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Research paper

Identification of Optimal Operating Condition of Six Bus System Based on Reliability Evaluation

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Abstract

Practical Transmission system interconnecting Ramagundam Thermal power plant, Kotagudam thermal power plant and Nagarjunasagar hydal power plant with Hyderabad, Karnool and Gooty load points is considered for present study. This six bus ring system is a part of the Telangana state transmission system. Reliability indices of the system for variable load at Hyderabad load bus are obtained. Based on the reliability indices the optimal operating condition of the system is identified. Operating the system at identified optimal operating point will nullify the installation of redundant components and adequacy improving components. Generation outage transmission outage and generation cum transmission outages are the possible contingencies which can occur during the operation of the considered practical composite power system. Telangana state transmission system is simulated for different possible contingencies with Power system simulation for Engineering software tool. Load point and system reliability indices evaluated for twelve different contingency cases. Referring to load point and system reliability indices, optimal operating point of ring system evaluated. Present study will indicate the load magnitude, upper boundary of load magnitude corresponding to reliable operation of the system.

Keywords: *Telangana state six bus system, Optimal operating point, Reliability indices.*

1. Introduction

Implementation of redundant component installation, adequacy improving components incorporation, will improve the efficiency of the power system[1]. An efficient system, not necessarily a reliable system, but a reliable system is obviously efficient system. Therefore instead of focusing on efficiency improving schemes, identification of optimal operating point in perspective of reliability of the system is cost effective solution, which results in higher reliability of the system. Identification of optimal operating point in perspective of reliability of the system is convincing than only considering the efficient operating condition of the system[2]. Hence optimal operating point of Telangana state six bus system is evaluated based on the reliability indices. Identification of optimal operating point will help in prioritizing the loads. Optimal operating load is an indicator to limiting the magnitude of the load while prioritizing. Simulation of power flows through transmission lines with Power System Simulation for Engineering (PSSE)[3] is basis for identification of Teleangana state six bus ring system optimal operating point.

2. Six Bus System Configuration

Configuration of Six bus system, interconnecting Ramagundam thermal power plant, Kotagudam thermal power plant and Nagarjuna sagar hydal power plant with Hyderabad, Karnool and Gooty load points, presented in Table 1 [4]. Bus one is slack bus, bus two and five are PV buses and bus three, four and six are load buses. Schematic of interconnection between sources and load points through transmission lines shown in the Fig. 1. Each bus voltage rating is 400 kV. Generation, load and Transmission details are given in Table 2, Table 3 and Table 4 respectively. Twin moose and Quad moose ACSR transmission lines are considered for the analysis [5].

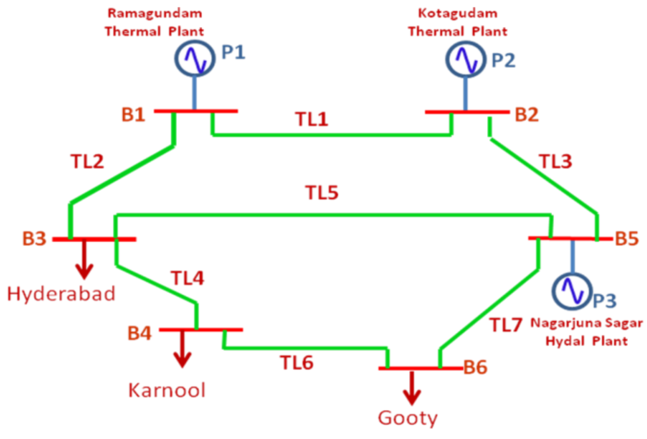


Fig 1. Telangana State six bus System

Table 1: System Configuration

No.of Plants	No.of Buses	No.of transmission lines	No.of Loads
3	6	7	3

Table 2: Generation Data

Plant	No.Of Generators	Capacity (MW)	Failure rate (failures/ Year)	Repair rate (repairs/ Year)
1	4	180	1	99
2	2	450	3	57
3	3	119	2	60

