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Reliability Assessment of Radial distribution system incorporating weather effects

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Abstract:- This paper presents a two-stage restoration technique incorporating weather effect considerations in reliability cost/worth evaluation of distribution systems. The weather conditions play a significant role on the reliability of a given power system leading to frequent incidence of failures to overhead system and their effectiveness. The physical stresses exerted by adverse weather increase the failure rates of transmission or distribution lines resulting in increased coincident failures of multiple circuits. Especially adverse weather can cause tremendous system damages and significantly strikes the reliability. Therefore, it is high time to address the issue by devising appropriate technique considering weather conditions. This paper briefly demonstrates the conventional two weather state models which are used for predictive reliability assessment incorporating normal and adverse weather conditions. The paper presents an approach to identify weather specific contributions to system reliability indices and illustrates the technique by utilizing a RBTS distribution system.

Keywords:- Reliability, Adverse weather, Partial automation

I. INTRODUCTION

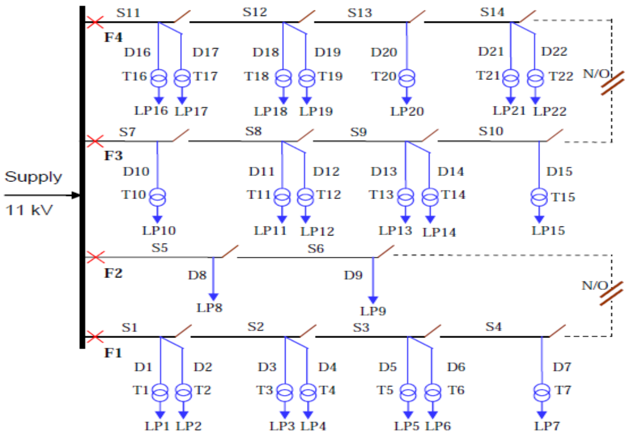
The weather environment is a vital element that severely impacts an electric utility's operational ability and system reliability in overhead transmission and distribution systems. All power system networks are exposed to varying weather conditions. Although extreme events have relatively low probabilities of occurring, when they do occur, they can cause considerable physical destruction resulting in large numbers of customers being interrupted for long periods of time. The impacts can vary depending on the nature of the weather event and the system topology. It is important to identify the weather specific contribution to the total system indices. This can provide a quantitative insight into the potential risk due to failures in the various weather conditions. The recognition of the risk contributed by a particular weather category can be valuable information in working to minimize the anticipated impact. This in itself would not pose any problems but it is found from experience that the failure rate of most components is a function of the weather to which they are exposed. In some weather conditions, the failure rate of a component can be many times greater than that found in the most favourable weather conditions. For these reasons, the effect of weather has been considered for several years and techniques have been developed that permit its effect to be included in the analysis. A distribution system usually occupies a small geographic area and therefore it is liable to be affected by prevailing weather situations. It is noted that the majority of power supply outages occur mainly in distribution systems and that most of these interruptions are due to bad weather conditions [1].

In the past, electric utility customers have tended to tolerate service disturbances with relatively few complaints. In the current electricity market, consumers are using more sophisticated computerized processes and are becoming increasingly sensitive to power interruptions. Customers in a competitive energy market may require different levels of supply reliability at the lowest associated cost. The balance between the reliability and economic aspects can be achieved by integrating reliability evaluation into the planning, design and operating phases. Transmission and distribution systems are usually overhead facilities that operate in a wide range of weather conditions. The failure rates of transmission and distribution lines are greatly enhanced in severe weather situations. Adverse weather conditions such as gales, lightning, snow, frost, icing, high wind, etc. can significantly increase the likelihood of multiple overlapping outages affecting the reliability. There are a number of reliability indices traditionally used to quantify reliability performance at different levels.. The most commonly used reliability indices to measure aggregate electric power utility performance are the System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI), the

Customer Average Interruption Duration Index (CAIDI), Expected Energy Not Supplied (EENS), Expected Customer Cost (ECOST), and Interruptible Energy Assessment Rate (IEAR).

