UTILISATION OF ENERGY STORAGES TO SECURE ELECTRICITY SUPPLY IN ELECTRICITY DISTRIBUTION NETWORKS

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ABSTRACT

Energy storage system technologies have been developed within the recent years. The energy capacity of the storages has been increased and also more power can be discharged from the storages. The development has opened new possibilities to utilise energy storages. The technical success has been the key factor but also falling prices of energy storages increase interest in storage applications. Thus, there is a demand to develop methodology to assess benefits of energy storages. This paper presents a method to analyse the benefits of energy storages in reduction of interruptions experienced by electricity end-users. The methodology is based on Monte Carlo simulation modelling reliability of distribution system.

INTRODUCTION

Significance of energy storages on electricity distribution systems is rising. Energy storages can be installed in network for several reasons [1], [2], such as levelling of the peak hours in consumption, levelling of the fluctuating production or to secure electricity supply when the primary supply chain, the distribution network, is cut off in consequence of a fault. This network reliability point of view has not been studied widely, and thus, it is investigated in this paper.

Reliability is a current issue in the electricity distribution and there have been a lot of discussion related to options to improve reliability. In Finland typically most of the interruptions are caused by medium-voltage (MV) network (even 90% of all interruptions) that thus interrupts electricity supply of the low-voltage (LV) networks supplied by the faulted MV network even the LV networks would not itself be faulted. This is a common situation in the Finnish distribution networks. For instance, the LV networks can already be cabled underground while the structure of MV network is overhead line, where the fault rates are much higher compared with underground cables. Thus, this supports the analysis of energy storage placement to the electricity distribution system.

When the faults occur in supplying MV network, energy storages provide an opportunity to improve the supply security of the customers. This has been discussed in [3] where the researchers present a Monte Carlo simulation method to assess the reliability improvement potential of energy storages, which are installed in the primary substation to MV network. In this study the storages are planned to be located to LV network, because in Finland faults typically occur in 20 kV medium-voltage network. Thus, installation of energy storages in LV network makes it possible to supply electricity to LV network when MV network is faulted by separating LV and MV networks, and thus, comprising an island network from the LV network. This is illustrated in Figure 1.

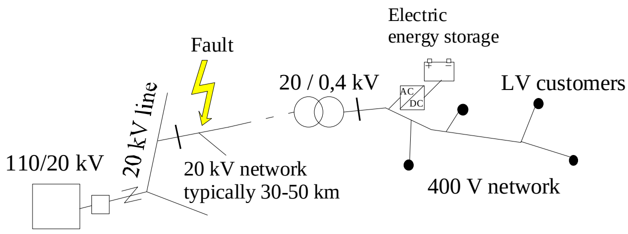

Figure 1. Principle scheme of the distribution network (including both MV and LV networks) to utilise energy storage to supply electricity during the outage in the MV network.

RESEARCH QUESTION AND APPLIED METHODOLOGY

The focus of the paper is on the development of a methodology to assess benefits of energy storages when they are installed in electricity distribution network.

The utilisation of energy storages in the improvement of supply security is approached by network reliability model utilising Monte Carlo simulation method. Figure 2 illustrates the methodology, how the study approaches the utilisation of storages. At first, fault and interruption statistics are analysed to create faulting models for the distribution network. This contains both, the analysis of individual repair times of faults and also fault rates in the specified line circumstances. The statistics are required for the interruption analysis so that reliability of distribution network can be estimated. Also, the network topology has to be modelled to be able to estimate the effect of each line section on the considered customer or substation. For this purpose, an analysis system has been developed to model the network using actual data from network information systems of distribution system operators (DSOs). The methodology takes into account the placement of the switching devices, normally-open switches, type of the switches (manually controlled and remote-controlled), environment of the distribution lines (forest, field and roadside) and types of the lines (bare overhead, covered conductor and underground cable). The methodology of the reliability calculation is discussed more detail in [4] and [5].

