ASSESSMENT OF COST RELATED RELIABILITY OF POWER SYSTEMS

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ABSTRACT

Cost/benefit analysis of power systems is becoming an essential factor in the determination of system reinforcement and expansion projects, due to the impact of electric utility deregulation and market competition. Economics play a major role in the application of reliability concepts and the attainment of an acceptable level of reliability. Inadequate reliability of electric power supply ultimately costs the customers much more than good reliability. It is therefore important to determine the optimal reliability level at which the reliability investment achieves the best results in reducing the customer damage costs due to power supply interruptions.

This paper describes the basis concepts required for system reliability cost/benefit analysis. The basic approach is to minimize a total cost composed of the overall investment cost and the customer damage cost. The customer damage cost is a function of interruption frequency, duration, load lost, location, and other societal effects.

System studies conducted on a part of Alexandria electricity distribution network are presented which provide insight into the variation of the indices with different system factors.

INTRODUCTION

Power system planning is traditionally based on deterministic criteria. A generally used criterion is that the loss of any single generating unit or transmission line should not cause load interruption. This criterion does not explicitly consider the probability of component failures and the value of service to customers. It can therefore result in overbuilt systems due to low probability events.

The criterion provides no economic input to the cost associated with a particular expansion plan in terms of the value of service provided to customers. Deterministic approaches are not sufficiently responsive to conflicting factors in the emerging competitive power supply environment.

System reliability normally increases with investment cost. On the other hand**,** the customer damage cost decreases as the reliability level increases. The total cost is the sum of the project and customer damage costs. This total cost exhibits a minimum, at which an optimum or target level of reliability is achieved.

The cost/benefit approach uses the total cost as a basis for ranking the system expansion alternatives. The approach can be: minimize the total cost which is the sum of investment cost and the customer damage cost. Where, the investment cost includes the capital cost and the operation/maintenance cost, the customer damage cost reflects the value of unsupplied energy.

The investment cost is basically deterministic in nature and can be obtained using well-established methods. The customer damage cost is conceptually the aggregated value the customers are willing to pay to avoid load interruptions or voltage standard violations, and is a function of interruption frequency, duration, load lost, location and other social effects.

The calculation of the customer damage cost is a necessary and complex task in reliability cost/ benefit analysis. The technique to calculate the customer damage cost and the application of the technique are developed and illustrated. The data for calculating the customer damage costs used in this paper come from the surveys conducted by Alexandria Electricity Distribution Company (AEDC).

CONCEPT OF CUSTOMER DAMAGE FUNCTION

A customer damage function (CDF) provides the interruption cost versus interruption duration for a specified group of customers.

Table 1 shows interruption cost data in the form of sector CDF. Five sectors were identified for data collection. The five sectors are: industrial, commercial, government& institutions, residential and agricultural

Table1 Sector CDF expressed in LE/kW

User sector	Interruption duration				
	1 min	20 min	1h	4h	8h
Industrial	6.26	13.82	37.48	96.87	205.65
Commercial	1.26	9.47	23.05	86.12	232.84
Gov.& Inst.	0.19	1.64	6.73	29.94	114.58
Residential	0.01	0.26	1.59	12.16	34.51
Agricultural	0.23	1.30	2.53	8.17	15.63

The five sectors are graphically shown in Fig.1

The Composite Customer Damage Function (CCDF) represents the total interruption cost as a function of the interruption duration for the combined customers in a particular service area.

The CCDF for a service area is obtained by weighting the sector CDF by the customer load composition for that area**.**

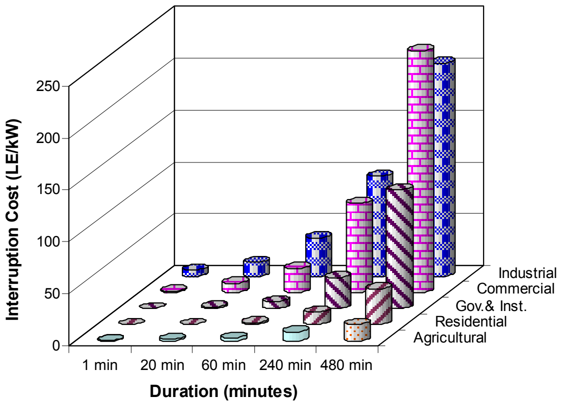

Fig.1. Sector customer damage functions (LE/kW)

The customer load compositions in terms of peak load and energy consumption percentages must be known in order to obtain the CCDF for the combined customers.