II. RBTS DISTRIBUTION SYSTEM ANALYSIS

The example system shown in Figure 1 is used to illustrate the proposed methodology. It is a part of the Roy Billinton Test System (RBTS) and represents a typical urban distribution system [2]. The customer types include residential, commercial, institution/government and small users. The transformers on Feeders 1, 3 and 4 are utility property and are included in the analysis. The transformers that supply the small users on Feeder 2 are customer owned and are not incorporated in the study. Although the feeders can be meshed through normally open points, they are normally operated as radial feeders. The feeder is sectionalized by disconnect switches. This permits isolation of the faulted sections and service to be restored to the customers on the healthy feeder sections.



Symbols : T – Transformer, D – Distributor, S – Section, F – Feeder, Lp – Load point

Fig. 1 Representative urban distribution system

A. Conventional Approach

Failure events at the specified load point can be identified by a visual inspection of the system topology. A faulted distributor is isolated automatically by a 100% reliable fuse; therefore, the fault on any distributor does not interrupt other loads on the same feeder. A load point on a feeder experiences an outage due to failure of the transformer on the load point, the distributor and any segment of the feeder. The approximate equation method [7] is used to calculate the primary indices. The outage duration depends on the applicable restoration process.

B. Weather considerations

1) *Two state weather modelling:*

The failure rate of a transmission or distribution line is a continuous function of the weather conditions.

i) *Normal weather:* It includes all weather conditions not designated as adverse or major adverse weather.

ii) *Adverse weather:* Designates weather conditions which cause an abnormally high rate of forced outages for exposed components while such conditions persist, but do not qualify as major storm disasters. Adverse weather conditions can be defined for a particular system by selecting the proper values and combinations of conditions reported by the weather bureau: thunderstorms, tornadoes, wind velocities, precipitation, temperature etc.

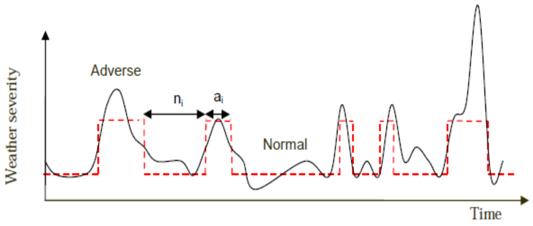


Fig. 2 Chronological weather pattern

n_i = duration of the i^{th} normal weather period

i_a = duration of the i^{th} adverse weather period

The adverse weather periods are assumed to occur randomly and the probability distributions associated with the weather durations are assumed to be exponential. The randomly occurring normal and adverse weather periods can be modelled by the periodic weather pattern shown in Figure 3 below:

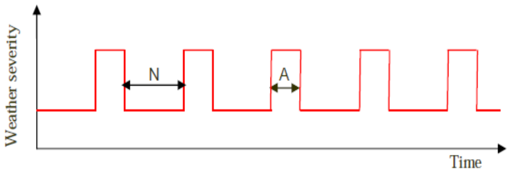


Fig. 3 Average weather profile

N = average duration of normal weather
A = average duration of adverse weather

2) *Failure rate considerations:*

The normal and adverse weather failure rates are expressed in failures per year of time in the respective weather state, not in the number of failures per year.

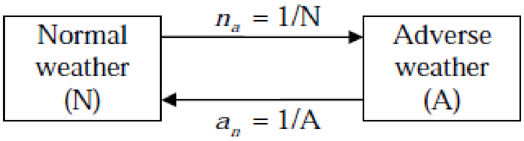


Fig. 4 Two State weather model

The average failure rate and the weather specific failure rates are related as shown in Equation below:

