Effect of Time-Variability Weather Conditions on the Reliability of Distribution Systems

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Abstract: -Reliable evaluation of distribution systems is of high importance in the maintenance and expansion of these systems. A time-sequential simulation technique is presented in this paper in which the effects of weather conditions and maintenance methods in the assessment of reliable cost of integrated distribution systems are provided. Time-Varying Weight Factors (TVWF) are defined to investigate the effect of weather conditions and present maintenance methods on Failure rates (FR). In fact, the average Failure Rate (FR) is combined with TVWF to provide time-varying repair times (TVRTs) for each component. Similarly, the average Repair Time (RT) is also combined with TVWF to produce Time-Varying-Repair Time (TVRT). An experimental distribution system showed that TVFR has more effects on the interruption costs of the sensitive costumers. It has also significant effects on the indices of all costumers. So, it is necessary to consider TVRT in evaluating the reliability of the network cost.

Key-Words: - Distribution systems, network reinforcement , reliability cost/worth

1 Introduction

The subscriber's interruption costs and reinforcement reliability costs of the network are useful indices for the network designers while making optimum designs and administrative decisions [1]–[3]. The reliability of these indices has great effects on the final decisions made by the network designers. The index reliability depends upon the techniques, component parameters, and the models employed in the analysis. The techniques employed for the reliability assessment of the power systems are totally divided into analytic graphs [4]-[5], Monte Carlo [5]–[8], and a combination of simulation and analytical methods [9]. The reliable parameters are mostly considered to be constant in the analytical techniques. So, the Failure Rate and Repair Rate (RR) parameters are constant. Time To Failure (TTF) and Time To Repair (TTR) have exponential distributions.

In actual power systems the restoration time can have other distributions such as normal or lognormal. The FR is a function of the weather conditions and environment. In adverse weather conditions, the Failure Rate of a component might be larger than that in the normal weather conditions [10]. The repair times of the components are also affected by variable weather conditions as well as repair methods. Restoration time during a winter season is greater than that considered for a normal amount. The repair time also depends on whether it is daytime, night, weekday or weekend. In a given weather condition the average time required for restoration during a weekend or within some hours at night can be greater than the usual amount during the weekdays or daytime.

The equivalent two-state model and the four-state weather model are employed in [10] and [11], respectively. Constant failure rate and repair time are considered in these models. Billinton and Li [12] employed the Monte Carlo sampling technique to incorporate variable weather conditions in a composite form. A uniform distribution for weather condition sampling based on occurrence probability and weather conditions was employed. The weather conditions are divided into normal and adverse in all states. The probabilities of normal and adverse conditions are employed to incorporate the effect of weather. The data analysis of weather conditions and repair methods are not considered in [10] and [12].

The time-varying nature and uncertainty of the system parameters can not be easily considered while employing analytical methods. The result of data analysis and system random behavior by the application of chronological simulation with the assumption of time-variable load and interruption cost models is presented in [8]. Vang and Billinton did not consider the time-varying FR and TR in [8].

Instead of the application of the probabilities of adverse or normal weather conditions, the issues of Time-Varying Failure Rate (TVFR) and Time-Varying Restoration Time (TVRT) are defined in this article to specify the weather condition effects and variable repair methods on the reliability of parameters of a component. The chronological simulation techniques for the incorporation of the results of data analysis and system random behavior are used in the evaluation of reliability. The effects of the load points of the reliable cost/worth indices of the system on TVFR and TVRT are presented in Expected Energy Not Supplied (EENS) and the Expected interruption COST (ECOST) for a test distribution system. The Reliability Worth of Network Reinforcement (RWNR) was studied to show the importance of employing TVRT.

2 Time-varying models

2.1 Diagram Model

Time-varying component models are two-state model for the evaluation of the reliability of a distribution system for a component .The FR and RR are considered constant in this model. The time-varying two-state model in this study is depicted in Fig. 1.

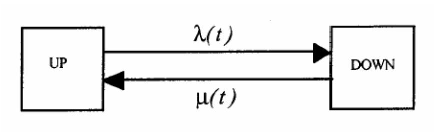

Fig.1. Diagram depicting time-varying two-state system

The FR and RR are function of time and one year is divided into 8760 discrete hours. The FR of each component for each hour is assumed to be constant and the repair times have a lognormal distribution. Other distributions can also be selected for the description of repair times.

2.2. Weather Condition

The time-varying failure rate (FR) divides the environment weather into three groups using IEEE 346[13].

