Stochastic Model for Preventing Blackouts: A Live Case

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ABSTRACT

Power system blackouts cause huge financial losses for the society and power utilities. Two types of blackouts have been identified. One involving load loss due to transmission lines reaching its limits and other involving failures of multiple transmission lines. Technologically advanced electricity transmission networks work in a financially just manner if a high rate of availability of the transmission networks is accomplished. Keeping this concept in mind, it is imperative to conduct the examination of transmission network availability, to design reliable electrical systems. This article discusses the stochastic availability modeling and analysis in transmission lines. The same is applied to a case of GED and the results obtained are discussed with the proper conclusion.

KEYWORDS

Blackouts, Markov Model, Reliability Analysis, Simulation, Transmission Lines

INTRODUCTION

Power is one of the fundamental needs of human beings. As the country grows economically there is a continuous demand for power (Bhagwat & Tiwari, 2017; Mudakkar, Zaman, Khan, & Ahmad, 2013; Sony & Mekoth, 2014; Michael Sony & Mekoth, 2017). Economic growth of the country coupled with continued increase in demand for power makes the power transmission system increasingly complex in the process of evolution over the process of time. The evolution and reliability of power systems are leading engineering accomplishments of the last century that underpin developed societies (Carreras, Lynch, Dobson, & Newman, 2004). However, widespread disturbances of power transmission systems result in significant cost to society and the power utilities (Michael Sony & Mekoth, 2015). To study the complex dynamics of blackouts in power transmission systems, a dynamic model of such a system must be developed. In principle, improving system reliability and reducing operation and maintenance costs are top priorities of electrical utilities. Power scenario assessment of the reliability of transmission lines and assurance of quality power to consumers becomes a vital issue, health of equipment is of utmost importance of industries and society alike, because revenue is affected by the condition of equipment, when demand is high, and equipment is in working order, substantial revenues can be realized. To date in the power systems context, continuous parameter Markov models have been applied most extensively to model power system, reliability, and maintenance models. Stochastic models have been used in very widely used power systems (Aghamohammadi & Salimian,

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2017; Alsammarae, 1989; Gupta, Kazi, Wagh, & Singh, 2018; Sony Michael, Mariappan, & Kamat, 2011), this paper intends to analyze a live case of power blackout situation using stochastic models, for optimum prevention strategies.

System Description

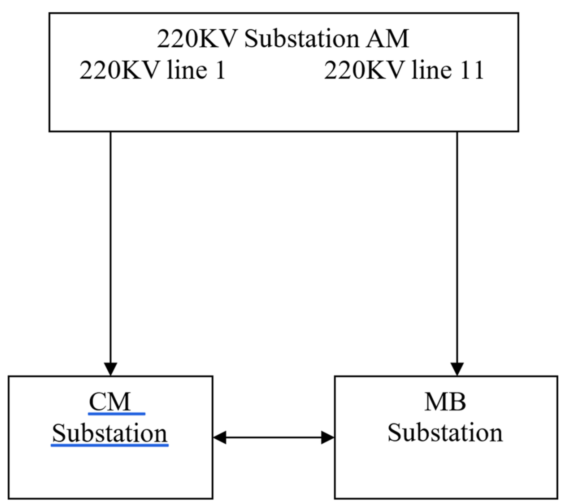
The power to Goa is coming from Western and southern region load dispatch centre. The power is wheeled through two 220kV transmission lines. Due to the apprehension expressed by officials, we do not give the exact names of transmission lines. The power transmission is utilizing the overhead lines. From substation AM two 220kV transmission lines emanate. They terminate in Substation CM and MB which are in Goa region. The network arrangement is given in Figure 1. In Goa region, these lines are in parallel. The transmission line protection relays are employed at substations.

A fault will be detected and the line at fault will be isolated and other lines will continue to feed non-faulty regions. As such the line which is not at fault will continue to be alive and transmit the power. The fault on line can occur anywhere along 118 Kilometer distance of the length of line. The different types of faults noted are earth faults, overcurrent, decapping of insulators, flashover of insulators, conductor related faults, transmission tower related faults which are permanent in nature. The various protections schemes at substations indicate the nature of the fault and the distance protection gives the location of the fault. It is noted that as there is little coordination between state power utilities in India and as such protection coordination studies are not meticulously done (Azavedo, 2017; Dubash & Rajan, 2001; S Michael, Mariappan, Amonkar, & Telang, 2009). It results in erroneous distance protection and nuisance tripping of transmission lines. The fault-finding crews have trouble in locating the faults and rely on manual patrolling of transmission lines in zones to ascertain the exact fault location.