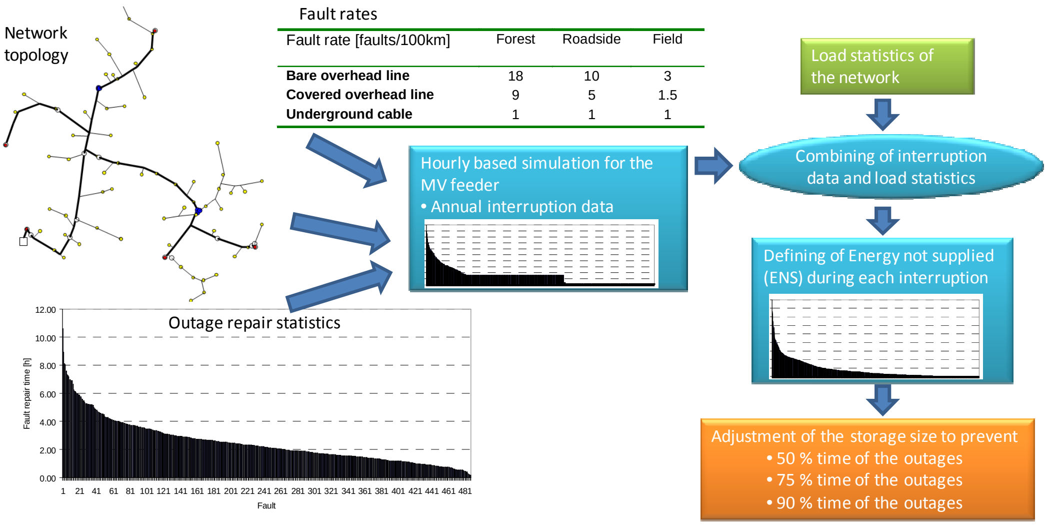

Figure 2. The methodology to analyse the size of installed energy storage.

Modelled network topology and reliability calculation are applied in the stochastic network analysis that is carried out by sequential Monte Carlo simulation process. The simulation contains a significant number of simulation loops of which each describes one year. The simulation process is carried out more precisely in [4] and [6]. The simulation provides interruption duration distribution that plays key role in the study. It comprises all the simulated interruptions of the simulation loops. For instance, if average fault number of the network is statistically two faults per year, in 1000 loop simulation there occur 2000 faults with different locations and durations. After the simulation, the simulated interruption data are compared with load statistics from the simulated network. As a result of the process is a distribution of energy not supplied (ENS), which shows the not supplied energy of each simulated interruption.

The ENS distribution is required for the analysis to estimate the potential of energy storages to prevent distribution outages. In the study it has been assumed that the interruptions are independent, which thus means that each interruption can be handled separately. The capacity of energy storage can be compared with the ENS during each interruption, which defines the potential to reduce interruptions. The study provides information for the sizing of the energy storage in the analysed network. A result can be an estimation of the storage size, which provides, for instance, 50 % reduction in number of customer experienced interruptions.

INITIAL DATA FOR ANALYSIS

The analysis requires a lot of data as it has been described in the previous methodology chapter and Figure 2. Fault statistics are important for the reliability analysis. Figure 3 presents a distribution of fault repair times in a Finnish electricity rural area distribution company that is utilised in the reliability analysis. The data consists of over 5000 fault events that have been gathered during several years.

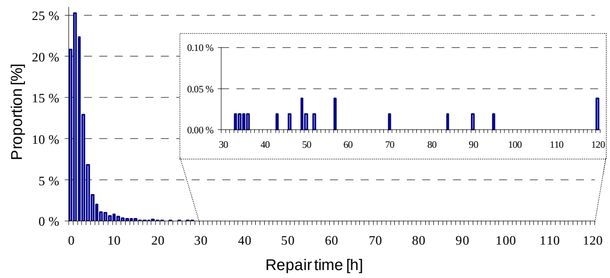

Figure 3. Proportion of fault repair times in a rural network based on a dataset including outage times of over 5000 fault events.

Fault rates utilised in the analysis (shown in Figure 2) are based on actual fault statistics. The fault rates are divided into three line types and three environmental conditions, and thus, there are altogether nine different fault rates. The highest fault rate is for overhead lines locating in forests where the rate is 18 faults per 100 kilometre line. In underground cable network the fault rate is one fault per 100 km. Table 1 presents calculated average fault numbers per year in the considered network for each network types in different environmental conditions.

Table 1. Fault numbers divided to different line types of the MV network in the studied network area

Calculated average fault numbers [faults/year]	Forest	Roadside	Field
Bare overhead line	0.68	1.28	0.33
Covered overhead line	0.00	0.02	0.04
Underground cable	0.00	0.00	0.00

Analysed network is presented in Figure 4. The network is an ordinary rural area feeder in Finland, where the average number of permanent faults is about 2.3 per year. The lines in the network consist mainly of overhead lines that locate mostly in fields. The network has four normally open points, which can be used to supply back-up power when the network is faulted. However, even the network includes several reserve power opportunities and switching devices, it always takes time to isolate the faulted network section. If the separation is carried out using remote controlled disconnectors, the switching time can be 10 or 15 minutes. If manually operated disconnectors are used, the switching time can be around one hour. However, if the customers locate at the faulted section, the only possibility is to repair the faulted line or to provide an alternative source of electrical power such as reserve power aggregate [7] or energy storage that has been studied in this paper.