$$\lambda_{avg} = P_n\lambda + P_a\lambda'$$

Where,

λ_{avg} □= average component failure rate expressed in failures per year

$P_n = \frac{N}{N+A}$ Steady state probability of normal weather

$P_a = \frac{A}{A+N}$ Steady state probability of adverse weather

λ□= failure rate expressed in failures per year of normal weather

λ'= failure rate expressed in failures per year of adverse weather

$$\lambda = \lambda_{avg}\frac{(1-F)}{P_n}$$

$$\lambda' = \lambda_{avg}\frac{F}{P_a}$$

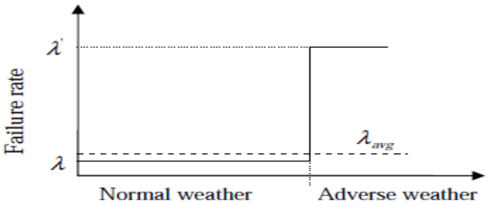


Fig. 5 Failure state representation in two state weather model

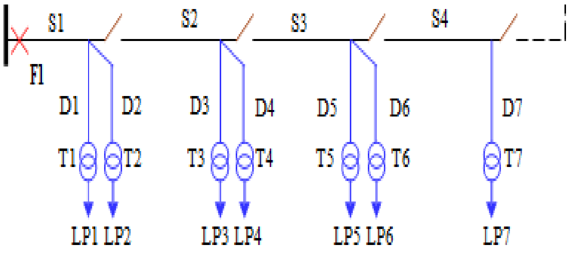


Fig. 6 Representation of feeder1 of RBTS system

The load point indices of average failure rate, average annual outage time and outage duration of feeder 1 are calculated by not considering weather effects and by considering weather effects are compared as shown in the table 1below:

Table1: Load Point indices considering weather effects

Load Point	Failure rate (failures/year)			Unavailability (hours/year)			Outage duration (hours)		
	N	A 40%	A 80%	N	A 40%	A 80%	N	A 40%	A 80%
1	0.2	0.2	3.9	0.8	0.9	9	3	3.3	3.3
2	0.3	0.3	3.9	0.8	1	9.2	3.1	3.4	3.3
3	0.3	0.3	3.9	0.8	1	9.5	3.1	3.4	3.4
4	0.2	0.2	3.9	0.7	0.9	9.3	3.1	3.3	3.3
5	0.3	0.3	3.9	0.8	1	9.2	3.1	3.4	3.3
6	0.3	0.3	4.9	0.8	1	14	3.1	3.4	3.8
7	0.3	0.3	5	0.8	0.9	14	3	3.3	3.7

The average load point failure rates obtained by including weather effects are equal to those obtained using the conventional approach. Unlike the failure rates, the unavailability and the average outage durations increase significantly when weather is included in the calculation. The graphs below represent the comparison of failure, unavailability and outage duration in normal and adverse weather conditions