1. normal
2. adverse
3. strong storm

The failure rate is constant for a given weather condition. In this paper the time-varying failure rate is defined to represent the time-varying nature of failure rate. A TVFR or $\lambda(t)$ can be obtained by using average FR in normal weather conditions weighted by weather data analysis scale as in Fig.2.

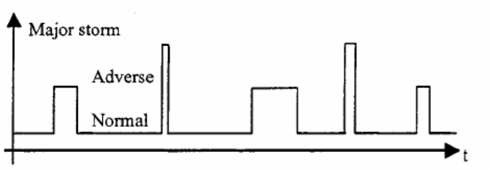

Fig.2. Time-varying weather condition weighing diagram

The failure rate at *t* time is calculated by the following equation:

$$\lambda(t) = w(t).\lambda(t) \qquad (1)$$

Where w(t) is time-varying weight index, and $FR = \lambda(n)$ is the FR for normal weather conditions.

2.3. TVRT Model

Time-varying repair time: the weather conditions and repair methods both affect the system repair time. The effect of weather conditions are produced by the weather weight factors which are calculated by the past repair experiments of the power company for different weather conditions. The weather weight factors with weather data analysis scale are incorporated to form a time-varying weather factor. $W_w(t)$ of the present repair methods can be produced by a daily TVRT weight factor. $W_d(d)$ and also an hourly TVRT weight factor $W_h(t)$ based on switching experiments and repair. The repair time (t) can be obtained by equation (2) in r which is the repair time for normal weather conditions.

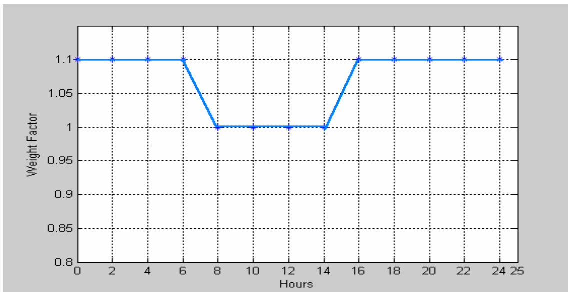

Fig.3. Hourly TVRT weight factors

The hourly TVRT weight factors used in this paper are depicted in Fig.3.

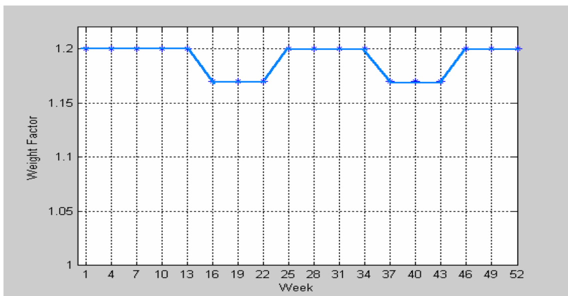

Fig.4. Weekly TVRT weight factors

The Weekly weight factors are depicted in Fig.4. The daily TVRT weight factor is 1.2 during a weekend.

$$r(t) = w_w(t) \times w_d(d) \times w_h(t) \times r \qquad (2)$$

It should be noted that the aim of this paper is to obtain a general method for considering the time-varying nature in the reliability of cost/worth assessment.

The failure rate and repair times are weighed during winter and summer. The weighted factors used in an actual system are based on the system past repair experiment in different weather conditions.

Attempting to provide universal time variable models for each parameter to be applicable for each power network is not realistic.

2.4. Load Models and Average Interruption Costs

Load models and Average Interruption Costs (AIC) for seven different types of customers are calculated on the basis of their Sector Customer Damage Functions (SCDF). In [14] the SCDF is depicted in Fig. 5.

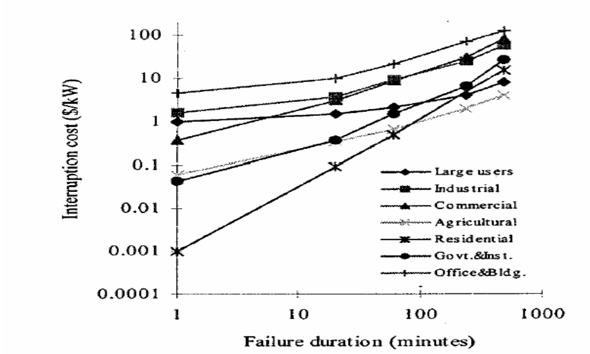

Fig.5. Load models and average interruption costs

Average models and time-varying variables for costs and load are expressed in [8] that can be used in analysis.