Significances of Transmission Line Failures

Being a emerging country, it relies on double circuit transmission lines to transmit power to various regions. The cost of proposing a new transmission line is high, besides it also involves social dimension like acquiring land of the public. Land acquisition in India is not a straightforward process. There is politics behind it and the legal process behind it is slow and cumbersome. Hence, the existing transmission networks are judicially used. A tripping of these 220kV lines results in the blackout of the region until alternative power is restored from other alternate means. As the existing networks

Figure 1. Block diagram of the system



are overloaded to load growth, to facilitate extra load the quality of power drops. The repair process consists of locating the fault and attending the fault which takes time. The consumer profile effected to outages include Hotels, industries like pharmaceuticals, hospitals, residential etc. Some industries like industry like a pharmaceutical unit incur a considerable loss, with even one second of power failure.

Background Theory

Blackouts are studied from the technical, economic and social point of view. A multi-dimensional study of blackout results in understanding its total implication. Besides it leads to the detailed study of the phenomenon (Yusheng, 2003). Blackouts are of two types. One involving load loss due to transmission lines reaching its limits and other involving failures of multiple transmission lines (Carreras et al., 2004). Interactions occur between both types of blackouts which results in cascade tripping. The critical loading of the transmission line is an important parameter. At the critical loading, there is a sharp rise in the mean blackout size. In addition, the power law probability distribution of blackout size that indicates a significant risk of large blackouts (Nedic, Dobson, Kirschen, Carreras, & Lynch, 2006). It was observed that for 2 consecutive days in July, India experienced blackouts. Nearly more than 600 million people, nearly a tenth of the world's population had to live without electricity. The Indian power sector got its much-needed attention due to blackout. The failing demand-supply gap along with its weak links like transmission systems, inadequate fail-safe techniques etc. were major factors contributing to blackouts (Romero, 2012). The congestion of transmission network results in vulnerability for blackouts. Hence proper generation and transmission planning will result in preventing such man-made power system catastrophes (Xue & Xiao, 2013). Operational systems consist of components that deteriorate and eventually fail. Upon failure, components are either repaired or replaced. Cheap and critical components are usually replaced, while expensive and non-critical ones are repaired before replacement (Hajeeh, 2014). This motivated the authors to stochastically model blackouts in transmission circuits as a run repair run systems to study its dynamic behavior which will help in better transmission line planning.

Modelling Black Outs

The transmission line failure data was collected from the power utility. It was subjected to data analysis using MATLAB. The failure parameters were estimated and are found as follows:

1. Failure rate(line 1) = 0.00324/hr Repair rate(line 1) = 0.0563/hr
2. Failure rate(line 2) = 0.00313/hr Repair rate(line 2) = 0.055487/hr

The distribution of failure and repair was found to be exponential. The level of significance was 5%. Being an exponential process, the entire stochastic phenomenon can be modeled as Markov process. Markov processes are used widely in decision-making processes (Guerreiro, 2018).

Modelling Line States

The state table for the model is given in Table 1.

Table 1. State table

Lines	1	2	3	4
Line 1	⊙	×	⊙	×
Line 2	⊙	⊙	×	×

⊙: denotes working state ×: failed state

State Transition Diagram

The state transition diagram is drawn in Figure 2.

Let:

x1 –is denoted as failure rate (line 1)
x2- is denoted as failure rate (line 2)
x11- is denoted as failure interaction rate of first line when second line fails
x22- is denoted as failure interaction rate of second line when first line fails
u1 – is denoted as repair rate (line 1)
u2 –is denoted as repair rate (line 2)
P_i (∞)= is denoted as the probability that the system is in state i at t=∞