The annual peak load percentage is usually used for weighting short durations (below 1 hour) , and the annual energy consumption percentage is used for weighting the longer durations.

Table 2 shows the load compositions in terms of:

1- The annual peak percentage
2- The energy consumption percentage

For a part of Alexandria Electrical System.

Table 2 Load Compositions for the study area

User Sector	Sector Peak%	Sector Energy %
Industrial	25	28
Commercial	8	7
Gov.& Inst.	6	9
Residential	57	53
Agricultural	4	3

The Composite Customer Damage Function (CCDF) for the study area is obtained as shown in Table 3, and is shown graphically in Fig.2

Table3.CCDF in (LE/kW) for the study area

AEDC Study Area	Interruption duration				
	1 min	20 min	1h	4h	8h
Industrial	6.26*0.25	13.82*0.25	37.48*0.28	96.87*0.28	205.65*0.28
Commercial	1.26*0.08	9.47*0.08	23.05*0.07	86.12*0.07	232.84*0.07
Gov.& Inst.	0.19*0.06	1.64*0.06	6.73*0.09	29.94*0.09	114.58*0.09
Residential	0.01*0.57	0.26*0.57	1.59*0.53	12.16*0.53	34.51*0.53
Agricultural	0.23*0.04	1.30*0.04	2.53*0.03	8.17*0.03	15.63*0.03
Total Customer Cost.Σ (LE/kW)	1.69	4.51	13.63	42.53	102.95

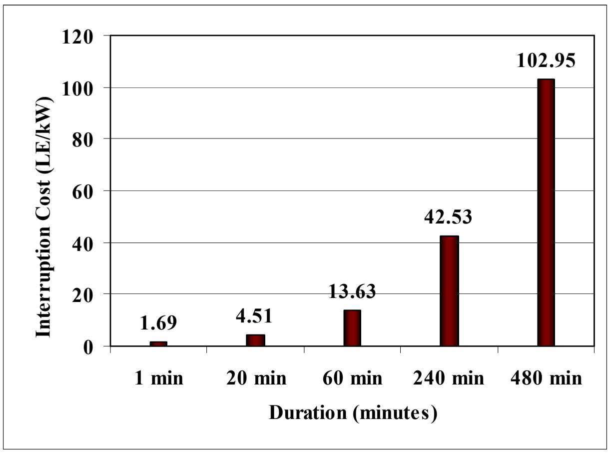

Fig.2. the composite customer damage function (LE/kW)

EXPECTED COST OF CUSTOMER INTERRUPTIONS

The equation for calculating the expected customer damage cost (ECOST) is developed from:

- The expected energy not supplied (EENS) index
- The composite customer damage function (CCDF)

The EENS is defined as:

$$EENS = \sum_{si \in F} p_{si} L_{c\,si}\, 8760 \qquad MWh \;/\; year \quad (1)$$

Where:

p_{si} : The probability of existence of outage state si

$L_{c\ si}$: The load curtailed in MW for the system in system state si

F : The set of system failure states in which load curtailments occur.

Equation (1) can be rewritten in the following form:

$$EENS = \sum_{si \in F} p_{si}\left(\mu_{si} + \lambda_{si}\right) d_{si} L_{c\,si} \qquad MWh / year \quad (2)$$

Where:

μ_{si}: the total repair rates of the failed components in system state si

λ_{si}: the total failure rates of the operating components in si

d_{si}: the expected duration at system state si

$= 8760 \;/\left(\mu_{si} + \lambda_{si}\right) h$

The ECOST can be calculated by replacing the d_{si} in equation(2) with the cost of the enrgy not supplied during the load loss event si ($c(d_{si})$).

The $c(d_{si})$ is given by the duration d_{si} and the CCDF for the system study area. The equation for the ECOST is as follows:

$$ECOST = \sum_{si \in F} p_{si}\left(\mu_{si} + \lambda_{si}\right) c(d_{si}) L_{c\,si} \qquad KLE / year \quad (3)$$

Where:

$c(d_{si})$ is measured in (LE/kW)

The annual ECOST is evaluated here using a direct approach, in which the hourly load duration curve is directly

incorporated in the calculation. In this direct approach, the available capacity at the system state si is first obtained and then combined with the load duration curve to obtain the expected load curtailment.
The equation for the EENS using the direct approach is:

$$\mathbf{EENS} = \sum_{si \in S} \left(p_{si} \sum_{Lj > Csi} \left(L_j - C_{si} \right) \right) \quad \text{MWh / year} \qquad (4)$$

