A Technique for Evaluating the Reliability Improvement due to Energy Storage Systems

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***Abstract*—Energy Storage Systems (ESS) can be employed to improve the reliability of power supply at isolated rural locations supplied by long radial networks. This study presents a Monte Carlo simulation based method for assessing the reliability improvement potential of such an ESS. The proposed methodology can be used to establish the proper power rating and storage duration to achieve a given reliability objective. The paper examines a case study for a rural community in Manitoba and establishes the relationship between the expected values of reliability indices and the energy storage duration. The results of the simulation demonstrate the improvement of reliability of power supply with the addition of an ESS located at the remote substation. However, according to ESS cost data published in literature, the proposed option may not still be economically feasible.**

Keywords- Energy Storage System; Supply reliability

I. INTRODUCTION

Some rural customers supplied by long radial sub-transmission lines in Manitoba experience a higher frequency and longer duration of interruptions as compared to customers on other parts of the integrated grid. The electricity interruptions arise from the outages on the long sub-transmission lines supplying isolated rural substations. Some of theses sub-transmission lines run through terrains that are accessible only through air or seasonal roads, and therefore repair is difficult and time consuming. Improving the reliability of power supply at these remote locations by strengthening the distribution grid, for example by constructing alternative lines is expensive and often subjected to opposition due to environmental concerns. Diesel based back-up power generation may be attractive despite fuel transportation and maintenance problems due to low capital cost (C$3.5 million for 10 MW). An alternative to this would be to introduce Energy Storage Systems (ESSs) at remote load centers.

Technology for electrical energy storage is rapidly maturing. Several energy storage technologies such as Battery Energy Storage Systems (BESS) and Flywheel Energy Storage Systems [FESS] are now commercially available. Also a number of large-scale ESSs have been practically implemented [1]. In addition to reliability improvement, ESSs can contribute to improve the dynamic stability, transient stability, voltage stability, frequency regulation and power quality [2] [3].

The technical planning of an ESS involves the selection of optimal power rating and storage duration to achieve a given reliability objective. The process often requires a method to quantify the reliability improvement resulting from a given ESS. This study presents a Monte Carlo simulation based method for assessing the reliability improvement potential of an ESS located at the remote end of a sub-transmission line. The following sections of this paper present the proposed approach through a case study. The simulation results and references [1], [3] and [4] were used to identify energy storage technologies suitable for the application. The scope of this paper is limited to establish a method for sizing the energy storage system. The viability of using ESS for reliability improvement applications is ultimately determined by the associated cost, which is not discussed in this paper.

II. RELIABILITY ASSESSMENT METHODOLOGY

The approach used in this paper involves four steps. The first step is to analyze the historical records of line operation to extract the Cumulative Distribution Functions (CDFs) of "Time between Outages" (TbO) and "Repair Time" (RT). These CDFs are used to create a simple two-state, state transition model for the line availability. The next step is to analyze the historical records of load demand and forecast the future load growth over the considered planning period. The third step is to consider various amounts of ESS. The last step is to run an hour by hour Monte Carlo simulation over the planning period and calculate the reliability indices.

In this paper, System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are used to quantify the reliability. These are the indices used by the Manitoba Hydro, the utility serving the studied area. Currently Manitoba Hydro attempts to maintain SAIDI below 92 minutes/customer/year and SAIFI below 1.3 events/customer/year [5]. Although the term "System" in SAIFI and SAIDI refers to the entire customer base of the utility, the same indices can be used to express the reliability of a given feeder or subsystem, when calculated over the customer base served by the feeder [6].

III. REMOTE SUBSTATION

The substation considered in the study has a 9 MVA capacity and is fed by a 275 km long, 66 kV, radial sub-transmission system. The overhead lines run through dense forest, many swamp lands, rivers and lakes. The major causes of line outages are fallen trees, lightning, and faulty insulators.

A. Analysis of Line Outages

Information gathered from the Breaker Operations Reports for the sub-transmission lines during the last nine years (1997-

2005) were analyzed to extract the CDFs of TbO and RT for the system being studied. Fig. 1 shows the distribution of outage events over different months of the year. Two distinct seasons in terms of the frequency of outages were clearly visible: the period from May to September ('summer period') where there were an abundance of outages and the period from October to April ('winter period') where there were few outages. Since the differences were significant, different CDFs were studied for the summer and winter seasons.