Markov Model

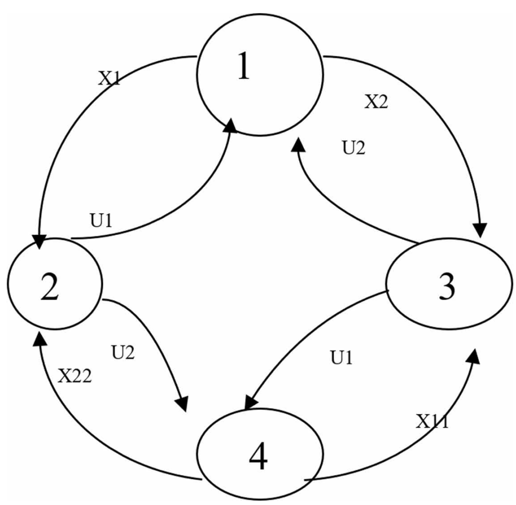
To model as Markov process the state transition table was constructed and it is elucidated in Table 1. Also, steady state transition matrix is as follows:

$$\begin{pmatrix} x1-x2 & u1 & u2 & 0 \\ x1 & -x22-ul & 0 & u2 \\ x2 & 0 & -x11-u2 & u1 \\ 0 & x22 & x11 & -u1-u2 \end{pmatrix}\begin{pmatrix} P_1(\infty) \\ P_2(\infty) \\ P_3(\infty) \\ P_4(\infty) \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

Such a system is modeled as a continuous-time Markov process with discrete states. Once the transition matrix is known the stationary probabilities can be computed and therefore the performance measures of the model under consideration can be easily evaluated (Diamantidis, Koukoumialos, & Vidalis, 2017).

It is evident from the equations in the matrix is not independent. Hence the sum of all probabilities equal to one, the matrix equations is revised as:

Figure 2. State transition diagram



$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ x1 & -x22-ul & 0 & u2 \\ x2 & 0 & -x11-u2 & u1 \\ 0 & x22 & x11 & -u1-u2 \end{pmatrix} \begin{pmatrix} P_1(\infty) \\ P_2(\infty) \\ P_3(\infty) \\ P_4(\infty) \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

The equations are solved and the solution is delineated below:

$$P_1(\infty) = \frac{u1*u2*(x22+u2+u1+x11)}{\begin{pmatrix} x22*u1*u2+x22*x1*x11+x22*x1*u2+x22*x2*x11+x11*x2*u1+x11*x2*u22 \\ +x22*x1*u1+x22*u1*x2+u1*\mathbf{u}2*x2+x1*u2\hat{\ }2+x1*u1*u2+x1*u2*x11+u1* \\ u2\hat{\ }2+u1\hat{\ }2*x2+u1\hat{\ }2*u2+u1*u2*x11 \end{pmatrix}} \quad (1)$$

$$P_2(\infty) = \frac{u2*(x1*u1+x2*x11+x1*u2+x1*x11)}{\begin{pmatrix} x22*u1*u2+x22*x1*x11+x22*x1*u2+x22*x2*x11+x11*x2*u1 \\ +x11*x2*u2+x22*x1*u1 + x22*\mathbf{u}1*x2+u1*u2*x2x1*u2\hat{\ }2+x1*u1*u2 \\ +x1*u2*x11+u1*u2\hat{\ }2+u1\hat{\ }2*x2+u1\hat{\ }2*u2+ u1*u2*x11 \end{pmatrix}} \quad (2)$$

$$P_3(\infty) = \frac{u1*(x22*x2+x22*x1+x2*u1+x2*u2)}{\begin{pmatrix} x22*u1*u2+x22*x1*x11+x22*x1*u2+x22*x2*x11+x11*x2*u1+x11*x2*u2+ x22*x1*u1 \\ +x22*u1*x2+u1*u2*x2+x1*u2\hat{\ }2+x1*u1*u2+x1*u2*x11+u1*u2\hat{\ }2 +u1\hat{\ }2*x2+u1\hat{\ }2*u2 \\ +u1*u2*x11 \end{pmatrix}} \quad (3)$$

We get the following values:

$P_1(\infty) = 0.9011$ $P_2(\infty) = 0.0518$ $P_3(\infty) = 0.0423$ $P_4(\infty) = 0.0049$

Diagrammatic representation using histogram is specified in Figure 3.