Table 3: Load Data

Load at bus	P load(MW)	Q load (MVAr)
3	200	75
4	200	75
6	200	75

Table 4: Transmission Lines Data

Transmission lines	From bus	To Bus	Capacity (MW)	Failure rate (failures/ Year)	Repair rate (repairs/ Year)
1	1	3	375	4	1095
2	1	2	250	5	1095
3	2	5	375	3	876
4	3	5	750	4	1095
5	3	4	375	3	876
6	4	6	250	5	1095
7	5	6	250	3	876

3. Capacity Outage Probability Table With Power System Simulation For Engineers

Under practical operating conditions system has the possibility of generation outage or transmission outage or generation cum transmission outage occurrence. Twelve contingency cases as listed in Table 7 which include exclusively generation outages, transmission outages and generation and transmission outages are considered for the analysis. Power available at each load point, for each contingency are obtained by simulating the system with PSSE software toll. Capacity Outage Probability Table (COPT) [6] for generation and transmission are obtained independently based on the failure rate and repair rates of each component of the system[7]. For selective twelve contingencies combined COPT is obtained at second level. COPT refers to the probability of occurrence of each contingency and frequency with which a contingency is occurring.

COPT for transmission and generation are shown in Table 5 and Table 6. Generation and Transmission combined COPT is shown in Table 7. Pkj is the probability of the system to fail to feed the load at load bus under investigation. Pkj is one for load greater than the power available at load bus and zero if load requirement

Table 5: Generation Capacity Outage Probability Table

Plant 1	Plant2	Plant 3	Capacity available	State Probability	Frequency
0	0	0	1977	0.785717944	12.57149
0	0	1	1858	0.078571794	5.814313
0	1	0	1527	0.082707152	5.789501
0	1	1	1408	0.008270715	1.058652
1	0	0	1797	0.03174618	3.619064
1	0	1	1678	0.003174618	0.546034
1	1	0	1347	0.003341703	0.561406
1	1	1	1228	0.00033417	0.075522

Table 6: Transmission Capacity Outage Probability Table

Outage Lines	Capacity available	State Probability	Frequency
0	2625	0.973691581	26.28967268
1	2250	0.003556864	3.9765742
2	2375	0.00444608	4.96627167
3	2250	0.00333456	3.001104187
4	1875	0.003556864	3.9765742
5	2250	0.00333456	3.001104187
6	2375	0.00444608	4.96627167
7	2375	0.00333456	3.001104187

is less than the power available at load bus. Fig 2 shows the simulation of system for 200 MW load at bus three with G1 L2 outage. Load point and system reliability indices are obtained for possible Outages in real time by referring generation cum transmission capacity outage probability table. 500 MW load at Hyderabad is resulting in highly reliable operating condition of the system. 900 MW is the upper boundary of the load beyond which system is highly non reliable.

Table 7: Generation & Transmission Capacity Outage Probability Table

Contingency	Power available(Mw)	Probability	Frequency	P_{kj}
0	213.6	0.765046947	32.89701873	0
G1	213.6	0.030910988	4.358449274	0
G2	213.6	0.080531258	7.811531986	0
G3	213.6	0.076504695	7.726974166	0
L1	196	0.002794692	3.169180778	1
L2	4.5	0.003493365	3.957982608	1
L3	213.6	0.002620024	2.399941793	0
L5	213.6	0.002620024	2.399941793	0
G1 L2	4.5	0.000141146	0.173750803	1
G3 L5	213.6	0.000262002	0.255190317	0
G2 L3	213.6	0.000275792	0.267518219	0
L2 L5	0	1.19636E-05	0.023998939	1
L3 L5	200.4	8.97268E-06	0.016052132	1

Based on the probability of failure of the system to feed the load and frequency of failure further load point indices and system indices are obtained

4. Evaluation of Reliability Indices

Load at Hyderabad (bus three), Karnool (bus four) and Gooty (bus six) are 200 MW. Optimal operating point of Telangana state six bus ring system is investigated for load variation from 100 MW to 1300 MW at Hyderabad by maintaining constant load of 200 MW at Karnool and Gooty buses. Power available at each load for normal operating condition and under contingencies are obtained by simulation. Fig 2 shows the simulation of system G1 L2 contingency condition. Power available to the load at Hyderabad is 4.5 MW, due to the failure of one generator of Ramagundam thermal power plant and transmission line connecting Ramagundam to Hyderabad, where as demand/requirement is 200 MW.