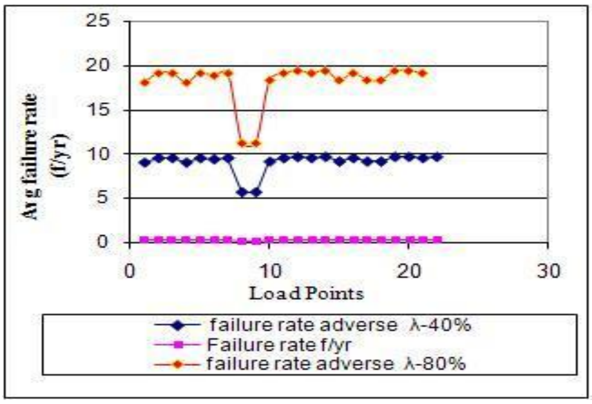


Fig.7. graph of comparison of failure rates

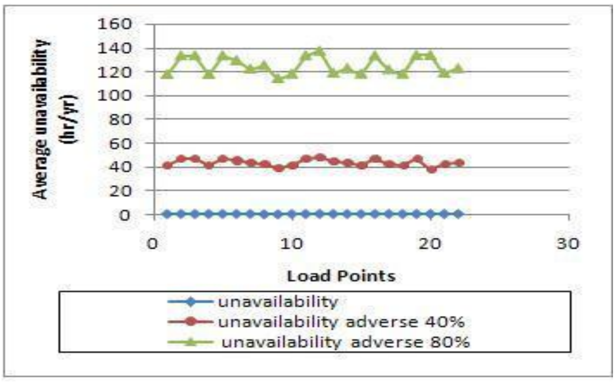


Fig.8. graph of comparison of unavailability

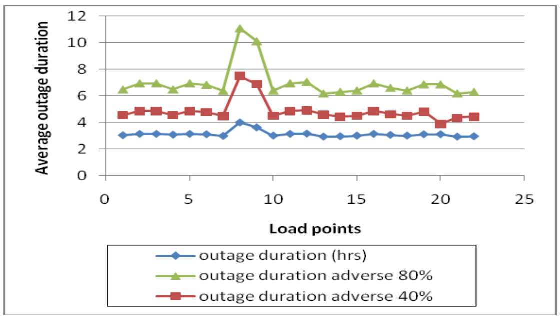


Fig.9. graph of comparison of outage duration

Table2: System indices considering weather effects

Feeder	**SAIFI**			**SAIDI**			**CAIDI**		
	N	A 40%	A 80 %	N	A 40%	A 80%	N	A 40%	A 80%
1	0.25	0.25	4.01	0.77	0.96	9.36	3.1	3.88	2.33
2	0.14	0.14	2.91	0.53	0.72	11.7	3.8	5.12	4.01
3	0.25	0.25	4.9	0.77	0.97	13.9	3.1	3.88	2.84
4	0.25	0.25	4.82	0.76	0.94	13.4	3.1	3.82	2.78
System	0.25	0.25	4.57	0.77	0.96	12.2	3.1	3.86	2.67

The study shows that the expected SAIFI, obtained from weather related failures and the SAIFI from a conventional calculation are the same. The expected SAIDI, however, is largely influenced by the bad weather conditions. The variations in SAIFI, SAIDI, and EENS with changing percentages of bad weather failures are illustrated pictorially in the table above. The system indices for the two cases when the system resides in two weather states are also shown. The table 6 illustrates that the SAIFI increases significantly when a large number of failures occur in extreme weather. The effect is more acute when the failure percentages in bad weather increase from 50% to 90%. The comparison clearly shows that the two state weather models severely underestimate the predicted SAIFI. Similar variations in EENS, ECOST and IEAR are illustrated in the table.

Table3: Cost/Worth indices considering weather effects

Feeder	**ECOST**			**EENS**			**IEAR**		
	N	A 40%	A 80%	N	A 40%	A 80%	N	A 40%	A 80%
1	8.2	10.8	116	2.7	3.4	37.7	2.93	3.1	3.07
2	20	24.7	390	1.1	1.5	25	17.3	16	15.6
3	5.2	6.9	82.7	2.3	2.9	42	2.21	2.4	1.97
4	14	10.3	130	2.5	3.1	46.2	5.31	3.3	2.81
System	47	52.9	719	8.8	11.1	151	5.29	4.7	4.76