Availability = $P_1(\infty) + P_2(\infty) + P_3(\infty) = 0.9951$

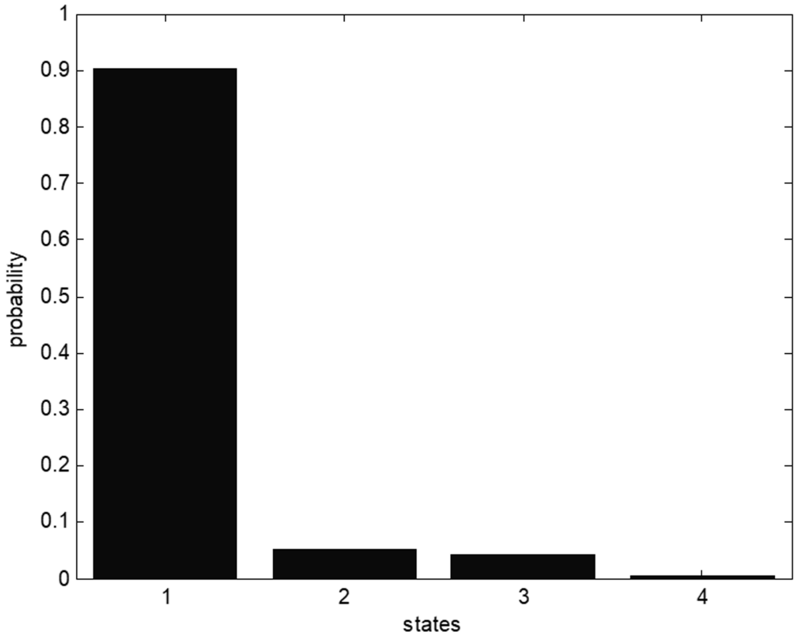
Blackout Residence Time and Cycle Time

To calculate the mean residence time in each state which has a special significance for modelling black outs. The state 4 residence time will indicate the expected black out time:

$$T_1\text{ (res)} = \frac{1}{(x1+x2)} = 172.5\text{ hrs}$$

$$T_2\text{ (res)} = \frac{1}{(x22+u1)} = 16.4\text{ hrs}$$

Figure 3. Histogram of probabilities and states



$$T_3(\text{res}) = \frac{1}{(x11 + u2)} = 16.2 \text{ hrs}$$

$$T_4(\text{res}) = \frac{1}{(u1 + u2)} = 9 \text{ hrs}$$

The cycle time between encountering each state or black out is very essential:

$$T_1\ (\text{sys}) = \frac{1}{A_1\ *(x1 + x2)} = 191.4 \text{ hr}$$

$$T_2(\text{sys}) = \frac{1}{A_2\ *(x22 + u1)} = 318\text{hrs}$$

$$T_3(\text{sys}) = \frac{1}{A_3\ *(x11 + u2)} = 382\text{hrs}$$

$$T_4(\text{sys}) = \frac{1}{A_4\ *(u1 + u2)} = 1853 \text{ hrs}$$

Significance of Cycle Time for Blackout and Brownout Analysis

The cycle time for encountering blackout i.e. in state 4 i.e. both 220 KV lines down phase is on an average 1853 hrs i.e. 77 days. Correspondingly, the cycle time for encountering brown out i.e. state 2 and 3 is 13 days and 16 days respectively. The preventive maintenance activities would not yield economically for exponential systems. Other techniques of maintenance management like condition monitoring of the lines should be done. The time of inspection for carrying out this activity is the min $\{T_3(Sys), T_4(Sys)\}$. It is advocated to monitor thermal parameters using IR cameras etc. Standard operating procedures with respect to actions to be taken in the event of failure of lines will result improper informed actions by the operating and maintenance personnel. This can result in further prevention of further cascade tripping's. This has also special significance to lead time for procurement in inventory management system. It is advocated, that the lead time for procurement should be less than the minimum cycle time of states, as there is a similarity in materials of both lines.