3. EENS AND ECOST PARAMETERS

The ECOST is presented as follows:

$$ECOST_j = \sum_{j=1}^{Ns} L_{ij} \times C_{ij} \times \lambda_j (\frac{K.S}{yr}) \qquad (3)$$

In which,

j = the number of elements affecting ECOST
i = The number of the regions with probable interruptions studied in ECOST calculation.
N_s = The total number of the elements causing failures in simulation period.
C_{ij} = interruption cost per unit.

L_{ij} = average load according to KVA

Also, EENS indices presented as follows:

$$EENS_j = \sum_{j=1}^{Ns} L_{ij} \times V_{ij} \times \lambda_j (\frac{MWh}{yr}) \qquad (4)$$

In which,

r_{ij} = interruption duration resulting from m_j element on m_i region.

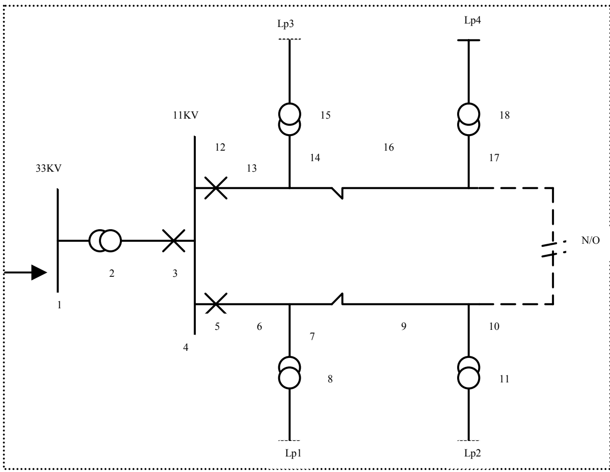

Fig.6. The network under study

4 THE CALCULATION OF DISTRIBUTION FACTORS IN SAMPLE NETWORK

Fig.6 depicts the intended sample network in which numbers indicates the elements of 20 and 33-kv networks and the locations of 0.4 and 20 kv power station specify the load points.

a) Specifications related to the sample network

Two weather conditions:

Average duration of normal weather = 680hr,
$\lambda_n = 0.0139F/yr$

Average duration of adverse weather = 48hr,
$\lambda_s = 5.86F/yr$

With regard to equation (5) λ can be calculated:

$$\lambda_{eq} = (\frac{n}{n+s} \times \lambda_n) + (\frac{s}{s+n} \times \lambda_s) \qquad (5)$$

In which "n" is the normal condition hours and "s" is the adverse condition hours.

b) Transmission line conditions:

Bus bars:

BUS 11kv: $\lambda b_2 = 0.001F/yr$

BUS 33kv: $\lambda b_1 = 0.001F/yr$

Breakers:

BUS 11kv: $\lambda b_c = 0.006F/yr$

Transformers:

Trans. 11kv / 0.45kv : $\lambda T_2 = 0.015F/yr$

Trans. 33kv / 11kv : $\lambda T_1 = 0.015F/yr$

Loads:

$P_1 = 650KVA, P_2 = 400KVA$

$P_3 = 400KVA, P_4 = 314KVA$

Lines:

$L_1 = 6km,\ L_2 = 2km,\ L_3 = 3km,\ L_4 = 1km$

$L_5 = 6km,\ L_6 = 2km,\ L_7 = 3km,\ L_8 = 1km$

With regard to graph (5) and considering $C = 0.15\%$ ($/hr) for four times.

For the calculation of ECOST of the total system, it is necessary to specify the effect of 18 elements on each of the eight regions and then their resulting values are added together and the EENS and ECOST of the total system are obtained.

It is necessary to study different states to specify the effects of weather conditions on the above indices.

A. Sample network 1 (case 1)

In this state the value of λ and r are considered to be constant and the values of ECOST and EENS are calculated for the whole system. Constant failure rate CFR and constant repair time CRR.

B. Sample network 2 (case 2)

In this state r is constant CRR and λ is in the form of TVFR and has a direct effect on the calculation of the above indices. As depicted in Fig.7, the effect of weather conditions on the above indices is evident.

