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Economic profit estimation of tranmission system using novel contingency ranking with markov modelling

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ABSTRACT

Technique to evaluate probability of occurrence of selected contingencies of 6 Bus Roy Billinton Test System (RBTS) and IEEE 9 Bus system by Markov modelling is presented in this paper. Obtained probabilities for selected contingencies are validated by comparing with binomial distribution based probabilities. Load flow analysis and performance index based contingency ranking of total elements of 6 bus RBTS and IEEE 9 Bus systems is simulated by Power System Simulation for Engineers (PSSE) software. Novel reliability evaluation technique which unify contingency ranking with Markov modeling is proposed for RBTS and extended to IEEE 9 Bus system. Accuracy, completeness and simple to implement are salient features of proposed novel reliability evaluation method. Reliability of RBTS and IEEE 9 Bus systems can be improved by incorporating Flexible Alternating Current Transmission Systems (FACTS) device. Improvement in the reliability and economic revenue of RBTS and IEEE 9 Bus systems due to Unified Power Flow Controller (UPFC) incorporation is evaluated.

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1. INTRODUCTION

System with higher operational efficiency along with economical benefit are more effective. Establishment of such systems is the need of the day [1]. Operating condition of transmission system significantly effects the composite power system operation. Physical property of merterial, environment to which conductor is exposed, the number of years a line is in service and thermal & electrical loading at which transmission line is operating will influence the failure of transmission line. Contingencies due to these causes will drag the composite power system into unreliable operation [2]. Economic and environmental factors introducing renewable energy sources and lot of automation into the existing electrical power system [3]. Reliability of such hybrid electrical power systems, improved by Dynamic Thermal Rating (DTR) system [4-6]. To evaluate and comprehend the improvement in the reliability of the composite power system it is essential to have clarity of basic electrical power system reliability. Then only it is possible to asses the degree of improvement in the reliability. A complete systematic method of reliability evaluation of basic composite power system is presented clearly in the present paper. Contingency analysis of composite power system deals with operational aspects such as fault analysis, power carrying capability of transmission systems [7]. Examination of composite power system operational aspects, based on contingency ranking [8-9] will present partial assessment of the system. Contingency ranking cum reliability evaluation based analysis results in holistic system analysis. Very less work has been presented in the literature on contingency ranking based reliability evaluation of transmission system. System reliability is evaluated by screening severe contingencies based on Probability Performance Index (PPI) [10]. But moderately severe and less severe outages do effect the system operation and contribute to the unreliable operation of the system. Hence negation of moderately and less severe contingencies will result incomplete analysis and inaccurate indices of the system. Novel method, which combine contingency ranking with Markov model for reliability evaluation, including severe, moderately severe and less severe contingencies proposed in this paper. Thus obtained results, load point and system indices [11] are more accurate reliability indices of the system. Contingency constrain related to generation and evaluation of Loss of Load Expected (LOLE) is presented [12], but the proposed approach analysis transmission contingencies along with generation and evaluates complete load point and system indices.

FACTS devices play critical role in improving the system performance by reducing the transmission losses [13-16]. System contingency states which will fail to feed the load are strengthened and made capable of feeding the load due to the incorporation of UPFC. Power transported through transmission system and supplied to the load increases, thus establish more reliable system. Load demand increases day by day and it is unpredictable to assess peak load occurrences certainly. General practice to meet this scenario is installation of huge generation capacity than the expected regular normal load. Losses corresponding to excessive generation capacity when system is operating at light loads will lead to unreliable operation of the system.

Investment corresponding to excessive capacity is another economical drawback, Due to light loads operating conditions, system will encounter over voltages problems [17-18]. UPFC will address over voltage problem by establishing voltage regulation thus resulting in reliable composite power system. Along with power consumed, distribution /consumer/ loads are charged even for the power transportation losses [19]. By reducing the transmission system losses, consumer will be supplied by higher amount of power for the same bill. Supplementary power available for the load will generate the additional income to the transmission system [20]. This approach of reducing the losses by incorporation of UPFC, more economical system can be established for the consumer. Higher reliable system with economical profit is the best system which is of first choice of every consumer.