Significance of Impact of Failure Interaction Rate on Blackout

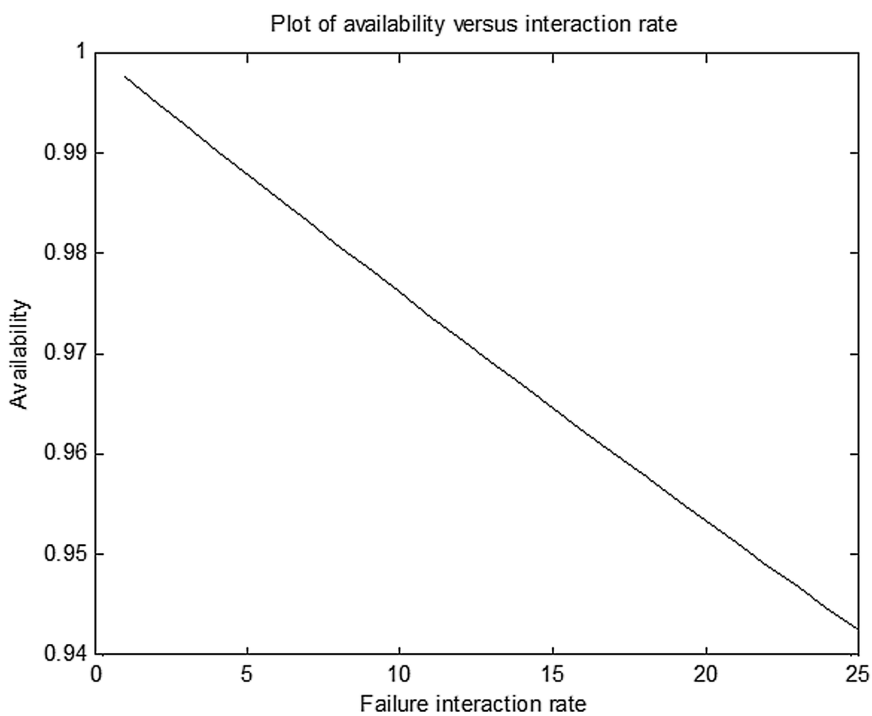
To investigate the impact of failure interaction rate on blackout an analysis in terms of the interaction rate variation is performed. Table 2 envisages the interaction phenomenon.

The graph of the above findings as shown in Figure 4 conforms to the normal notion that increased interaction rate decreases the availability of the system.

Table 2. Interaction rate and availability

Interaction Rate	1	2	3	4	5	6	7	8
Availability	0.9976	0.9951	0.9927	0.9903	0.9879	0.9856	0.9832	0.9808
Interaction rate	9	10	11	12	13	14	15	16
Availability	0.9785	0.9762	0.9739	0.9715	0.9692	0.9670	0.9647	0.9624
Interaction rate	17	18	19	20	21	22	23	24
Availability	.9602	0.9579	0.9557	0.9535	0.9512	0.9490	0.9468	0.9447

Figure 4. Availability versus failure interactions



Sensitivity Analysis

The sensitivity analyses of the model are carried out to study the impact of the proposed options on blackouts. The reliability of a system can be changed by incorporating various measures which will help in improving the system.

Using Single Repair Squad

An analysis is carried out, here to stress the fact that if there would be only one repair crew available for repairs, how the availability would reduce and also how it pays to have independent repair crews. The system failure and the repair rates are assumed to be constant. Markov and supplementary variable methodologies have been used to achieve the mathematical analysis of this model (Ram & Manglik, 2016).

The Steady State Markovian Transition Matrix:

$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ x1 & -x22-ul & 0 & u1 \\ x2 & 0 & -x11-u1 & 0 \\ 0 & x22 & x11 & -u1 \end{pmatrix} \begin{pmatrix} P_1(\infty) \\ P_2(\infty) \\ P_3(\infty) \\ P_4(\infty) \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

The set of above matrix equation is solved using code written in MATLAB 7.0:

$$\mathrm{P}_1(\infty) = \frac{\text{u1^2*(u1+x11)}}{\begin{pmatrix}\text{x22*x2*x11+x22*x1*x11+x22*x1*u1+2*x11*x2*u1} \\ \text{+x1*u1*x11+x1*u1^2u1^3+u1^2*x2+u1^2*x11}\end{pmatrix}} \tag{4}$$

$$\mathrm{P}_2(\infty) = \frac{\text{u1*(x1*u1+x2*x11+x1*x11)}}{\begin{pmatrix}\text{x22*x2*x11+x22*x1*x11+x22*x1*u1+2*x11*x2*u1} \\ \text{+x1*u1*x11+x1*u1^2+u1^3+u1^2*x2+u1^2*x11}\end{pmatrix}} \tag{5}$$

$$\mathrm{P}_3(\infty) = \frac{\text{u1^2*x2}}{\begin{pmatrix}\text{x22*x2*x11+x22*x1*x11+x22*x1*u1+2*x11*x2*u1} \\ \text{+x1*u1*x11+x1*u1^2+u1^3+u1^2*x2+u1^2*x11}\end{pmatrix}} \tag{6}$$

we have:

$P_1(\infty) = 0.8969$; $P_2(\infty) = 0.0559$; $P_3(\infty) = 0.0377$; $P_4(\infty) = 0.0096$

Blackout Analysis is carried out the option as follows.

