].

The electricity demand in GCC countries has increased at a rate of three times the global average over the past few years [4]. A forecast of a continued rise in power consumption in Bahrain has been the driving force behind the requirement to develop an ultimate electricity network plan. The current reserve margin of 19% is not expected to meet anticipated demand. The Kingdom of Bahrain Electricity and Water Authority (EWA) are currently planning for generation and transmission expansion through the development of additional generating units and commissioning of new electricity infrastructure. The developed and primarily urbanised distribution network, which is operated at 11kV, must also be able to cater for rapid future...
expansion phases while maintaining appropriate standards at least economic cost. To date, the expansion of the distribution network in Bahrain has primarily been in response to the rapidly growing supply demands. New infrastructure in the distribution network must not only be responsive to growth in the existing network but must also be driven by future developments and network strengthening to improve performance.

Network planners in Bahrain face challenges as the load is continuing to grow. As a result, equipment utilisation rates are high, contingency capability is in short supply and sites are limited in well developed areas. Anticipated growth in greenfield areas is currently not served, hence addition to, or extension of, the network must be built to meet forecasted load. Often short term plans require greater network re-enforcement to support contingency and/or overloaded existing network under normal conditions.

Mutually re-inforcing existing network, while supplying new loads, however increases complexity and requires flexibility in configuration and operation. Lead times and cost additionally drive the requirement for accurate and orderly development of the network. Network modelling and simulation are essential to ensure technical and economic viability. The network will evolve gradually, through addition and reconfiguration, until it reaches its end state as forecast in the ultimate spatial load study, to form a reliable, optimum network to cater for anticipated redevelopment. Therefore, short term plans must also be in line with the ultimate network development.

2. PLANNING OVERVIEW

The evolution of a distribution power system comprises a number of stages of development, as shown in Figure 2.

Although capacity, security and quality/efficiency of supply are of concern throughout the development of a system, the focus shifts over time. In the early stages of rapid load growth, the priority is to build sufficient capacity to meet the load demands. Following establishment of the network and loads, security of supply becomes a critical factor. Once the system has matured, the focus is on optimization in terms of supply quality and efficiency.

The planning process in Bahrain, along with many other GCC countries [5], must cater for greenfield planning, often in areas of reclaimed land, or previously undeveloped regions, along with economical upgrade of established distribution systems. Areas with mature networks do not offer the same flexibility and scalability for development of the distribution system, as areas where there is no existing infrastructure. Expansion of the network requires balancing capacity, availability, quality and cost with impact on the system [6].
Establishment of a Distribution System Development Plan aims to meet rising energy demands and to support the economic and land development strategies.

This plan is compiled in line with current generation and transmission expansion plans. As well as providing supplies to new loads, identified in an ultimate spatial load forecast, the plan must also serve to improve and to make best use of existing infrastructure. It is also driven by performance standards for the system and standard plant sizes and loading policy. An overview of the planning approach is illustrated in Figure 3.

2.1 Data Collection & Analysis
As a prerequisite to the planning function, a significant amount of data is collated and analysed. This includes data from the SCADA electrical database system in Bahrain, historical load and outage records, along with site survey information. For planning purposes, it is also necessary to have a geographical representation of the electrical network, along with a map of the country including the locations of roads and buildings, both existing and planned, from the GIS system in place in Bahrain.

2.2 Overview of Existing Network
Figure 4 provides an overview of the electricity system structure in Bahrain.

Organisationally, the distribution interface lies at the 11kV outlets from the 66/11kV substations. The 11kV distribution system is designed and operated as a radial system, with open loops. 11kV feeders are connected to 11kV busbars of primary substations, the majority of which have a voltage transformation ratio of 66/11.5kV.

In general, 11kV feeders are interconnected on the 11kV networks, through 11kV ring main unit type switchgear. In addition, switching stations are utilised at the 11kV voltage level and large customers are fed by express feeders at 11kV. The system typical single line diagram is shown in Figure 5.

There are currently approximately 5,500 11kV/LV substations on the Bahrain distribution system. The majority of these contain one 11kV/LV transformer however a small number contain between two to four transformers. Over three quarters of the 11kV/LV transformers have a rating of 1,000kVA with the remaining transformers ranging from 300 to 1,600kVA.