2. CONTINGENCY RANKING WITH MARKOV MODELLING

Newton Raphson (N-R) load flow [21] simulated on RBTS and IEEE 9 Bus systems for base case in Power System Simulation for Engineers (PSSE) software [22]. Configuration of RBTS [23-25] is shown in Figure 1 and Table 1. Figure 2 and Table 2 present the configuration of IEEE 9 Bus system. By creating each element outage based on the corresponding magnitudes of active power flows through transmission lines, contingencies are ranked in the descending order. Performance index (PI) will indicate percentage of overloading of the transmission lines. Based on PI value beyond (N-1) and (N-1)-1 contingencies, system control schemes will come into the operation and restore the system to safe operating conditions. Thus N-1 and (N-1)-1 contingencies are selected and corresponding power available to the load are listed out in Table 4 and Table 5.

Peak load of 237 MW for RBTS and 230 MW for IEEE 9 Bus system are considered for load flow. Binomial distribution is one of the standard distributions which has its application in reliability evaluation. Probability of occurrence of operating state of an element is availability A and the probability of occurrence of failure state of an element is unavailability U then the availability of each element is obtained by $nC_rA^{(n-r)}U^r$ where n is the total number of components r is outage components.

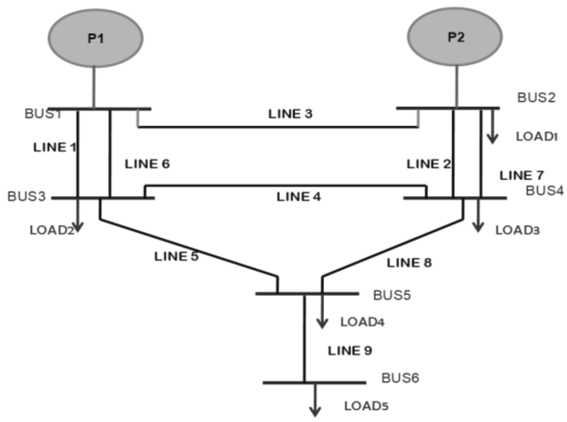

Figure 1. Schematic diagram of RBTS 6 bus system

Table 1. RBTS Configuration

No. of Generators	Capacity (MW)	Total Capacity (MW)	Failure Rate λ_G (failures/year)	Repair Rate μ_G (repairs/year)
1	10	10	4	196
1	20	20	5	195
2	40	80	6	194
2	5	10	2	198
4	20	80	2.4	157.6
1	40	40	3	147
Transmission lines	From Bus	To Bus	Failure rate λ_L (failures/year)	Repair rate μ_L (repairs/ Year)
1	1	3	1.5	876
2	2	4	5	876
3	1	2	4	876
4	3	4	1	876
5	3	5	1	876
6	1	3	1.5	876
7	2	4	5	876
8	4	5	1	876
9	5	6	1	876

Table 2. IEEE 9 Configuration

No. of Generators	Capacity (MW)	Total Capacity (MW)	Failure rate λ_G(failures/year)	Repair rate μ_G(repairs/year)
1	250	250	1.1	73
1	300	300	1.1	73
1	270	270	0.5	100
Transmission lines	From Bus	To Bus	Failure rate λ_L (failures/ year)	Repair rate μ_L (repairs/ year)
1	4	5	5	1095
2	4	6	3	876
3	5	7	5	1095
4	6	9	3	876
5	7	8	4	1095
6	8	9	4	1095

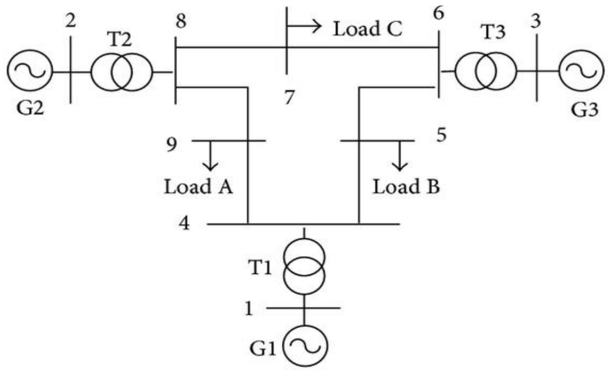

Figure 2. IEEE 9 bus system

Markov modelling is the best method out of all analytical techniques to evaluate the reliability of the system with stochastic behaviour. Application of Markov Modelling to RBTS and IEEE 9 Bus systems enable more accurate indices evaluation. Developed Markov state space models of IEEE 9 Bus system is presented in Figure 3. Stochastic transmission probability matrix is derived from limiting state equations. By solving limiting state equations the primary reliability index i.e probability of occurrence of selected contingencies is obtained. Based on this primary index remaining load point and system indices are evaluated. Probability of occurrence of contingencies obtained by Markov model are validated by comparing with binomial distribution probabilities and tabulated in Table 3. Negligible error between binomial distribution probabilities and Markov model probabilities indicate the correctness of developed Markov models.

