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Research paper

Dualistic Common Mode Outage Model for Reliability Assessment of Composite Power System

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Abstract

Composite power system reliability estimation is gaining attention of researchers due to the rapid growth in interconnected networks. Traditional methods deploy independent outage model for reliability studies. Globally, climate changes are inevitable as hurricanes, tornados and other environmental factors are not under system operator control. As the transmission lines are exposed to environment the model chosen for reliability studies must account for common mode outages involving multiple outages owing to single triggering event. This paper investigates the consequence of common mode outages on composite power system reliability. A dualistic model for common mode pair of transmission lines was adopted for system studies. The proposed methodology is more pragmatic for messily interconnected systems like Indian grids. Reliability experimental networks like RBTS-6 node network and RTS-24 node networks were deployed to validate the methodology.

Keywords: *Common mode outage; Composite power system; Dualistic Model; Reliability assessment; RBTS.*

1. Introduction

Worldwide Electrical Power Systems are becoming more complex and highly interconnected. The primary objective of a power system is to provide electricity to consumers with high degree of continuity and low cost. Reliability is very important parameter considered in power system forecasting and control. Economically viable reliability solution is required for modern competitive electricity markets. Due to over investment operating cost increases and under investment may lower the degree of reliability. So the economic trade-off of these two aspects is quite challenging for power system planner. Environmental and economic constraints forced power system engineers to construct multiple transmission lines on single structure or same right-of-way. All the associated lines of a single tower structure may be affected by a common cause like floods, tornados, earthquakes, accidents etc. Such events resulting in multiple failure effects due to single external cause are designated as common mode outages.

Application of common mode outages was studies for composite power systems [1]. Several models were presented for employing to various system configurations. Adverse effects of weather were integrated using common cause outage model and their numerical analysis was presented in [2]. Novel definition for common cause outage was outlined and the technical and administrative decisions were exercised by authors in [3]. Bayesian networks were exploited to avoid dimensional dilemma in common mode outages during hurricanes. Random sampling was utilized to develop conditional probability distributions in [4]. Terminal equipment at substations may also cause common mode outages. Equipment like circuit breaker and bus bar failures result in common cause outages of lines. Such problem was addressed and effects of protective equipment outages were examined on composite system reliability [5]. In current research a dualistic model [6] was adopted for estimating the reliability of hierarchical level two power system. The proposed methodology is easy to employ for large systems and the system studies become realistic with such common mode outage model.

2. Composite system reliability evaluation

The basic functional sectors of a power system are generation, transmission and distribution. It is very difficult or perhaps impossible to analyzing the entire power system as a distinct entity exercising a completely accurate and comprehensive procedure. A power system is, therefore, generally divided in to segments which may be analyzed distinctly as in [7]. These segments are denoted as generation, transmission and distribution operative regions as shown in below Fig.1

There are two methods available for computing the reliability of Hierarchical Level II systems.

1. Monte Carlo Simulation Techniques.
2. Analytical Methods.

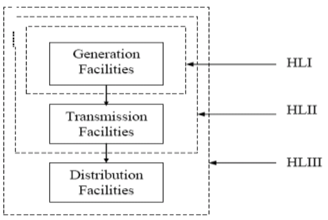

Fig.1: Power system hierarchical levels

Monte Carlo methods of simulation compute the reliability indicators by considering the inadvertent characteristic of the system. These methods consider the problem as a sequence of experiments.

In analytical methods a mathematical representation is exploited to characterize the system and the reliability indices are computed from this model. In this paper state space enumeration approach is used. Analytical methods and Monte Carlo methods have their own advantages and disadvantages as shown in [8].
The computational time required for obtaining the indices is relatively less in analytical techniques. Particular simplifying assumptions are needed when the system is complex and large. Truncation of state space was utilized to condense the state space to a reasonable size so that the computational endeavor reduces with increase in dimension of system [9]. On the other hand the simulation methods may need long time for the computation.