2.3 Distribution Review
The initial step in the planning process is to assess and document the state of the existing distribution network. The general review included aspects of system performance, equipment loading, operation procedures, plant data, design and planning. The outcomes of the review are used to evaluate the existing systems in place and recommend necessary improvements.

2.4 Analysis of Existing Network
In conjunction with the review an analysis on the existing network is carried out. A system model of the Bahrain distribution network is developed in the network calculation software package PSS®Sinca. The model is based on network topology and collected data, for example, peak load demands, historical load data for the calculation of growth rates, as well as a geographical
representation of the network incorporating known future developments.

The model provides an accurate picture of the existing loading conditions on the 11kV distribution circuits and 66/11kV primary transformers. Network calculations include load flow and contingency analysis and results allow for the identification of weak points in the networks and assessment of the primary substation transformer loadings under different network operating conditions. In order to perform this function the model includes details on all 11kV and 66kV substations and transformer ratings on the network. The 11kV cables and overhead lines are also modelled in detail. Measured peak load readings from the SCADA system are used to assign loads to the individual 11kV substations. The network model forms the starting point for the short term planning function.

3. PLANNING STANDARDS AND CRITERIA

For this project performance targets and quality of supply criteria are developed. In order to ensure effective, safe, reliable and economical development of the network, both in the short and long term, it is necessary to define planning criteria. Customer service performance standards define and specify the quality of service to be provided to customers who take supply from the 11kV primary distribution system.

These performance standards, in accordance with international standards [7-8] and practices [9-10], which are developed specifically for the Bahrain distribution system, are as follows:

- Voltage
- Service Reliability (Continuity)
- Rapid Voltage Changes
- Lamp Flicker
- Harmonic Voltages
- Supply Voltage Unbalance

For each of the six customer service performance standards the following is specified; values, maximum permitted measures, control, and monitoring procedures. The criteria and standards are established to unify the distribution system design practice through the development of a common understanding of the concepts, techniques and procedures employed. The developed criteria, in line with international practice and standards, are to be used in the development, review, approval and implementation of 11kV network designs.

For utilities, reliability of supply is one of the key indicators by which performance is measured and also by which investment in network improvements is decided [11-12]. For this reason benchmarking of the reliability of supply against other utilities is important. This will enable EWA to monitor performance and improvements achieved, against a set of agreed and consistent standards and measurement methodologies on a year on year basis. Reliability is dependent on both inherent and inherited factors, such as circuit length, proportion of overhead line, customer density, etc. The Bahrain distribution system consists of both new and ageing networks, therefore, as part of the establishment of the planning standards and criteria, performance indicators for both new and existing networks are specified.

4. ULTIMATE SPATIAL LOAD FORECAST

4.1 Ultimate Land Use

The development of the 11kV distribution system proceeds in small increments, each of which must be consistent with the eventual development of the system. This is achieved by first designing the distribution system which will serve the demands expected when the land in consideration is fully developed, and then making sure that every incremental development is consistent with this design.

The magnitudes and locations of future loads are identified in an ultimate spatial load forecast in conjunction with an ultimate land use forecast. The ultimate land use forecast aims to forecast land use, changes in zoning and predict customer end usage of electricity and hence determine the demand density which is expected to eventually exist. The timescale of this is as far into the future as reasonable estimates can be made. For this work, the ultimate land use forecast is derived from the 2030 land development strategy.

To assist with the process of forecasting future demand, load profiles and diversity factors are estimated for typical load classes, for example residential, commercial and industrial. In this project, the calculation of load density factors is influenced by the presence of significant air conditioning load in residential and commercial developments.

A spatial load forecast is carried out to allocate load growth to specific locations. Load trending techniques, based on historical load data, are used in conjunction with future developments where the location, size and date of completion are known.

4.2 Ultimate Network

Knowledge of both position and degree of future load supports strategic long term planning needs. It allows for studies to be carried out to identify the optimum location of new 66/11kV primary substations. Early identification of future primary substation sites assists
with the development of a site acquisition programme to secure the necessary sites and to reserve cable routes 5 to 10 years in advance of the start of construction. This is of particular importance in Bahrain where much of the north of the country is urbanized and the availability of suitable sites is limited. Optimal substation placement will reduce the risk of stranded assets and attendant increased costs.