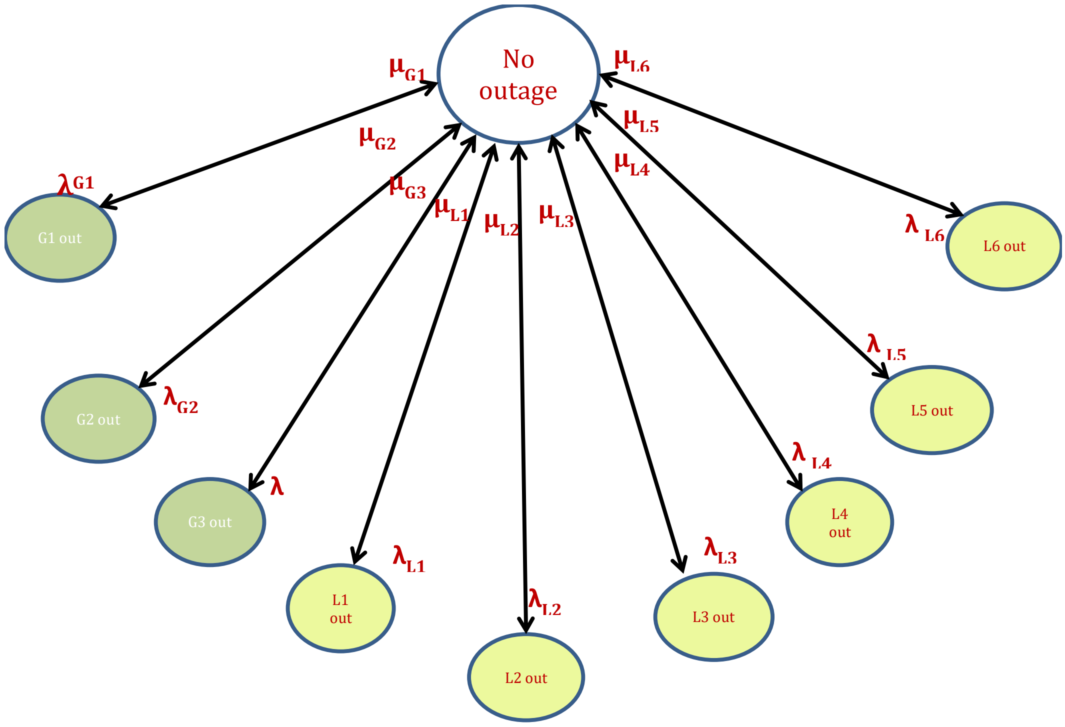

Figure 3. State space diagram of IEEE 9 bus system

Table 3. Comparison of Contingency Occurrence Probability by Binomial Distribution and Markov Model Methods

S.No	Contingencies	Binomial Distribution Probabilityof Occurrence	Markov Model Probability of Occurrence
1	No outages	0.943516341	0.944800362
2	L3	0.004308294	0.004314157
3	L5	0.003446635	0.004314157
4	L2	0.00323122	0.003235618
5	L4	0.00323122	0.003235618
6	L6	0.003446635	0.003451326
7	L1	0.004308294	0.004314157
8	G2	0.01421737	0.014236718
9	G3	0.004717582	0.004724002
10	G1	0.01421737	0.014236718
11	G1 L3	6.49195E-05	6.14194E-05
12	G1 L5	5.19356E-05	4.91355E-05
13	G1 L2	4.86896E-05	4.60646E-05
14	G2 L3	6.49195E-05	6.14194E-05
15	G2 L5	5.19356E-05	4.91355E-05
16	G2 L2	4.86896E-05	4.60646E-05
17	G3 L3	2.15415E-05	2.03801E-05
18	G3 L5	1.72332E-05	1.63041E-05
19	G3 L2	1.61561E-05	1.52851E-05
20	G1 G2 L1	9.78239E-07	8.74411E-07
21	G2 L1	6.49195E-05	6.14194E-05
22	G2 G3 L1	3.24597E-07	2.90146E-07
23	G2 G3 L2	2.43448E-07	2.17609E-07
24	L1 L3	1.96726E-05	1.86119E-05