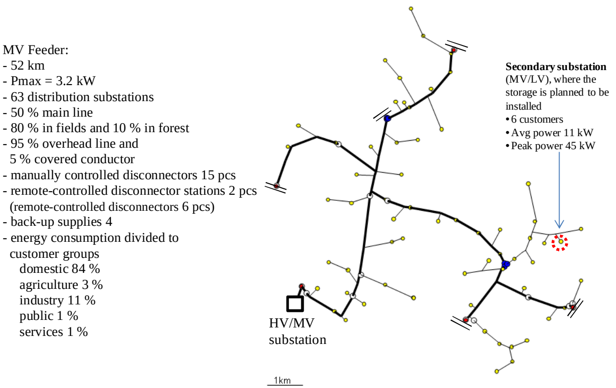

Figure 4. Considered rural area MV network feeder. Secondary substation, of which LV network the energy storage is planned to installed, is highlighted.

The calculations of the energy storage are carried out for LV network of a secondary substation that is marked in Figure 4. The criteria of LV network selection were the location at the end of MV network, because the customers at the end of the network experience longer interruptions than the customers nearby the primary substation (HV/MV). The selected LV network contains six customers, which all are residential households, and thus, the load stays moderate. Load curve of the analysed LV network is illustrated in Figure 5. The peak power of the LV network is 44.5 kW while the average power is 11 kW. Annual energy use of the customers is about 100 MWh, where the consumption of single customer varies from 9 MWh to 28 MWh. The loads are typical for Finnish detached households. All the LV networks, which are wanted to be protected against interruptions utilising energy storages, require their own storage unit, and therefore a separate study.

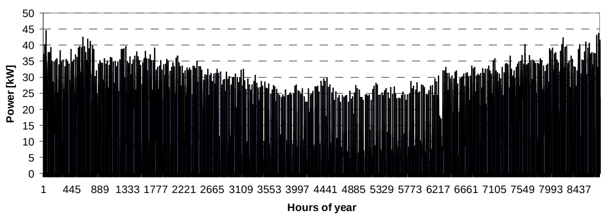

Figure 5. Load curve of analysed LV network.

CASE SIMULATION

Figure 6 presents simulated duration of interruptions with 1000 loops of simulations, which each represents a period of one year. The total number of interruptions during the simulation is 2261 that makes approximately 2.3 faults per year. The length of the interruptions varies from nine hours to ten minutes. As it can be observed, most of the interruptions are relatively short that is provided by several disconnectors and back-up supplies. The switching times of the disconnectors are predetermined for both manually controlled and remote-controlled disconnectors that explain the constant values in the interruption duration curve for both 1.6 and 0.17 hours. 1.6 hours is the switching time of the normally open disconnector to supply reserve power and 0.17 hours is the switching time of remote controlled disconnectors to separate the faults occurring in other disconnector sections. The longest interruptions are due to fault incidents on the same disconnector zone where the considered LV substation locates.

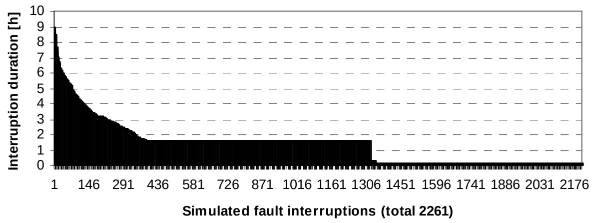

Figure 6. Interruption duration of the customers in the considered MV/LV substation.

Figure 7 shows ENS distribution related to interruption duration in Figure 6. The ENS values in the simulated interruptions vary from 150 kWh to 1 kWh. The figure indicates that significant part of the interruptions can be avoided with relatively small storage capacity. For instance, 10 kWh energy storage decreases about half of the interruptions.

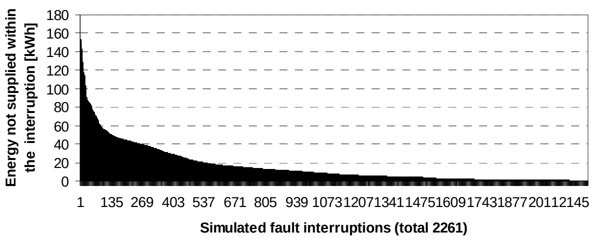

Figure 7. ENS within the simulated interruptions.