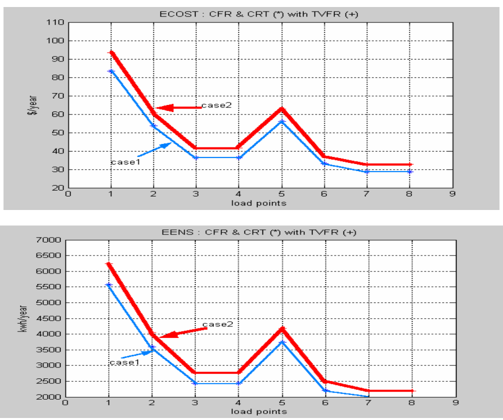

Fig.7. ECOST, EENS graphs in CRT, CFR, TVFR states

C. Sample network 3 (case 3)

In this case λ is considered constant. CFR and r are a function of weather conditions TVRT. It's effect is depicted in the above indices Fig. 8.

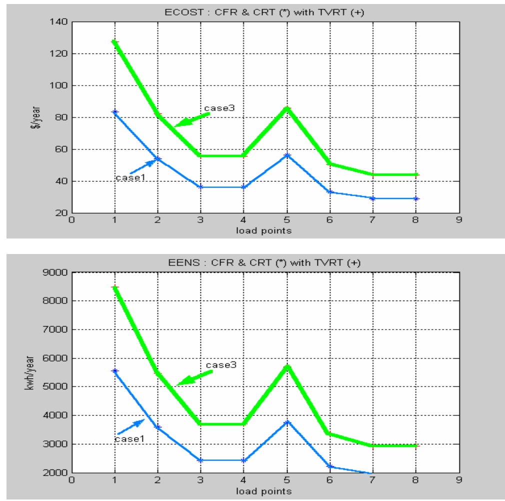

Fig.8. ECOST and EENS in CRT, CFR, TVRT states

To better compare the obtained results and prove that the time-varying weather condition has greater effect on the above factors, the obtained results are studied through Fig. 9.

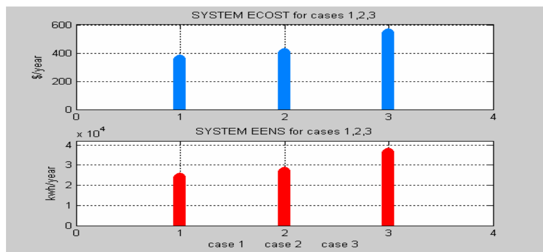

Fig. 9. ECOST and EENS graphs in case 1, 2, 3

As it was expected from the above graphs, we reached a conclusion, that by including weather conditions in repair conditions there were more effects on the EENS and ECOST indices and by this inclusion the system approaches actual conditions and leads to more accurate values to be considered in the study.

Now we introduce the RWNR index system for the comparison of weather effect on ECOST which is calculated as follows:

$$RWNR = EcostB - EcostA \quad (6)$$

and the resultant graphs are obtained as in Fig. 10.

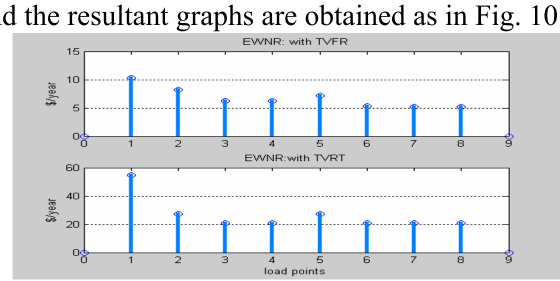

Fig.10. EWNR graph in TVFR and TVRT states

5 ASSESSMENT OF THE RELIABILITY OF DISTRIBUTION NETWORK

Assessment of distribution system reliability is carried out by the related indices that IEEE standard presents them. These indices are defined as load point indices.

5.1 Load point index

In the calculation of reliability, the required parameters should be specified for each load point (20 – 0.4) KV as well as for each circuit element. These parameters are:

A. Failure rate (λ): Failure average number for each component in a definite time. The failure rate is usually expressed according to the number of failures in a year.

B. Repair time (r): The time required to replace or repair the faulty component and start working again. Repair time is usually expressed in hours.

C. Switch time (st): The length of time lasting for the faulty component to be disconnected from the network and other components be electrified in case it is possible with regard to the new network arrangement. Switching time is expressed in hours.