3. ECONOMIC PROFIT DUE TO UPFC INCORPORATION

Load flow is simulated for selected contingencies at 237 MW of peak for RBTS. Power available to the load is less than the demand for 8 contingency states and is indicated by P_{kj} = 1 in Table 4, where P_{kj} is the probability of system failing to feed the load at k^{th} bus for j^{th} contingency. Due to the incorporation of UPFC power carrying capability of transmission system improves, system fails to meet the demand only in 2 contingency states instead of 8 states. Obtained reliability indices with the incorporation of UPFC indicate improvement in the system reliability.

Peak load of IEEE 9 Bus system is 230 MW and 17 contingencies were driving the system to failure mode of operation. UPFC incorporation resulted in reducing this to 11 states. Composite power system failure states with and without UPFC incorporation are presented in Table 5.

Incorporation of UPFC improves the power delivered to the load. Additional power delivered to the load will generate economy to the Transmission system. Transmission charges for FY 2018-2019 are 73.1243 Rs / kW / Month [26]. Without investing on erection of extra transmission lines, additional revenue is generated by incorporation of UPFC. Incorporation of UPFC is a smart solution than erection of additional transmission lines which involves environmental board clearances and right of way etc.

Table 4. RBTS-Power Available to the Load for Contingencies with and without UPFC

S.No	Contingencies	Without UPFC (MW)		With UPFC (MW)	
		Power available to Load	P_{kj}	Power available to Load	P_{kj}
1	base case	237	0	237	0
2	G1G1	237	0	237	0
3	G2G2	237	0	237	0
4	L1	237	0	237	0
5	L2	237	0	237	0
6	L3	237	0	237	0
7	L4	237	0	237	0
8	L5	237	0	237	0
9	L6	47.3	1	237	0
10	L8	237	0	237	0
11	L5L6	146.5	1	237	0
12	L6L7	47.4	1	203.3	1
13	L6L8	47.4	1	237	0
14	L2L3L6	233.7	1	237	0
15	L2L5L6	128.1	1	237	0
16	G1G1L2	237	0	237	0
17	G1G1L3	237	0	237	0
18	G1G1L4	237	0	237	0
19	G1G1L2L5L6	237	0	237	0
20	G2G2L2	237	0	237	0
21	G2G2L3	237	0	237	0
22	G2G2L4	237	0	237	0
23	G1G1G2G2	237	0	237	0
24	G1G1G2G2L2	100	1	237	0
25	G1G1G2G2L3	237	0	237	0
26	G1G1G2G2L4	237	0	237	0
27	G1G1G2G2L5	130	1	191	1
			8 states		2 States

Table 5. IEEE 9 Bus - Power Available to the Load for Contingencies with and without UPFC

S.No	Contingencies	Without UPFC (MW)		With UPFC (MW)	
		Power available to Load	P_{kj}	Power available to Load	P_{kj}
1	No.of outages	230	0	230	0
2	L3	229.1	1	230	0
3	L5	230	0	230	0
4	L2	227	1	230	0
5	L4	230	0	230	0
6	L6	230	0	230	0
7	L1	0.1	1	230	0
8	G2	110.4	1	110.4	1
9	G3	229.9	1	229.9	1
10	G1	230	0	230	0
11	G1 L3	229.1	1	230	0
12	G1 L5	230	0	230	0
13	G1 L2	227	1	227	1
14	G2 L3	134.8	1	134.8	1
15	G2 L5	147.3	1	147.3	1
16	G2 L2	2.3	1	40.5	1
17	G3 L3	149.5	1	202.2	1
18	G3 L5	230	0	230	0
19	G3 L2	223.6	1	230	0
20	G1 G2 L1	0.1	1	0.1	1
21	G2 L1	0.1	1	230	0
22	G2 G3 L1	0.3	1	102	1
23	G2 G3 L2	209.9	1	52.5	1
24	L1 L3	0	1	0	1
			17 states		11 states