It is noted that there is a reduction in availability with one repair crew. Going to the further details of the implications of the reduction in availability:

Availability with each unit having its own repair crew = 0.9951
Availability with each unit having only one repair crew = 0.9904
As both lines operate round the clock let us calculate in one-month availability = 24x30 = 720 hrs

Availability with each unit having its own (dedicated) repair crew = 0.9951x720 = 716.4720 hrs
Availability with each unit having only one repair crew =0.9904 x 720 = 713.0880
Extra availability in one month each unit having own repair crew = 3.3840 hrs.
Monthly average units transmitted = 71,000,000 KWH (past data projections)
Units/ hr = 70,000,000 / (30 *24) = 98611 units
Cost of buying = Rs.1.003/-
Extra Number of units (due to independent repair staff) = 98611 *3.3840 = 333699 units
Transaction worth = Rs.1.003 * 333699 = Rs.334700/- is lost by the Electricity Department / month.
Wijayatunga and Jayalath (2004) that the loss caused to the society is around 0.9% of GDP of the region)
Loss to Electricity Department = Rs.334700/-
Loss to society (Wijayatunga & Jayalath, 2004) = Rs. 33,90,410/-

This works out to be loss to Electricity department and loss to the society as well. Hence it can be inferred that both the lines are desirable to have independent repair crews /machines.

Case of Reducing Repair Time

In this analysis let us try to reduce the repair time than see the corresponding change in availability. To this effect it is coded in MATLAB 7.0 with various repair times. The effect of repair time reduction and respective change in availability are given in Table 3. This table is quite useful for maintenance policy decisions.

Blackout Analysis is carried out for this option as follows, For the sake of analysis, the repair time of these lines are divided into three parts:

1. **Operational/maintenance readiness:** Which is making line ready for maintenance or recharging the line after maintenance. This involves issuing of line clearance and obtaining no feedback clearance from concerned substations;
2. **Fault location:** This involves location of fault. Once the fault occurs we get information from the distance relay. As the zones in distance relay will indicate in which zone the fault. The entire line is divided into three zones. Roughly at 40 KM stretch. Now this distance is patrolled by men to locate the fault physically. After getting the fault the remaining part is also patrolled to ensure some other section is faulty or not;
3. **Man/material/machine arrangement and actual repairs:** Here we actually arrange the materials and repair the lines.

From the experience of maintenance staff, it is learnt that on an average the percentage of time spent on repairs is 10% for operational/ maintenance readiness, 50% for fault location & material arrangement, 40% for actual attending of repairs.

Table 3. Repair time reduction and availability

% Reduction in Repair Time	0	5	10	15	20	25	30	35
Availability	.9951	.9956	.9960	0.9964	0.9968	0.9972	0.9975	.9979
% Reduction in repair time	40	45	50	55	60	65	70	75
Availability	0.9982	0.9985	0.9987	0.9990	0.9992	0.9994	0.9995	0.9997
% Reduction in repair time	80	85	90	95	100			
Availability	0.9998	0.9999	0.9999	.99999	1.0			

Let us find the coefficient of variation of both repair times:

Standard deviation of repair time for line1 = 16.8851
Mean of repair time for line1 = 17.9886
Coefficient of variation = Standard deviation / mean = 0.9387
Standard deviation of repair time for line2 = 15.8385
Mean of repair time for line2 = 18.0308
Coefficient of variation = Standard deviation / mean = 0.8784

The coefficient of variation of both lines are almost equal which suggest that both this repair crew is using the same technique for repairing the fault or in other words there is high degree of consistency in repair time i.e. = 93.5762% of both this independent repair crew, which makes us believe that present technique adopted by the department is followed very strictly and useless wasting of time by doing un productive work is very less i.e. around 100 – 93.5762 = 6.4%. This leaves a very little scope for improvement with the existing technique followed by the department. Therefore, better technique, improved technology & new tools /equipment for repairs are to be thought of.