Other parameters to be presented in this part is the inaccessibility to energy or unavailability (u). These parameters represent annual time duration for a component to be disconnected from a network. This time duration is calculated by multiplying (r) and (λ) and its unit is hours/year.

$$U_s = \sum_{i=1}^{n} \lambda_i r_i = \lambda_s r_s \quad (7)$$

$$r_s = \frac{\sum_{i=1}^{n} \lambda_i r_i}{\sum_{i=1}^{n} \lambda_i} = \frac{U_s}{\lambda_s} \quad (8)$$

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \quad (9)$$

Radial distribution system is modeled in the form of serial system. Therefore, equations related to serial system is also true for it. In this system, the above parameters can be obtained from the following equations.

5.2 System indices

A. System average interruption duration index (SAIDI)

$$\text{SAIDI} = \frac{\sum_{i}^{n} U_i N_i}{\sum_{i}^{n} N_i} = \frac{\text{Total customer interruption durations}}{\text{Total number of customers}} \quad (10)$$

N_i is the number of the customers for N_i load point and U_i is the time duration for its exit. For the above sample system is as in Fig.11.

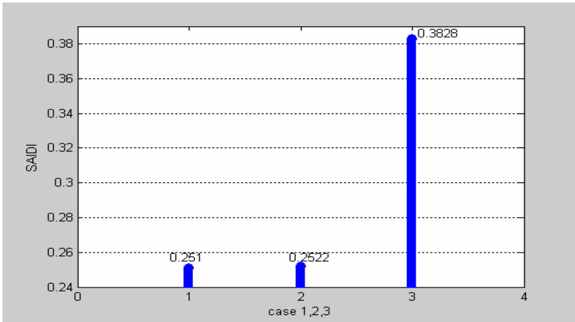

Fig.11. System average interruption duration index (SAIDI)

B. System average interruption frequency index (SAIFI)

$$\text{SAIFI} = \frac{\sum_{i}^{n} \lambda_i N_i}{\sum_{i}^{n} N_i} = \frac{\text{Total customers interruptions}}{\text{Total customers}} \quad (11)$$

N_i is the number of the customers connected to N_i load point and λ is the failure rate. This index shows that how many times each customer experiences interruption on average during the specified time as in Fig.12 in the above system.

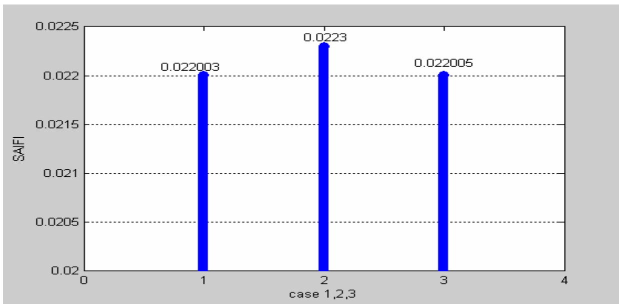

Fig. 12. System average interruption failure index (SAIFI)

C. Customer average interruption duration index (CAIDI)

$$\text{CAIDI} = \frac{\sum_{i}^{n} U_i N_i}{\sum_{i}^{n} \lambda_i N_i} = \frac{\text{Total customer interruption time durations}}{\text{Total customer interruptions}} \quad (12)$$

In this index, the average interruption time for each customer for each interruption is considered. This is investigated in the above system in Fig. 13.

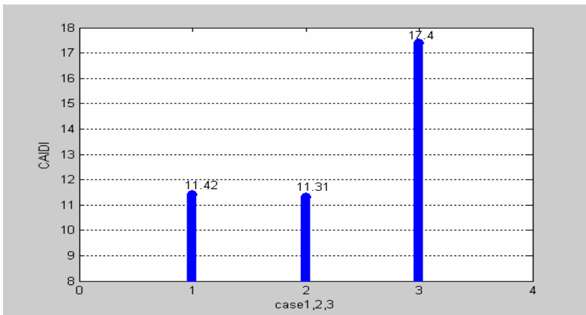

Fig.13. Customer average interruption duration index

D. Average system availability index (ASAI)

$$ASAI = \frac{\sum_{i}^{n} U_i T - \sum_{i}^{n} U_i N_i}{\sum_{i}^{n} N_i T} \quad (13)$$

$$= \frac{\text{Customer availability total hours during study}}{\text{Total hours for all customers during study}}$$

This index shows the customer accessibility rate to electricity in the percentage of the hours connected in relation to the time duration total hours that leads to the results in Fig.14. for the above system considering one-year duration.