2.1 State Space Enumeration Method

A system state in state space enumeration method is described by the present state and the transition that can occur between states. The system state is the present working condition of working, failed, maintenance etc. The change in state causes the transition from one state to another. Such possible combination of all states makeup the system state space. The state space method has the advantage of applying the markov model for the transition of system states.
One of the main applications of state space method is it can be applied to systems which are repairable and also replaceable. By using probability, frequency of failure and other indices the reliability of repairable systems can be found. As these approach uses calculation of indices by considering state by state it is called as state enumeration method.
Estimation of bulk electrical network reliability is a complex task. The data required for reliability assessment can be divided in to two sets as deterministic data set and stochastic data set. Deterministic data includes line impedances, current carrying capacities and susceptances which is generally available with system planner before conducting reliability studies. Stochastic data like component failure rate and repair rate is difficult to ascertain during planning studies. Hence, stochastic data forms the major basis for composite system reliability evaluation

3. Proposed methodology

3.1 Types of outages

Generally, stochastic component data varies with type of outages considered. Component outages are classified as follows:

a) Independent outages
b) Dependent or conditional outages
c) Common mode outages
d) Station initiated outages

3.1.1. Independent outages

Most of the reliability studies performed in literature assumes the component outages as independent outages. A two state fundamental component prototype is used in which a component is either in upstate or in down state. Failure rate in such model is the rate of departure from upstate to down condition. The frequency of reinstatement from down condition to upstate is designated as repair rate. The outage of an independent even is the product of individual probability of each element. The individual outage probabilities are small then the product becomes extremely low. However, the likelihood of a common mode outage resulting in a similar event could be very high. It is effortless to analyze the system with independent outage model.

3.1.2. Dependent outages

Dependent component outage model assumes that outage is dependent on occurrence of other events. Example of a dependent outage is overload removal of one line of double circuit transmission line due to outage of other line. In order to account dependent outages in reliability evaluation system specific data is needed in additive to component data. Hence, usually dependent outages are not considered for reliability assessment [10]

3.1.3. Common mode outages

The influence of common mode outages system reliability indicators can be more significant. Example of a common mode outage is outage of two lines of a double circuit line supported by single structure [11].

3.1.4. Station initiated outages

Apart from common mode failures two or more lines may be affected due single event at terminal substation. A bus fault, stuck breaker at switching stations could be a triggering event for multiple outages which need not necessarily be common mode outages [12].

3.2. Dualistic Common Mode Outage Model

For two lines on the identical right-of-way or tower structure a dualistic common mode outage model is adopted as shown in fig.2 The availabilities of a common mode pair of transmission lines is obtained as follows:

$$A_c = \frac{\mu_c}{\lambda_c + \mu_c}$$
$$U_c = \frac{\lambda_c}{\lambda_c + \mu_c}$$

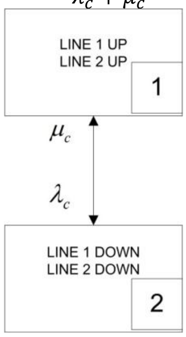

Fig. 2: Dualistic common mode outage model

A simplest model [13]designated as dualistic model used for common mode outages is show in Fig. 2. This model assists to model a pair of lines on the same transmission tower or shared by a common right-of-way.
Where, λ_C and μ_c are rate of departures from states 1, 2 respectively. The individual state probabilities for both states are computed using the following equations

$$P_1 = \frac{\mu_c}{\lambda_c + \mu_c}$$

$$P_2 = \frac{\lambda_c}{\lambda_c + \mu_c}$$

This model is similar to the traditional model with independent failure rates for each line and also valid for common mode pair of transmission lines. Steps followed in the computation of reliability indices is elucidated in the flow chart shown in Fig. 5.

4. Reliability Test Systems

The RBTS is a miniature instructive assessment system created as portion of graduate curriculum in power network reliability estimation at the University of Saskatchewan. The RBTS is a six bus scheme [14] it consists a pair of voltage control nodes, four load nodes, eleven generating sources and nine transmission branches.