Hence to further reduce repair time, the following recommendations are proposed:

1. Reducing operational / maintenance readiness which amounts to 10% of overall repair time under existing system can be reduced by better system design, by work study experts;
2. Reducing fault locating/material arrangement. Fault location time can be reduced by using new technology like Global Positioning System mapping of transmission lines, Power Line Carrier Current for distance protection etc. Since the material for attending fault are simple, like conductors, insulators (3 types), pulleys and steel rope. So, these materials can be carried on the vehicle which transports men for fault finding. This will reduce the repair time;
3. While deciding on any new technology it is recommended that reduction in repair time may be compared with our table (Table 3) and then accordingly corresponding increase in availability and economic feasibility may be calculated.

Case of Reduced Failure Interactions

Here an attempt is made to investigate implication of reduced failure interaction on availability of transmission lines.

The Steady State Markovian Transition Matrix:

$$\begin{pmatrix} 1 & 1 & 1 & 1 \\ x1 & -x2-u1 & 0 & u2 \\ x2 & 0 & -x1-u2 & 0 \\ 0 & x2 & x1 & -u2 \end{pmatrix} \begin{pmatrix} P_1(\infty) \\ P_2(\infty) \\ P_3(\infty) \\ P_4(\infty) \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

The set of above matrix equation is solved using code written in MATLAB 7.0:

$$\mathrm{P}_1(\infty) = \frac{u1 * u2}{\mathrm{u1*u2+x1*x2+x1*u2+x2*u1}} \tag{7}$$

$$\mathrm{P}_2(\infty) = \frac{\mathrm{x1*u2}}{\left(\mathrm{u1*u2+x1*x2+x1*u2+x2*u1}\right)} \tag{8}$$

$$P_3(\infty) = \frac{x2*u1}{(u1*u2+x1*x2+x1*u2+x2*u1)} \quad (9)$$

substituting the values:

$P_1(\infty)$= 0.9033 $P_2(\infty)$ = 0.0520 $P_3(\infty)$ = 0.0423 $P_4(\infty)$ = 0.0024

The availability is calculated to be = A (∞) =0.9976.
Blackout Analysis is carried out as follows:

The availability when the interaction rate is twice = .9951(as calculated)
Availability in a month when interaction rate is twice = 0.9951x720 = 716.4720 hrs
Availability in a month when interaction rate is single = 0.9976x720 = 718.2720 hrs
Extra availability hrs in month = 718.2720 - 716.4720 = 2.20hrs
Average number of units transmitted per hour = 97222
Extra units transmitted per month = 97222* 2.20 =213890
Extra transaction per month = Rs. 1.003 * 213890 = Rs.214530/-
As per Central Public Department manual the age of transmission line 25 years
Transaction cost worth = 25 * 12* 214530 =Rs. 64359000/-

Considering it as simple active parallel system availability would be 0.9976 which amounts to extra transaction of Rs. 2, 14,530/- per month. The useful life of transmission line as per CPWD (Central Public Works Department) manual is 25 years. Transaction worth = 25 * 12* 214530 =Rs. 6, 43, 59,000/- will be possible if such a philosophy is implemented. However, the cost of constructing a 220KV tower line is around Rs.59, 00,000/- per kilometer. So total cost of transmission line is 120 x 59, 00,000 =Rs.70, 80, 00,000/-. This amount to 11 times the profit. Hence such an option is not economically feasible. However existing conductor & insulators is replaced with a higher current carrying one, than still the independency would be maintained, and these costs will amount to Rs.28,32,00,000/-. (70,80,00,000 x 0.40). This also is around 4.5 times the value of the profit. This also is not an economical option. So, in order to reduce failure interactions during the fault on any one line, it is recommended to de-rate the healthy line. Also, it is recommended to reduce the repair time of faulty line. This solution will not solve the problem from the root; however, this short-term solution will temporarily avoid total failure of the system / black out. Power is one of the infrastructures for development hence, while deciding on either going for another transmission line or changing the conductor to higher value etc., it is recommended to the Department, to analyze not only the loss, to the department, but also the loss to the society i.e. around Rs. 42, 90,600/- per month. Hence the option of changing the conductors to new one will break even in in 66 months or 5 years and 6 months. The other option of going for new transmission line will break even in 165 months or 13 years and 9 months. Considering both the options it is proposed that for finding permanent solution to the above problem the option of changing the conductors & insulators to higher value may be implemented.