One of the main results of the study is the amount of interruptions that can be avoided utilising energy storage. Figure 8 illustrates the percentages of the interruptions that can be avoided with different size of energy storages. In the study the considered energy storage capacities have been from 0 to 50 kWh. It can be seen from Figure 8 that 50% of interruptions can be avoided with seven kWh energy storage as well as 25% of interruption can be avoided with two kWh energy storage. However, in the case of small-size energy storages, a problem of insufficient power capacity may arise, because the energy storage may not be able to supply enough power.

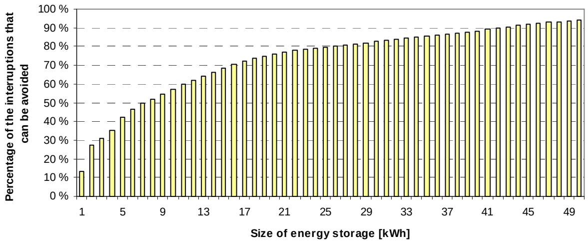

Figure 8. Interruptions avoided with different energy storage capacities

Other benefits of the energy storages can be, for instance, decreasing of momentary interruptions caused by reclosings. Often, they are more common in electricity distribution than permanent interruptions. This indicates that considerable benefit from the end-customer point of view can be achieved decreasing the number of momentary interruptions. When the momentary interruptions are considered, the requirements of the energy storage are not usually focused on energy capacity, because the interruptions are very short, but the power rating plays the key role, which is also the case in the reduction of the shortest long interruptions.

Economic aspect of storages

Economic benefit of the storages consists of decreasing of customer outage costs (COC) due to customer experienced interruptions. Thus, the storage is economically feasible investment if the savings of COC are bigger than investment costs of the storage.
The study indicates that half of the interruptions can be avoided with the 7 kWh storage. With the price of 1000 €/kWh the investment is 7000 €. The annuity of the storage is thus 670 €/a, when lifetime of the storage is 15 years and interest is 5%. If half of the annual faults (2.3 faults per year in the case network, average interruption duration 2 h) can be avoided with the storage, the annual interruption cost saving is with Finnish interruption unit costs (1.26 €/kW and 12.6 €/kWh) [8]

$$COC_{saving} = 11.4\text{kW} \cdot 50\% \cdot 2.3\frac{\text{fault}}{\text{a}} \cdot \left(1.26\frac{€}{\text{kW}} + 12.6\frac{€}{\text{kWh}} \cdot 2\text{h}\right) = 346\frac{€}{\text{a}}$$

Savings of avoided permanent faults are 346 €/a that is not enough to cover the expenses of the storage. However, often a considerable part of the benefit comes from decreasing of momentary interruptions. Thereby including them in the COC_{saving} calculation with the Finnish interruption unit costs [8], where the unit cost of high speed automatic reclosings (HSAR) is 0.63 €/kW and delayed automatic reclosings (DAR) 1.26 €/kW, the total benefit is higher. The average number of HSAR is in the case network 20 fault/a and DAR 5 fault/a.

$$COC_{saving} = 11.4\text{kW} \cdot \left(20\frac{\text{fault}}{\text{a}} \cdot 0.63\frac{€}{\text{kW}} + 5\frac{\text{fault}}{\text{a}} \cdot 1.26\frac{€}{\text{kW}}\right) = 216\frac{€}{\text{a}}$$

Together the savings are 560 €/a, which is near cost-effective investment. Thus, the simple economic approach shows that economic feasibility of storages is reasonable to study more in the future.

CONCLUSION

This paper presents a methodology to assess the utilisation of energy storages to prevent customer interruptions. The study shows that in the case network a considerable proportion of the interruptions can be cut with relatively small energy storages. Even 7 kWh storage, which means 1 kWh per supplied customer, decreases the number of customer experienced interruptions by 50%. Also a significant benefit that can be achieved with energy storages is decreasing the number of momentary interruptions, which do not require high energy capacity. However, a problem with small-size storages to supply enough power to the loads may arise that may decrease the benefits.
Also, the paper shows that there are potential to utilise energy storages economically. The economic profitability is not far with current energy storage prices. Thus, the future work is to develop methodology to analyse the economic effects of the storages.

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