The smallest and the largest sizes of the generators are 5MW and 40MW correspondingly. The rated voltage of the experimental system is 230KV and the voltage boundaries for the network buses are presumed as 1.05 per unit and 0.95 per unit. The network has a highest load of 185 MW and the entire installed generating size amounts to 240 MW. The lengths are indicated according to their real lengths. The geographic depiction of the network indicates the arrangement an extra physical fascination and can be deployed to consider numerous sections of the network in terms of the real consumers linked to those areas. The IEEE 24 node Reliability Assessment network [15] was instituted in 1979 by an IEEE committee as a testimonial network which may be exploited to examine and compare approaches for network reliability findings. The network comprises ten generator nodes, seventeen load nodes, thirty eight power transmission links. The network consists of thirty two generators as input. The smallest and largest rating of the generators is 12 MW and 400 MW individually. The aggregate network highest load is 2850 MW and the overall production is 3405 MW.

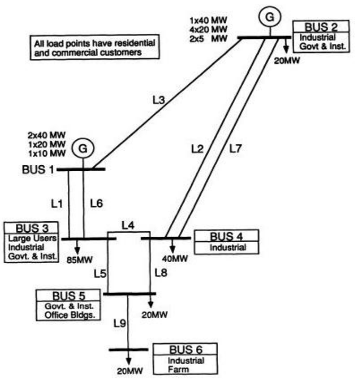

Fig. 3: RBTS-6 bus reliability test system

5. Results and discussion

The proposed methodology was simulated on RBTS-6 node network and RTS-24 node reliability experimental system using MATLAB software. One line scheme of RBTS-6 node network is presented in Fig. 3. There exist two dual circuit lines which are vulnerable to common mode outages. One dual circuit line is between buses 1, 6 and other is between buses 2, 7. Set of indices given in reference [7] are computed for RBTS system for both with and without common mode outage cases and are arranged in Table.1. The effect of common mode outage on system indices may significantly change for different systems. Consequences of considering common mode outages change by changing network topology, size, and complexity of the network. The common mode outage rate of dual circuit line is taken as 10 per cent of the largest outage rate of distinct line forming a double circuit line. The duration of repair is taken as 1.6 times the independent repair duration as given in [1].

The following indices were considered for simulating the reliability experimental systems.

Expected Load Curtailed (ELC) $= \sum_{\substack{k=1 \text{ to } N \\ J=1 \text{ to } n}} L_{kj} F_j$ MW

Expected Energy Not Supplied (EENS) $= \sum_{\substack{k=1 \text{ to } N \\ J=1 \text{ to } n}} L_{kj} P_j * 8760$ MWh

Expected Duration of Load Curtailed (EDLC) $= \sum_{\substack{k=1 \text{ to } N \\ J=1 \text{ to } n}} P_j * 8760$ Hrs

Bulk Power System Disruption Index (BPSDI) $= \sum_{\substack{k=1 \text{ to } N \\ J=1 \text{ to } n}} \frac{L_{kj} F_j}{L_s}$ MW/(MW Yr)

Bulk Power Energy Curtailment Index (BPECI) $= \sum_{\substack{k=1 \text{ to } N \\ J=1 \text{ to } n}} \frac{L_{kj} F_j D_k}{L_s * 8760}$ MWh/(MW Yr)

The results of RBTS-6 bus system shows that the reliability indices increase marginally by considering common mode outages. The RTS-24 bus reliability test system contains more common mode pairs of transmission lines as it is inherently complex in nature. The results will be more prominent for large interconnected systems like RTS-24 bus test system. Though failure probability and outage frequency vary marginally change in other indices is more significant. The results indicate the need to embrace the common cause outages in system studies.

