Available online at www.sciencedirect.com
ScienceDirect
Electrical Power and Energy Systems 29 (2007) 767–774
ELECTRICAL POWER & ENERGY SYSTEMS
www.elsevier.com/locate/ijepes

Outage costs quantification for benefit–cost analysis of distribution automation systems

Chun-Lien Su [a,*], Jen-Ho Teng [b]

[a] *Department of Marine Engineering, National Kaohsiung Marine University, Kaohsiung 805, Taiwan*
[b] *Department of Electrical Engineering, I-Shou University, Kaohsiung 840, Taiwan*

Received 14 July 2006; received in revised form 22 May 2007; accepted 3 June 2007

Abstract

Deregulation of electric power industry has motivated electricity customers to pay more attention in evaluating both the direct cost of electric service and the monetary value of reliable electric service. This movement has been recognized by the utilities and the value-based aspects are introduced into the planning and design of power systems to consider the outage costs. The value of service reliability that can portray and respond to actual utility and customer impacts as a result of power interruptions plays a major role on justifying whether a distribution automation (DA) system is beneficial or not. However, for the value of service reliability, there are a number of factors that can affect it. To exactly evaluate the service reliability value, two formulas for quantifying the customer interruption costs and utility reduced energy revenues associated with power failures are derived in this paper. The customer types, feeder loads, feeder failure rate, number of switch, restoration time, and repair time are taken into account. The proposed formulas can provide an exact estimate in outages costs of a feeder and their computation is simplified and straightforward. The estimated outage costs can then be used to calculate the reliability improvement benefit of DA systems for the system benefit–cost analysis. A practical DA system implemented by Taiwan Power Company is used to illustrate the proposed formulas and the benefit–cost analysis result is presented. Sensitivity analysis is also performed to reduce the effects of benefit–cost analysis parameters on the analysis result.

Keywords: Distribution automation; Outage cost; Benefit–cost analysis

1. Introduction

Today's energy market that is moving toward an intense price competition has forced electric utilities to face many challenges. One of the major challenges is to increase the market value of services. To provide lower electricity rates for customers, utilities have provided adequate reliability, and reduced its costs of operation, maintenance, and construction. Since distribution networks provide the final link between the bulk transmission system and the customers, it is important to the total electrical supply system. It has been reported that over 80% of customer service interruptions are due to failures in distribution networks. To achieve significant and immediate improvement in the distribution supply reliability and concurrently to enhance the customers service quality, various types of distribution automation (DA) systems are implemented by the utilities worldwide. DA systems have been defined by IEEE as systems that enable an electric utility to monitor, coordinate, and operate distribution network components in real-time mode from remote control centers [1].

DA systems are usually modular and can be implemented in phases to include remote monitoring and control of substations, feeders, and consumer loads. DA systems are built to achieve the goals of operation and maintenance (O&M) cost reduction, capital investment deferment, supply reliability improvement, and operation efficiency

* Corresponding author. Tel.: +886 7 8100888x5226; fax: +886 7 5716013.
E-mail addresses: cls@mail.nkmu.edu.tw (C.-L. Su), jhteng@isu.edu.tw (J.-H. Teng).

0142-0615/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2007.06.026

enhancement [2,3]. The installation of a DA system requires a large capital investment; therefore, the benefit–cost or economic analysis of DA systems is critical to identify the DA functions that produce significant operational benefits.

Many methods were proposed for the DA economic analysis [4–10]. Ref. [4] proposed a set of general guidelines for evaluating the benefits of various DA functions. Ref. [5] developed a computer program to evaluate the benefits and costs of the DA functions using standard engineering economic methods. A comprehensive methodology and application guidelines were used in [6] to evaluate the DA functions and a master plan was developed to implement the DA system on a system-wide basis. Ref. [7] used a present worth method to determine the savings and costs of the DA functions under considerations and conducted the economic analysis for different combinations of the DA functions by using a cost–benefit analysis method. Reliability worth assessment is currently receiving considerable attention as it provides an opportunity to incorporate the costs or losses incurred by utility customers as results of power failure. A distribution reliability program was used in [8] to evaluate the reliability of supply to the customers. The reliability indices used in justifying capital expenditure were computed and the best option is selected from various available alternatives. Ref. [9] proposed an analytical approach to study the impact of DA on the distribution reliability and used historical outage and customer interruption cost (CIC) data to conduct the DA economic analysis. The unserved-energy costs and momentary-outage costs considering feeder loads and outage duration are determined in [10] to determine which DA functions are beneficial.