6. SHORT TERM PLANNING

Along with a general overview of the task of long term distribution planning, detailed short term planning procedures must be carried out. Short term planning (0-3 years) requires network modelling and simulation. Simulations are carried out using a sectional assessment method in PSS®Sincal. Simulations allow for scenario analysis to assess the impact of load shifting and network reconfiguration to support defined performance criteria targets.

The short term plan should balance load growth with infrastructure replacement and reliability improvement. Integrating the planning across the voltage levels, particularly 66kV and 11kV is essential and knowledge of the infeeds from the transmission plan (location, magnitude etc.) is included.

Due to a shortage of available land in the north of Bahrain, network expansion plans must optimise the use of the existing network, while ensuring that new network infrastructure is strategically placed for maximum benefit. Weaknesses in the existing network, as identified through system studies detailed previously, must be addressed. Economically justifiable solutions to improve the existing network performance are investigated while catering for a future increase in system demand. Where feasible maximum overloaded primaries are alleviated first. Overloaded feeders, rate of growth (based on historical data), reliability and type of switchgear are furthermore considered. In Bahrain network structure, cable sizing and maximum loading are assigned a priority. Short term plans are required to meet new planning targets and meet N-1 criterion.

Resulting from the rapid growth in Bahrain in recent times, equipment utilisation rates are near or exceeding 100% in ageing areas. Under contingency, each primary substation must be supported by its neighbouring substations, and these substations must have adequate margins of capacity to accept the additional load, without exceeding equipment ratings. The planning process therefore, often requires more robust and extensive interconnection of network. Network performance in mature areas is improved by making maximum use of equipment and ensuring high reliability by careful configuring and flexible interconnection.

Figure 6 illustrates an area of the Bahrain distribution network which has been overlaid on the zoning map of the area. Known new developments are also indicated on this zoning map. A new development is planned for the area with an ultimate load forecast of 20 MVA. The utilisation rates of primary substations A and B are currently approaching their firm capacity and hence the forecasted ultimate load necessitates a new primary substation in the area to meet this load.

Figure 7 illustrates the same section of network as represented in the PSS®Sincal software. A load flow analysis indicates that under standby feeding conditions certain 11kV cables have exceeded their thermal ratings. As such, any developments to the distribution network should aim to supply the new development, while also relieving the existing overloads on the networks.

The area is planned with the addition of the new primary substation C as shown in Figure 8. This new primary substation feeds the new load but additionally supports the existing primary substations, while relieving the overloads. Operating flexibility and configuration of this newly integrated network is critical to reliability.
7. EXPECTED RESULTS

Upon completion of the Distribution System Development Plan it is expected that the distribution system will evolve in an efficient and economical manner in line with defined standards and criteria. The distribution system must at all times have adequate capacity, security of supply and quality/efficiency. Monitoring of customer service performance standards, particularly performance indicators, permits quantitative analysis of reinforcement alternatives for short term planning [13]. Reliability improvement to meet newly defined performance indicators may warrant replacement of ageing equipment and/or proactive ageing cable replacement forming part of a strategic investment plan. The outcome of the ultimate spatial load forecast assists in planning for the ultimate network and site acquisition and right of way (ROW) are attained in a timely and economical manner. Network planning in Bahrain however, remains challenging as major new developments may not proceed or exact location and timing may be unknown.

8. CONCLUSIONS

Socio-economic factors, rising energy demands and anticipated energy intensive developments in Bahrain have driven the need for a Distribution System Development Plan. The plan ensures that network augmentation and/or expansion is in line with best practices. Strategic distribution planning for increased reliability, while maintaining minimum standards at least economic cost, can prove challenging. This paper outlines the planning approach for Bahrain’s distribution system required to develop the distribution network to meet the ultimate development vision. Short term planning must meet service demand requirements, while long term vision and network performance must adhere to planning criteria and design standards. Network modelling and simulations ensure best practice planning is implemented so that proposals are in accordance with medium and long term plans.

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REFERENCES