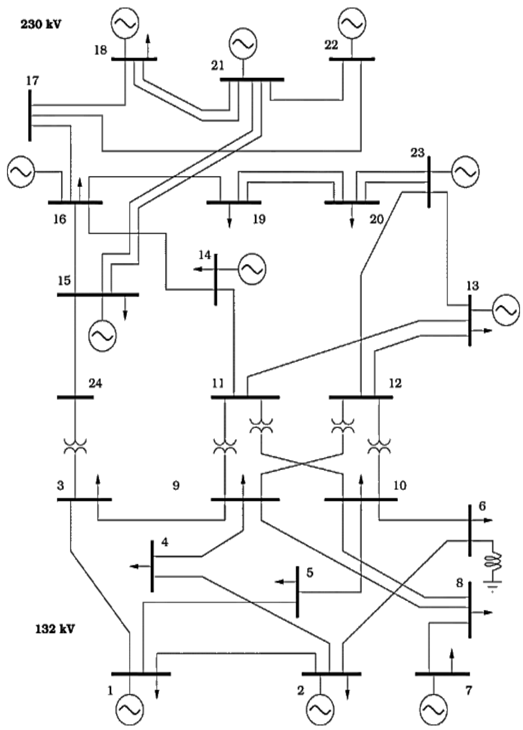

Fig. 4: RTS-24 bus reliability test system

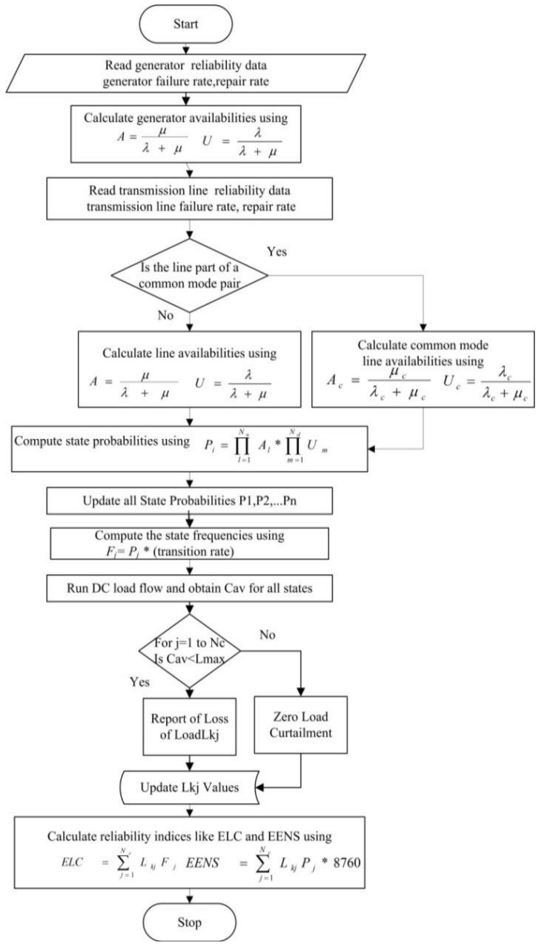

Fig. 5: Flowchart for the proposed methodology

Table.1: Reliability Indices for RBTS-6 bus system

RBTS-6 Bus Test System		
Reliability Index	**Without CMO**	**With CMO**
Probability of failure	0.00117	0.0257
Frequency of failure (f/yr)	1.11987	2.46215
Expected Load Curtailed (MW)	13.6439	25.4156
Expected Duration of Load Curtailed (hours)	10.2935	12.1254
Expected Energy Not Supplied(Mwh)	123.7054	155.2762
Bulk Power Disruption Index(MW/Mw-yr)	0.073751	0.13738
Bulk Power Energy Curtailment Index(Mwh/MW-yr)	0.75915	1.6658

Table.2: Reliability Indices for RTS-24 node system

RTS-24 Bus Test System		
Reliability Index	**Without CMO**	**With CMO**
Probability of failure	0.08098	0.090697 6
Frequency of failure (f/yr)	53.78486	60.23904 3
Expected Load Curtailed (MW)	9404.86	10533.44 3
Expected Duration of Load Curtailed (hours)	709.46	794.5952
Expected Energy Not Supplied(Mwh)	124120.28	139014.7 1
Bulk Power Disruption Index(MW/Mw-yr)	3.29995087 7	3.695945
Bulk Power Energy Curtailment Index(Mwh/MW-yr)	2341.18314 9	2936.780 1

6. Conclusions

Dualistic model simplifies the states of common mode outages for simulating a complex interconnected power system is presented in this paper. An attempt was made to study the effect of common mode failures on composite system reliability indices. The system indices for RBTS-6 bus system shows marginal to moderate change. The influence of common mode failure event on RTS-24 node reliability test system is blended. The basic indices are marginally affected by common mode model. However the system indices are more sensitive to dualistic model. The estimated load curtailed, anticipated energy not supplied and bulk system indices dramatically increase with consideration of common mode outages. The simulation studies revealed the significance of considering common mode outages in composite system reliability of large electric system. Alternative models integrating artificial intelligent techniques may be explored as future work.

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