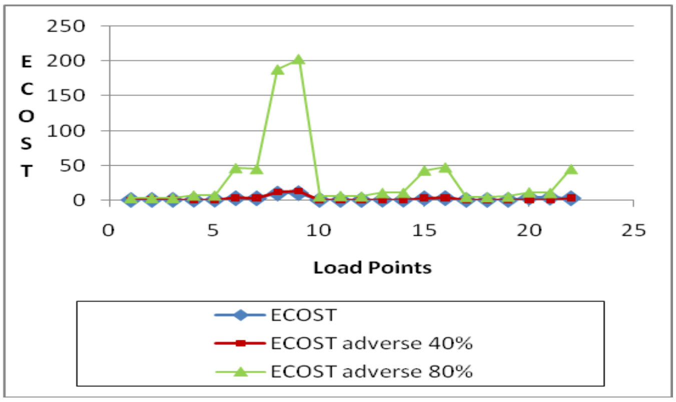


Fig.10. graph of comparison of ECOST

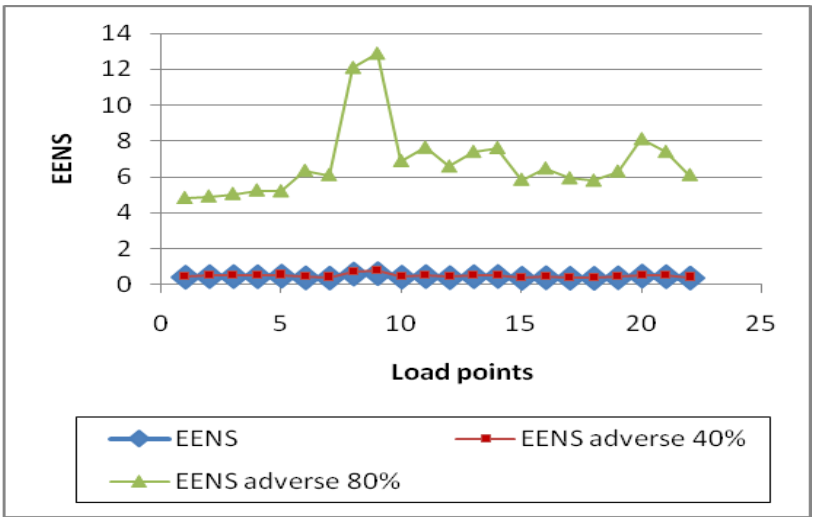


Fig.11. graph of comparison of EENS

Effect of automation on reliability:

Two stage restoration is a viable switching/restoration strategy when a feeder contains automated devices. An automated sectionalizing device operates a very short time after a fault occurs. Device operation may be automatic, or may be performed by a dispatcher through a combination of manual and automated devices. The failure rate of the system remaining the same, the unavailability and the outage duration of the system decrease with automation

Table4: Effect of automation on load point indices considering weather effects

Load Point	**Unavailability (hours/year)**				**Outage duration (hours)**			
	A 40%	P.A	A 80%	P.A	A 40%	P.A	A 80%	P.A
1	0.9	0.8	9	6.1	3.3	3.2	2.3	1.5
2	1	0.8	9.2	6.3	3.4	3.4	2.3	1.6
3	1	0.9	9.5	6.6	3.4	3.4	2.4	1.7
4	0.9	0.8	9.3	6.4	3.3	3.2	2.3	1.6
5	1	0.9	9.2	6.3	3.4	3.4	2.3	1.6
6	1	0.8	14	11	3.4	3.4	2.8	2.2
7	0.9	0.8	14	10	3.3	3.1	2.7	2.1

Table5: Effect of automation on system indices considering weather effects

Feeder	**SAIFI**				**SAIDI**				**CAIDI**			
	A 40%	P.A	A 80%	P.A	A 40%	P.A	A 80%	P.A	A 40%	P.A	A 80%	P.A
1	0.3	0.2	4	4	0.98	0.8	9.4	6.5	3.9	3.3	2.3	1.6
2	0.1	0.1	2.9	2.9	0.7	0.8	12	11	5.1	5.9	4	3.7
3	0.3	0.2	4.9	4.9	0.98	0.8	14	11	3.9	3.3	2.8	2.3
4	0.3	0.2	4.8	4.8	0.9	0.8	13	10	3.8	3.3	2.8	2.2
System	0.3	0.2	4.6	4.6	0.98	0.8	12	9.3	3.9	3.3	2.7	2

Table6: Effect of automation on cost/worth indices considering weather effects

Feeder	**ECOST**				**EENS**				**IEAR**			
	A 40%	P.A	A 80%	P.A	A 40%	P.A	A 80%	P.A	A 40%	P.A	A 80%	P.A
1	10.8	8.8	116	101	3.5	3	38	27	3.1	3	3.1	3.7
2	24.7	28	390	401	1.5	1.8	25	23	16	16	16	17
3	6.94	5.5	82.7	71	3	2.5	42	33	2.4	2.2	2	2.2
4	10.3	8.7	130	115	3.2	2.8	46	36	3.3	3.1	2.8	3.2
System	52.9	51	719	688	11	10	151	119	4.7	5.1	4.8	5.8

A- Adverse weather, P.A- Partial automation

III. CONCLUSION

This paper introduces an approach to divide the overall reliability index into segments related to the weather conditions. A series of case studies are performed on RBTS to examine the effect of failures that occur in bad weather. The numerical results show that the load point failure rates are immune to variations in the percentages of failures occurring in bad weather and load point unavailability's and average outage durations are directly influenced. The SAIFI therefore remains constant but the SAIDI is largely affected. This paper firstly introduces partial automation technique which is caused to reduce the SAIDI, CAIDI effectively. Partial automation technique to limit the adverse effects on system indices would go a long way to overcome the effects of bad and adverse weather conditions on overhead systems.

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