Blackout Prevention Strategy

Maintenance optimization models aim at finding an optimum balance between the cost of running a system with maintenance and the benefits obtained from it. Generally, maintenance optimization models cover four categories: (*1*) a description of the technical system, (*2*) a modelling of the system deterioration and its consequences, (*3*) a description of the available information of the system, and (*4*) an objective function and an optimization technique for finding best alternative or balance (Hajeeh, 2011). 100% reliability of transmission system is a theoretical assumption, rather than practical possibility. Acts of God like storms, hurricanes etc can derail a power system. In addition, human errors cannot also be reliability. The goal of any black out prevention program should be to achieve optimum level of practical reliability (Pourbeik, Kundur, & Taylor, 2006). Some strategies like the prioritized replacement of transmission control and/or protection equipment. In addition, there should be regular maintenance of transmission lines. The evaluation, and testing of power plant should be given a priority. The substation equipment should be periodically inspected to ensure that the equipment is maintained in a good condition. Also, it should be confirmed that he equipment's are operating within design parameters. Life cycle assessment of equipment should be carried out to prolong the equipment life through proper maintenance and testing.

CONCLUSION

The following recommendations are presented:

1. Stochastic modeling of transmission lines was performed on 220KV Line-1 & Line -2 to Goa region. The Markov model was used in the situation and availability of both these transmission lines when we assumed that only one repair crew/tools/equipment was found to be 0.9904. When the same model was solved with the assumption that there exist an independent repair crew/tools/material for both these lines than the availability was found to be 0.9951. Due to this increase in availability the transaction worth Rs. 334700/- can be had by the Electricity department and this also reduces the loss to the society worth Rs. 3390410/-.Hence it is recommended to use independent repair crew for both the lines;
2. Analysis of reduction in repair time reveals increases the availability, our analysis further shows that there is a high degree of consistency (93.6%) in repair time for this both independent repair crews, which makes us believe that present technique adopted by the department is followed very strictly and useless wasting of time by doing un productive work is very less i.e. around 100 – 93.5762 =6.4%. Hence to further reduce repair time, the following recommendations are proposed:
    a. Reducing operational / maintenance readiness which amounts to 10% of overall repair time under existing system can be reduced by better system design, by work study experts;
    b. Reducing fault locating/material arrangement. Fault location time can be reduced by using new technology like Global Positioning System mapping of transmission lines, Power Line Carrier Current for distance protection etc. Since the material for attending fault are simple, like conductors, insulators (3 types), pulleys and steel rope. So, these materials can be carried on the vehicle which transports men for fault finding. This will reduce the repair time;
    c. While deciding on any new technology it is recommended that reduction in repair time may be compared with our table (Table 3) and then accordingly the corresponding increase in availability and economic feasibility may be calculated;
3. Considering it as simple active parallel system availability would be 0.9976 which amounts to extra transaction of Rs. 2,14,530/- per month. In 25 years transaction worth Rs. 6,43,59,000/- will be possible if such a philosophy is implemented. However, the cost of constructing a 220KV tower line Rs. 70,80,00,000/-. This amount to 11 times the profit. Hence such an option is not economically feasible. However, if the existing conductor & insulators are replaced, with a higher current carrying one than still independency would be maintained and its costs will amount to Rs.28,32,00, 000.This also is around 4.5 times the value of the profit. This also is not an economical option as far as department is concerned. Hence in order to reduce failure interactions during the fault on any one line, we have to resort to de-rating of healthy line & reduce the repair time of faulty line. This solution will not solve the problem from the root, however, this is a short-term solution to temporarily avoid total failure of the system / black out;

4. Power is one of the infrastructures for development hence, while deciding on either going for another transmission line or changing the conductor to higher value etc., we recommend to the Department, to analyze not only the loss, to the department, but also the loss to the society i.e. around Rs. 42, 90,600/- per month. Hence the option of changing the conductors to new one will break even in in 66 months or 5 years and 6 months. The other option of going for new transmission line will break even in 65 months or 13 years and 9 months. Considering both the options it is proposed that the option of changing the conductors & insulators to higher value will permanently solve the problem.

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