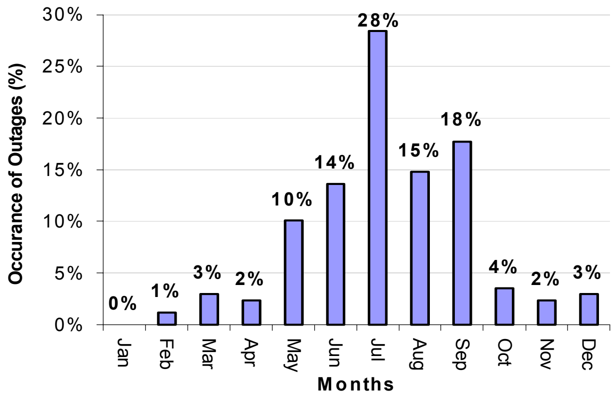

Figure 1. Outages for the period 1997 – 2005

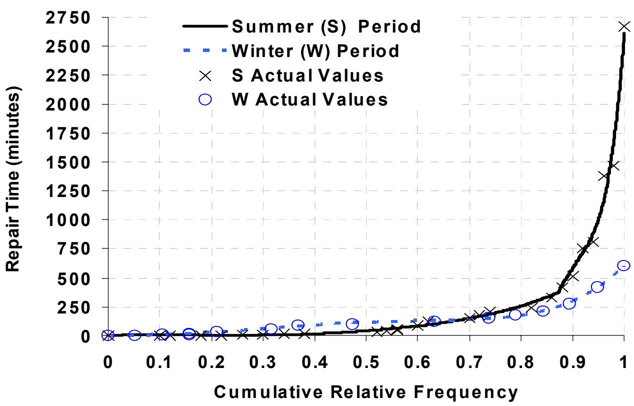

Figure 2. Repair Time (RT)

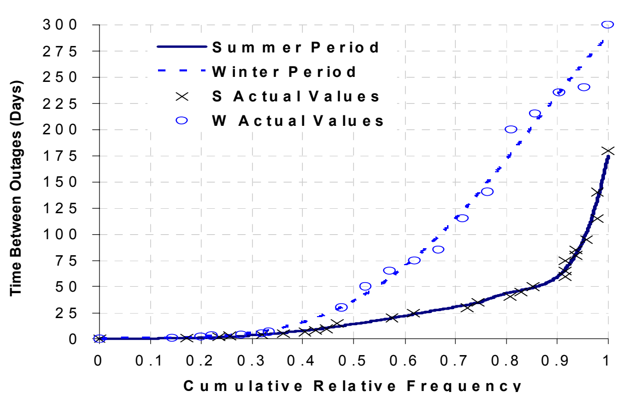

Figure 3. Time btween Outages (TbO)

Figs. 2 and 3 show the cumulative relative frequency distributions obtained for RT and TbO respectively. Polynomial equations fitted to these curves were used to represent these CDFs in Monte Carlo simulations.

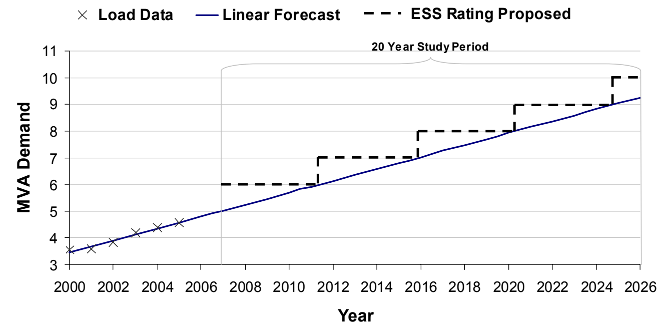

Figure 4. Forecast of Annual Peak Load Demand

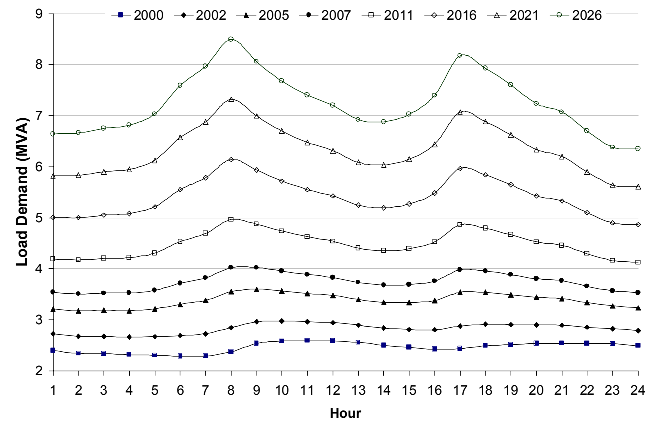

Figure 5. Forecast of Daily Load Profile for January

B. *Load Forecast*

Historical load data for the period from 2000 to 2005 was used to forecast the annual peak demand and the hourly load demands over the 20 year planning period. The load forecast assumed a linear load growth as it seemed to be the most reasonable fit for the historical data. Fig. 4 shows the forecast of peak demand and Fig. 5 shows the change of the daily load curve for the month of January. Similar forecasts were made for all other months.

IV. ENERGY STORAGE SYSTEM

A. *ESS Power Rating*

The ESS considered in this application was to support the total load supplied by the substation when the grid power is lost. Thus its power rating should always be greater than the forecasted peak load demand. Most ESSs are available in modular form and therefore it is possible to increase the capacity of ESS incrementally as the load grows. As illustrated in Fig. 4, the ESS capacity can be added in steps. The intervals at which the capacity is added can be decided based on the type of energy storage technology used. For example, if battery energy storage is used, the capacity expansion can be timed to coincide with the replacement of the existing batteries. Since