Where:
S: the set of all investigated system states
Lj: the hourly peak load in one year at a specific load bus in system state si
Csi: the available capacity at the specific load bus in system state si.
The equation for the annual ECOST can be derived from the annual EENS equation in the same way as that for the annualized ECOST. In this situation, as the system state si is not a complete failure state using a single constant load, the expected system state failure duration $d_{f\,si}$ is used for the interruption cost calculation.
The annual ECOST is given by:

$$\mathbf{ECOST} =$$

$$\sum_{si \in S} \left(p_{si}(\mu_{si} + \lambda_{si}) c(d_{f}\, si) \sum_{L_{j} > C_{si}} \left(L_j - C_{si} \right) \right) / 8760 \quad \text{kLE/year} \qquad (5)$$

Where:
$d_{f\,si} = \sum_{L_{j} > C_{si}} 1/(\mu_{si} + \lambda_{si})$ is the hours in which the load is greater than the available capacity at a specific load bus in system state si.
The ECOST analysis was applied to a part of Alexandria Electrical system. The results are shown in Fig.3
Fig.3. shows the system ECOST at different load levels for the part of Alexandria electrical system.

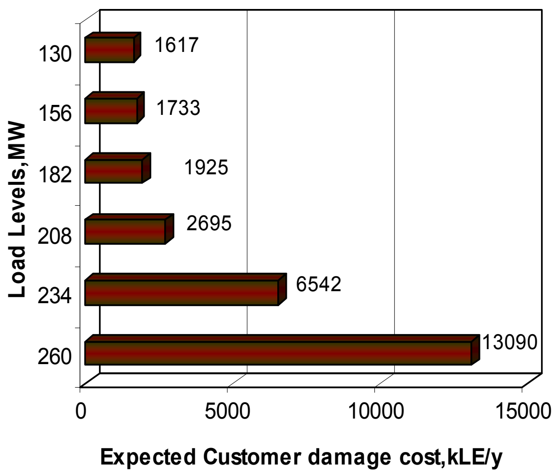

Fig.3. Expected customer damage costs for the study system at various load levels

The graph shows that the system ECOSTdecreases rapidly when the load level decreases from 260 to 208 MW and does not vary significantly when the load level decreases from 208 to 130 MW.

INTERRUPTED ENERGY ASSESSMENT RATE (IEAR)

An often used index in reliability cost analysis is the interrupted energy assessment rate (IEAR), which is calculated as the ratio of ECOST and EENS.

$$\mathbf{IEAR} = \frac{\text{ECOST}}{\text{EENS}} \qquad (\text{LE / kWh}) \qquad (6)$$

The IEAR is a convenient and readily understandable index, which provides a momentary evaluation of energy deficiencies for the system from a customer damage cost point of view.
The results of IEAR analysis for the part of Alexandria electrical system are shown in Fig.4

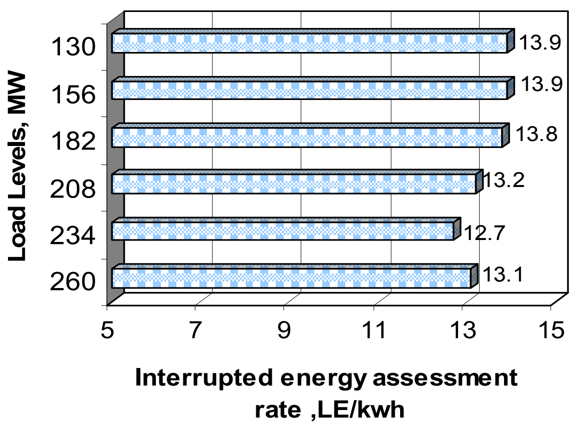

Fig.4. Interrupted energy assessment rate for the system at various load levels

Fig.4. indicates that the IEAR index is quite stable with respect to load level variations.

CONCLUSIONS

The paper illustrates the essential techniques and philosophy of reliability cost/ benefit analysis in power systems. The customer damage cost is a function of interruption frequency, duration, load lost, location and other societal effects.
The paper illustrates the calculation of the ECOST (Expected Customer Damage Cost) and related IEAR (Interrupted Energy Assessment rate) indices in power systems.
The data used to calculate the ECOST and IEAR come from surveys conducted by the study group. The ECOST and IEAR of a part of Alexandria electrical system were calculated for the system under various conditions. The

results are illustrated, compared and analyzed.

The results show that the ECOST decreases rapidly with reduction in load level. The ECOST can be very large and very sensitive to system load level variations, when the system load level is relatively high. The system studies show that the IEAR index does not change significantly with variation in system load level.

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