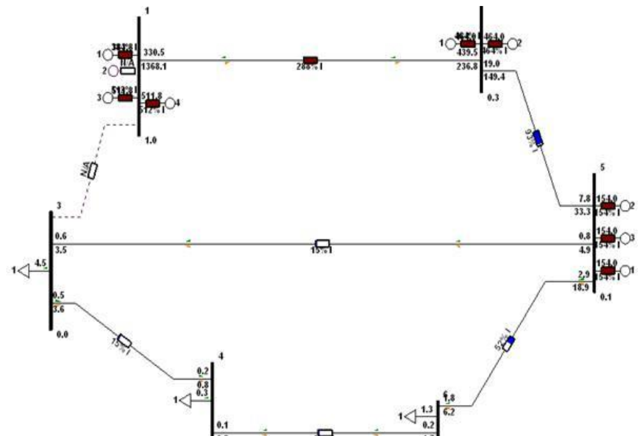


Fig .2. Simulation of G1 L2 outage condition.

Probability of occurrence of an outage, frequency of outage, Expected Number of Load Curtailments (ENLC), Expected Energy Not Supplied (EENS), Expected Duration of Load Curtailment (EDLC) and Expected Load Curtailment (ELC) are load point indices indicated by equations 1 to 4. Bulk Power Interruption Index(BPII), Bulk Power Supply average MW curtailment/ Disturbance(BPAC/D) and Severity Index(SI) are the overall system indices, evaluated by equations 5 to 7, which measure the reliability level of the system. For a rang of 100 MW to 1300 MW load variation at Hyderabad load bus, reliability indices are calculated. Table8 shows comparative statement of failure probability of the system to feed the power to the load under variable load conditions for considered outages. As load increases system tending toward higher failure probability.

Table 8: Failure Probability & Capacity Available for Contingencies

Load /Contin Gencies	Available power at 100Mw & 37.5	P_{kj}	Available power At 300Mw & 112.5Mvar	P_{kj}	Available power At 500Mw & 187.5Mvar	P_{kj}	available power at 700Mw & 262.5Mvar	P_{kj}	available power at 900Mw & 337.5Mvar	P_{kj}	available power at 1100Mw & 412.5Mvar	P_{kj}
0	106.8	0	320.4	0	534	0	194.3	1	75.2	1	111.1	1
G1	106.8	0	320.4	0	534	0	194.3	1	75.2	1	111.1	1
G2	106.8	0	320.4	0	534	0	747.6	0	632.9	1	843.7	1
G3	106.8	0	320.4	0	534	0	747.6	0	68.2	1	237.7	1
L1	106.8	0	155.3	1	424.5	1	472	1	295	1	400.3	1
L2	2.2	1	1.3	1	534	0	6	1	961.2	0	1.6	1
L3	106.8	0	320.4	0	534	0	192.4	1	191	1	508	1
L5	101	1	287.2	1	412.4	1	747.6	0	961.2	0	8.6	1
G1 &L2	2.2	1	1.3	1	534	0	6	1	961.2	0	1.6	1
G3 &L5	106.8	0	320.4	0	423.7	1	429.6	1	183.2	1	0	1
G2 & L3	106.8	0	320.4	0	534	0	747.6	0	191	0	508	1
L2 &L5	0.1	1	0	1	2.2	1	0	1	961.2	0	1174.8	0
L3 &L5	106.8	0	291.7	1	435.5	1	522.4	1	277.1	1	1174.8	0

