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Comparison of subtransmission system reliability worth for diverse systems by including health considerations

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Abstract

The fundamental concepts associated with quantitative reliability assessment of electric power systems are reasonably well established and accepted by the power industry. The evaluation of the costs and benefits of competing investments has now become a standard practice in power system planning. In order to make a consistent appraisal of economics and reliability, it is imperative to compare the investment cost needed to attain a specified level of reliability with the reliability worth or benefits derived by the society at that level of system reliability. Customer interruption costs, which serve as surrogates for the perceived worth of supply reliability, have been determined for several jurisdictions, areas, provinces, and countries as diverse as Canada, United Kingdom, Nepal, and Thailand, among others. This paper extends the well-being framework to include the societal worth of electric service reliability in subtransmission systems associated with the above four countries/systems. Systems well-being is defined in terms of the three system states of healthy, marginal, and at risk, thus combining the deterministic and probabilistic approaches into a single framework. The main objective of the paper is to present results of reliability worth indices of expected cost of interruptions (ECOST) and interrupted energy assessment rate (IEAR), for both the healthy and at risk states in the well-being framework. The concepts associated with extending the well-being framework to include reliability worth parameters are illustrated by application to a small reliability test system designated RBTS. Customer interruption data from the four countries are used in conjunction with the RBTS subtransmission system in order to obtain the reliability worth indices.
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Keywords: Subtransmission system; Expected cost of interruption; Interrupted energy assessment rate

1. Introduction

The fundamental function of an electric energy system, regardless of whether the system is vertically integrated or deregulated, is to provide electricity as economically as possible, and with a reasonable assurance of quality and reliability. The major difficulty faced by power system managers and planners is in justifying new facilities and equipment (and the associated investment cost) to improve service reliability vis-a-vis the benefits accruing to the society due to these facilities. Power system planners strive to determine the optimum balance between costs and reliability to meet the ever-increasing customer load requirements. The basic question then is "what is an acceptable level of service reliability?" The answer to this question, however, is not so straightforward. What constitutes an "acceptable" level can best be examined in terms of the costs and the worth (benefits). This form of evaluation is sometimes also designated as value-based reliability (VBR) evaluation [1–13].

The economic evaluation of reliability requires the determination of "benefit (worth)" from the customers' perspective and its explicit incorporation into the planning process. A number of general approaches have been used to assess reliability worth, most of which are based on indirect methods of customer outage costs. Unable to assess reliability worth directly, many researchers have turned their attention to eval-

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uating the impacts or losses resulting from supply interruptions, i.e., in terms of customer interruption costs, in the form of the societal cost of unreliability. It must be clearly appreciated that interruption (outage) costs are not equal to reliability worth but are rather indicative of the perceived worth. It is widely accepted that the customer survey method, in which electricity consumers are directly contacted and asked to answer a set of questions, is the most reliable and practical. Many such surveys have been undertaken by various research groups. The Power Systems Research Group at the University of Saskatchewan has been instrumental in conducting many such surveys since 1980. This paper utilizes the research findings of this group [14] for four countries, namely Canada, United Kingdom, Nepal, and Thailand, in reliability worth evaluation of subtransmission systems with well-being considerations.

The main objective of this paper is to include the customer interruption costs of the above four countries in a reliability well-being assessment of subtransmission systems and to compare the results in the form of reliability worth indices of expected cost of interruptions (ECOST) and interrupted energy assessment rates (IEAR). Value-based reliability planning approaches seek to assist utilities in establishing a balance between the cost of improving service reliability and quality, and the economic benefits that these proposed improvements bring to customers have become an integral part of the electricity supply industry. This paper is, therefore, another application of the VBR concept in system planning.

2. Customer damage functions utilized

The traditional interruption cost model is known as a composite customer damage function (CCDF), which defines the overall average costs of interruptions as a function of the interruption duration in a given service area that was used in the surveys. These data can be used to create CDFs for specific customer classes (sectors). The average sector costs associated with each studied interruption scenario are used to create sector SCDFs, which are then (usually) weighted by peak demand for short duration interruptions (up to 30 min) and by their respective energy consumptions for durations longer than 30 min, in order to create a CCDF for the entire studied area [7]. Data collected from the University of Saskatchewan surveys [xx] are shown in Table 1 for three customer classes (residential, small industrial, and commercial) for Canada—these data were normalized with respect to the sector peak load (using a 1991C$ base). Sector interruption cost data for United Kingdom, Nepal, and Thailand [14] are shown in Tables 2–4, respectively. The interruption cost data shown in Table 3 are demand normalized (Thai Baht/kW) using the average loads, whereas the outage data presented in the other three tables (Tables 1, 2 and 4) are demand normalized using the peak loads. In addition, Table 3 data have assumed that category small general service (SGS) and medium general service (MGS) [14] are replaced by commercial and small industrial (Sm. Ind.) users, respectively, for the RBTS [15,16] Bus 4 subtransmission system—the reliability test system used to describe all studies reported in this paper. The RBTS Bus 4 single line diagram is shown in Fig. 1. The system consists of three 11 kV supply points (SP) connected through 33 kV subtransmission network and station equipment. The basic component data for this configuration are given in Ref. [16]. The percentage peak demands and

Table 1
SCDF (in 1991 C$/kW) of the RBTS Bus 4 customer sectors (Canada)

Duration	Residential	Small industrial	Commercial
2 s	–	0.9033	0.2684
1 min	–	2.1585	1.8847
20 min	0.0278	3.0887	5.5764
1 h	0.1626	6.5264	15.065
2 h	–	11.5995	31.6023
4 h	1.8126	23.8083	75.904
8 h	4.0006	44.0597	121.9695
24 h	18.2491	70.1317	146.9024

Table 2
SCDF (in 1992 British Pounds/kW) of the RBTS Bus 4 customer sectors (UK)

Duration	Residential	Small industrial	Commercial
2 s	–	6.15	0.99
1 min	–	6.47	1.02
20 min	0.15	14.27	3.89
1 h	0.54	25.26	10.65
4 h	3.72	72.22	39.04
8 h	–	120.11	78.65
24 h	–	150.38	99.98

Table 3
SCDF (in 1995 Thai Baht/kW) of the RBTS Bus 4 customer sectors (Thailand)

Duration	Residential	Small industrial	Commercial
1 min	0.55	20.58	21.02
5 min	0.88	23.53	28.10
10 min	9.87	24.63	39.08
30 min	20.17	80.98	125.87
1 h	35.3	103.24	203.00
2 h	111.4	149.90	338.98
4 h	327.16	228.68	594.84

Table 4
SCDF (in 1996 Nepal Rupees/kW) of the RBTS Bus 4 customer sectors (Nepal)

Duration	Residential	Small industrial	Commercial
1 min	–	5.16	38.19
20 min	1.52	11.31	130.35
1 h	8.05	20.50	281.37
2 h	–	28.26	675.92
4 h	42.08	72.45	1108.31
8 h	86.43	145.38	1568.74
24 h	310.16	532.31	2031.82

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