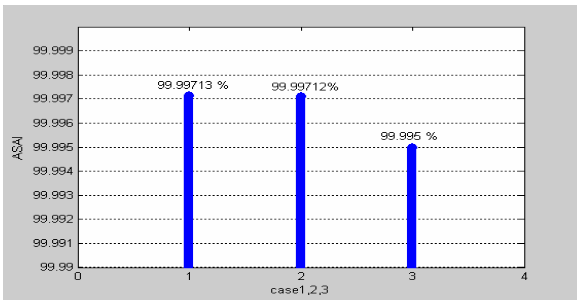

Fig.14. Average system availability index (ASAI)

6 CONCLUSION

It is possible to calculate the reliability in a distribution system by obtaining the unfed energy and reliable indices through the method presented in the paper. The optimization of the network can be carried out by this method. By studying the effect of weather conditions and their effects on the failure and repair promoting conditions as it was predicted before and with regard to the results obtained we can conclude that the TVRT conditions on ECOST and EENS indices of the system are more effective than the TVFR state on the intended system which results in higher indices of SAIDI and CAIDI of the system. It is important to note that in the calculation of reliability, the accessibility to reliable results based on actual data is possible when the power industry can provide precise and comprehensive statistic for the component and element failures in the network as well as repair time or network connection shifting time. This is because the calculation of reliability is not valid and we can never use them as parameters in design without having access to statistics based on facts.

References

[1] M. J. Sullivan, T. Vardell, B. N. Suddeth, and A. Vojdani, "Interruption costs, customer satisfaction and expectations for service reliability,", IEEE Paper 95 SM, 572-8 PWRS.

[2] J. G. Dalton III, D. L. Garrison, and C. M. Fallon, "Value-based transmission planning,", IEEE Paper 95 SM , 566-0 PWRS.

[3] G. Neudorf *et al.*, "Cost benefit analysis of power system reliability:Two utility case studies," *IEEE Trans. Power Syst.*, vol. 10, pp. 1667–1675, Aug. 1995.

[4] R. E. Brown, S. Gupta, R. D. Christie, S. S. Venkata, and R. Fletcher, "Distribution system reliability assessment using hierarchical Markov modeling," *IEEE Trans. Power Delivery*, vol. 11, pp. 1929–1934, Oct. 1996.

[5] R. Billinton and P.Wang, "Teaching distribution system reliability evaluation using Monte Carlo simulation," *IEEE Trans. Power Syst.*, vol. 14, pp. 397–403, May. 1999.

[6] P. Noferi, L. Paris, and L. Salvaderi, "Monte Carlo methods for power system reliability evaluation in transmission and generation planning," in *Proc. Annu. Reliab. Maintainab. Symp.*,Washington, DC, Paper 1294, 1975.

[7] J. C. O. Mello, M. V. F. Pereira, and A. M. Leite da Silva, "Evaluation of reliability worth in composite systems based on pseudo_sequential Monte Carlo simulation," *IEEE Trans. Power Syst.*, vol. 9, pp. 1318–1326, Aug. 1994.

[8] P. Wang and R. Billinton, "Time sequential distribution system reliability worth analysis considering time-varying load and cost models," *IEEE Trans. Power Delivery*, vol. 14, pp. 1046–1051, Jul 1999.

[9] M. V. F. Pereira, M. E. P. Maceira, G. C. Oliveira, and L. M. V. G. Pinto, "Combining analytical models and Monte Carlo techniques in probabilistic power system analysis," *IEEE Trans. Power Syst.*, vol. 7, pp.265–272, Feb. 1992.

[10] R. Billinton and R. N. Allan, *Reliability Evaluation of Power Systems*. New York: Plenum, 1984.

[11] K. A. Clements, B. P. Lam, D. J. Lawrence, T. A. Mikolinnas, A. D. Reppen, R. J. Ringlee, and B. F.Wollenberg, "Transmission system reliability methods-mathematical models, computing methods and results," Power Technologie Inc., Schenectady, NY, EPRI EL-2526, Jul. 1982.

[12] R. Billinton and W. Li, "A novel method for incorporating weather effects in composite system adequacy evaluation," *IEEE Trans. Power Syst.*, vol. 6, pp. 1154–1160, 1991.

[13] *Terms for Reporting and Analyzing Outages of Electrical Transmission and Distribution Facilities and Interruptions to Customer Service*, IEEE Stand. 346, 1973.

[14] R. N. Allan, R. Billinton, L. Goel, I. Sjarrief, and K. S. So, "A reliability test system for educational purposes-basic distribution system data and results," *IEEE Trans. Power Syst.*, vol. 6, pp. 813–820, 1991.