4. RESULTS

Load point and system indices of RBTS are evaluated and tabulated in Table 6. Expected load curtailment (ELC) is reduced to 0.071 MW due to UPFC incorporation from 192 MW, which indicates 99% improvement in the supply to the load. Number of Load Curtailments (NLC) inorder to balance the generation and demand are also reduced to 0.002 / Year. Reduction in the Excepted Duration of Load Curtailment (EDLC) indicate the improved unintarupperted power supply to the load. 0.01 h EDLC of RBTS and 168 h of EDLC of IEEE 9 Bus system indicated reliability improvement of the respective systems. 99% improvement is achieved in Bulk Power Interruption Index (BPII). Nearly 1795 MWh energy not supplied to the load due to the contingencies. For the same contingencies due to UPFC incorporation almost same energy made available to the load, contribute for more reliable system and additional revenue generation for the transmission system.

Improved reliability indices of IEEE 9 Bus system are tabulated in Table 7. Reduction in ELC from 1339 MW to 199 MW indicate 85% improvement in the system performance. Supply interruption reduced to 2 h from 1127 h indicates highly reliable system. Improvement in Expected Energy Not Supplied (EENS) is 37%. For RBTS 7.573 MWh/MW-yr to 0.00144 MWh/MW-yr and for IEEE 9 Bus system 38 MWh/MW-yr to 24 MWh/MW-yr severity index (SI) reduction inducate reduction in bulk power energy curtailment.

Rs. 8,34,05,858 /kW/Month or $ 1176221.37 revenue is generated for IEEE 9 bus system and Rs. 1,40,11,592 /kW/Month or $ 197596.84 revenue is obtained for RBTS system with UPFC incorporation, (1 Rupee = USD 70.86). Inverstment to procure IGBT based converters, control circuitry, switchgear and installation of complete valve house costs around Rs. 150Cr. Payback period for RBTS and IEEE 9 Bus system are tabulated in Table 8. Payback period = (investment / Revenue generated). For RBTS system and IEEE 9 Bus system payback period is Nine years and one and half years respectively.

Table 6. Load Point and System Indices of RBTS

RBTS	Without UPFC	With UPFC
Load Point Indices		
ELC(MW)	191.6847633	0.07141128
NLC	1.011650243	0.00211876
EENS(MWh)	1794.956267	0.34277062
EDLC(h)	9.46765074	0.01016984
System Indices		
BPII(MW/MW-yr)	0.80879647	0.00030131
SI(MWh/MW-yr)	7.573655136	0.00144629

Table 7. Load Point and System Indices of IEEE 9 bus System

IEEE 9 Bus system	Without UPFC	With UPFC
Load Point Indices		
ELC(MW)	1339.428248	198.8244
NLC	1126.878426	2.2884431
EENS(MWh)	24086.51943	15129.274
EDLC(h)	273.3631002	168.22509
System Indices		
BPII(MW/MW-yr)	2.126076584	0.3155943
SI(MWh/MW-yr)	38.23257053	24.01472

Table 8. Payback Period of RBTS and IEEE 9 Bus Systems

System	Power not supplied to the load due to contingencies without UPFC(ELC MW/Year)	Power not supplied to the load due to contingencies with UPFC (ELC MW/Year)	Improvement in power delivered to the load due to UPFC Incorporation (MW/Year)	Transmission tariff (Rs/kW/Month)	Revenue to Tranmission system (Rs/kW/Month)	Pay back period (years)
RBTS	191.6847633	0.071411276	191.613352	73.1243	14011592.24	9
IEEE 9 Bus system	1339.428248	198.8244021	1140.603846	73.1243	83405857.81	1 ½

5. CONCLUSIONS

Novel contingency ranking with Markov model reliability evaluation is proposed. Markov model of IEEE 9 bus system is validated by binomial distribution method. Contingency ranking and selection criteria for RBTS and IEEE 9 Bus systems is clearly presented. Reliability improvement due to UPFC incorporation is assessed with PSSE simulation. Additional economic revenue to transmission system and payback period of UPFC is evaluated. Scheme to improve reliability is proposed in detailed manner and also economical profit associated with the proposed scheme is evaluated.

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