The number of switch that is strongly relative to outage duration and outage cost is not considered in the existing outage cost assessment methods. To more exactly quantify the customer interruption costs and utility reduced energy revenues associated with power failures, two outage costs quantification formulas are derived in this paper. The customer types, feeder loads, feeder failure rate, number of switch, restoration time, and repair time are taken into account. The proposed formulas can provide an exact estimate in outages costs of a feeder and their computation is simplified and straightforward. The estimated outage costs can then be used to calculate the reliability improvement benefit of DA systems for the system benefit–cost analysis. Application of the proposed formulas to benefit–cost analysis of a practical DA system implemented by Taiwan Power Company (Taipower) is presented.

2. Outage costs quantification

Unreliability supply can cause huge economic losses and significantly affect the peoples' life and social operations. Generally the losses due to unreliability of electric supply can be classified into the quantifiable losses and the unquantifiable (intangible) losses. The quantifiable outage costs such as lost production, production spoilage, paid staff unable to work, reduced energy revenues, etc., can be further divided into customer interruption costs and utility reduced energy revenues and expressed as dollar values. The unquantifiable outage cost including transportation unavailable, risk of injury, bad public image, etc., are difficult to be expressed in formulas and therefore, is not included in the proposed economic analysis.

To quantify customer interruption costs and utility reduced energy revenues, two formulas are derived. In the derivations, feeder loads are assumed to be evenly distributed on the feeder. The detailed derivations are shown in Appendix A. The final derivation results are shown in Eqs. (1) and (2). For a feeder with average failure rate λ (failures/mile/year), load L (kW), number of switch n, and feeder length l (mile), the customer outage costs can be calculated by

$$\mathrm{CIC}(\$/\mathrm{year}) = \frac{\lambda * l * L}{n+1} * (0.5 * n * \mathrm{IC}(t_{\mathrm{ss}}) + \mathrm{IC}(t_{\mathrm{repair}}) + 0.5 * n * \mathrm{IC}(t_{\mathrm{feeder}})) \quad (1)$$

where $\mathrm{IC}(t)$ is the customer interruption cost per kilowatt ($/kW). Different customer types have different values of $\mathrm{IC}(t)$. t_{ss}, t_{feeder}, and t_{repair} are the average time for restoration from substation, from other feeders, and fault repair for each power failure, respectively.

The utility reduced energy revenues due to a power failure can be expressed as

$$\mathrm{RR}(\$/\mathrm{year}) = \frac{K_A * \lambda * l * L}{n+1} * (0.5 * n * t_{\mathrm{ss}} + t_{\mathrm{repair}} + 0.5 * n * t_{\mathrm{feeder}}) \quad (2)$$

where K_A($/kWh) is energy cost.

Loads on a distribution feeder vary over a day from morning to evening according to the daily load curves. Network topology may change due to restoration and maintenance. Using specific load values and network topology for CIC and energy revenue calculations are not reasonable, since the interruption event occurring at a distribution feeder cannot be exactly predicted. Nevertheless, from the historical data the average outage data such as outage rate and outage duration etc. can be predicted; therefore, the future interruption cost of a distribution feeder can be predicted by the average load and average outage data. Of course, some complicated stochastic methods such as Monte Carlo simulation can be used to more exactly predict the interruption cost; however, they are more time-consuming and are not used in this paper. In (1) and (2), the customer interruption costs and utility reduced energy revenues are computed not only on the basis of customer types, feeder outage rate, average load, number of switch, and feeder length, but also on the basis of restoration time and repair time following a power failure. The annual expected values of utility energy revenue losses and the customer interruption cost before and after DA systems implementation are computed by using (1) and (2). Therefore,