Expected number of load curtailments

$$NLC = \Sigma_{j\in x,y} F_j \quad \ldots\ldots \quad (1)$$

Expected energy not supplied

$$EENS = \Sigma_{j\in x,y} L_{kj} D_{kj} F_j \text{ MWh} \ldots\ldots \quad (2)$$

Expected duration of load curtailment

$$EDLC = \Sigma D_{kj} * F_j \text{ hours} \ldots\ldots \quad (3)$$

Expected load curtailed

$$ELC = \Sigma_{j\in x,y} L_{kj} * F_j \text{ MW} \ldots\ldots \quad (4)$$

Bulk Power Interruption Index

$$BPII = (\Sigma_k \Sigma_{j\in x,y} L_{kj} F_j) / L_s \ldots\ldots \quad (5)$$

Bulk Power Supply average MW curtailment/ Disturbance

$$PS = (\Sigma_K \Sigma_{j\in x,y} L_{kj} F_j) / \Sigma_{j\in x,y} F_j \text{ MW/Disturbance} \quad (6)$$

Severity Index

$$SI = (\Sigma_K \Sigma_{j\in x,y} 60 L_{kj} D_{kj} F_j) / L_s \text{ MW/Disturbance} \ldots\ldots (7)$$

5. Results

Load point indices and system indices for 100 MW, 300 MW, 500 MW, 700 MW, 900 MW and 1100 MW are tabulated in Table 9. NLC, EENS, EDLC and ELC are annualized indices evaluated with respective to load at bus three. Lesser value of NLC, EENS, EDLC and ELC indicate reliable operation of the system. For complete range of load variation, number of load curtailments are around 6 which is minimum at 500 MW load. Lesser value of NLC indicates lesser failure tendency of the system. Least value of EENS indicates system capability to feed more power to the load under same contingencies. 5339 MWh is minimum value of EENS, occurring at 500 MW of load. In order to establish uninterrupted power supply to the load EDLC must be negligible. Minimum value of ELC indicates system capacity to feed more load.

Beyond rated load of 200 MW at Hyderabad bus, 50 Hr EDLC and 629 MW ELC are minimum when load is 500 MW. BPII, BPAC/D and SI are evaluated with respect to overall load on the system. Minimum vales of 1 MW/MW-yr BPII and 6 SI are occurring at 500 MW load over a range of 100 MW to 1300 MW load variation at Hyderabad bus. Fig. 3 indicates the EENS at bus three for a load variation from 100 MW to 1100 MW. Duration of load curtailment resulting in corresponding EENS is indicated in Fig.4, Fig. 5

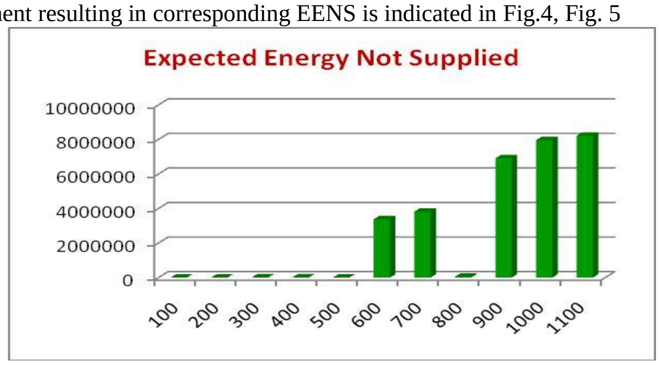
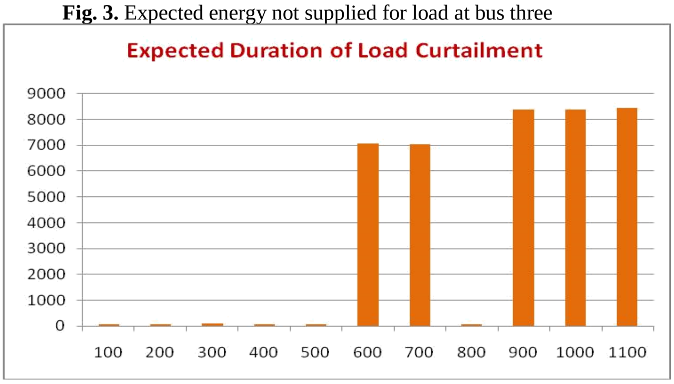


Fig. 3. Expected energy not supplied for load at bus three



.**Fig. 4.** Expected duration of load curtailment Vs load variation.

shows minimum hours of power interruption to the load and least value of over all system bulk power interruption of power to the load respectively. Least and safe severity

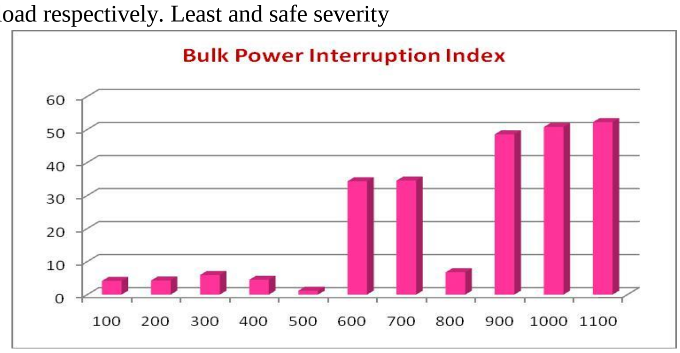


Fig. 5. Overall system bulk power interruption index Vs load variation

Table 9: Load Point & System Indices for Variable load at bus 3

Load/ Reliability indices	100MW	300MW	500MW	700MW	900MW	1100MW
ELC (MW)	436.8594506	1876.895004	628.5702046	25390.75519	45894.1537	60339.87312
NLC	6.555674143	9.740907053	5.86436396	47.25156537	58.90185739	65.41748046
EENS (MWh)	3379.246547	14570.26894	5339.042038	3812977.107	6909387.933	8213626.757
EDLC (hours)	54.95092525	79.45462978	49.91145323	7054.34128	8400.449042	8455.160167
BPII(MW/MW-yr)	4.160566196	5.958396837	1.19727658	34.54524516	48.56524202	52.24231439
BPAC/ D (MW/dist)	66.63837174	192.6817486	107.1847192	537.352678	779.1630984	922.3814903
SI	6.436660089	19.82349515	5.649779934	3301.278881	5061.822662	5215.001115

index is indicated in Fig 6, which is occurring at 500 MW load.

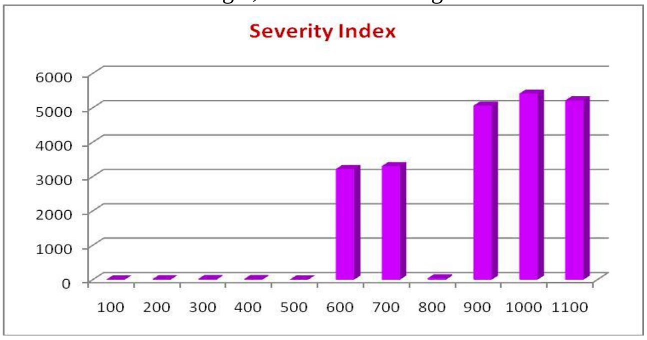


Fig. 6. Overall system Severity index Vs load variation

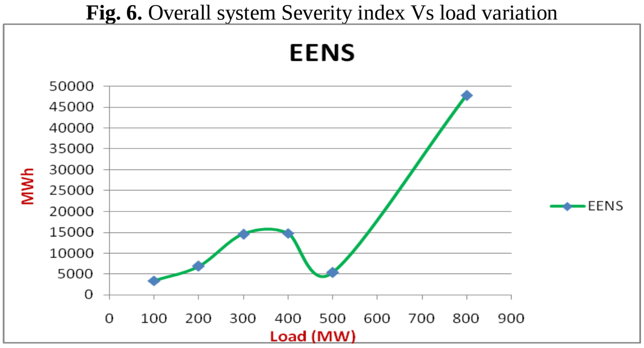


Fig. 7. Expected energy not supplied for load at bus three.

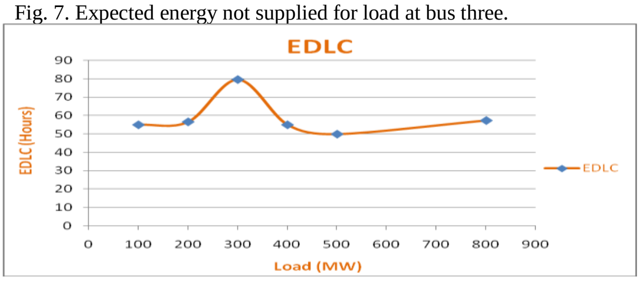


Fig. 8. Expected Duration of Load Curtailment at bus three.

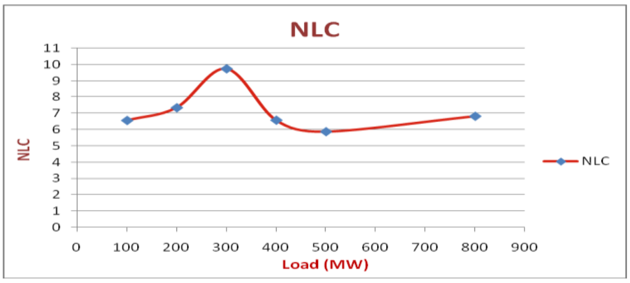


Fig. 9. Expected Number of Load Curtailment at bus three.

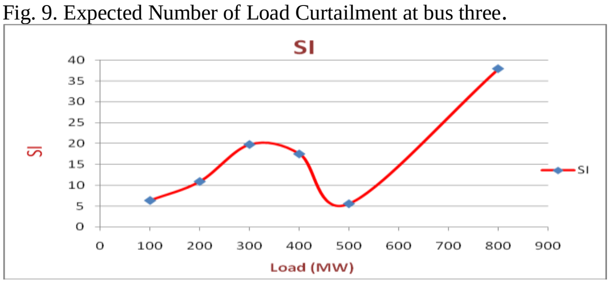


Fig. 10. Overall system Severity index Vs load variation

Fig. 7, Fig. 8, Fig. 9 and Fig. 10 indicate the minimum values of EENS, EDLC, NLC and SI. A load of 480 MW is indicating reliable operating point with minimum values of load point indices

6. Conclusion

Due to endlessly increasing demand operation of the power system beyond rated load is a continuous scenario. The analysis presented in this paper is a method to identify highly reliable operating point of overloaded system, under the constraints of contingencies and implementation of bulk power transfer enhancement schemes or redundant system installations. Lesser EENS, EDLC, ELC and NLC will indicate the adequacy of the system. Beyond rated load of 200 MW, 400 MW to 500 MW load is the reliable operating range for considered Telangana state six bus ring system. An EENS value of 4400 MWh, NLC value of 6, EDLC of 50 hours, SI value of 5 are minimum values indices, occurring at 480 MW load. Beyond 900 MW load, system indices indicate non-reliable operation of the system. Hence 900 MW is the upper boundary for the load at Hyderabad load bus. Driving the system operation beyond 500 MW by incorporating bulk power transfer capacity enhancing schemes involves lot of investment, complex control strategies. Only ten to fifteen percent compensation is possible by compensating schemes. Hence this method of identification of optimal operating condition and operating the system at obtained reliable 480 MW load, is smart and cost effective solution than implementation of compensating schemes. Application of this method is more advantageous when ever implementation of bulk power transfer capability enhancement schemes are restricted for various reasons. Obtained load magnitude will play significant role in prioritizing loads, under load shading requirements.

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