Selection and Contingency Analysis of EV Charging Station on 24-bus IEEE system

Surbhi Aggarwal; Amit Kumar Singh

National Institute of Technology Delhi, surbhi@nitdelhi.ac.in
National Institute of Technology Delhi, amitsingh@nitdelhi.ac.in

Abstract

In today's deregularized electricity grid, power system security has become a challenging task for power system engineers. Operational engineers must make reasonable efforts to address unnoticed contingency issues. As a result, contingency planning is essential to ensuring the safety and security of power systems. Performance Index is a contingency ranking mechanism that places the best performance index line first, followed by the remaining lines descendingly depending on the computed performance index. It aids in the establishment of adequate security measures for power systems. The paper uses Newton Raphson's (NR) technique for contingency ranking based on the Voltage Performance Index and the Active Power Performance Index. The 5MW charging stations are connected to the load bus lines as if they were real loads in the course. The suggested technique is evaluated on a 24-bus IEEE system with pre-installed Charging Stations.

Keywords. Contingency method, Newton Raphson method, Performance Index, Power system Security

1. INTRODUCTION

As the world's industrialization and population growth, as the standard of living rises, so does the power demand. This condition may result in a constrained transmission network[1]to keep up with demand and supply. Congestion Management [2]is one of the problems with the security and safety of the current deregulated power grid. The paper covers several congestion management options for a reorganized power system, as well as various essential issues and challenges for system stability and security. A power system is a multiplex network of various equipment and test case conditions. Breakdown to meet any test conditions or equipment failure can cause a loss of reliability, resulting in a power system outage [3], [4]. Some contingency scenarios may result in line overloads or bus voltage magnitude limit violations [5], [6]. Power system operators should rapidly identify such unfavorable situations for a more thorough analysis. Contingency analysis (CA) is a "preview" analysis tool. It is an online tool for operational engineers to analyze the consequence of future outages. The line outages' Performance Index (PI) is one of the contingency ranking methods. It starts with the best performance index line and progresses in descending order for all line outages based on the determined PI.

Reference [7] discusses the new congestion point, considering system limitations and the transmission system's physical limitations. Reliability, dynamic stability, transient stability, and node voltage limits are under the category of system limitation, whereas the equipment's thermal limits are considered under the system's physical limitation. For power system security, prediction of violation in bus voltages, and inline power flows, full CA has been presented in [8], [9]. References [10], [11] present radial basis function networks for the contingency evaluation of the power system. A fast-approximate method is presented in [12] for solving the line and generator outages for the AC load flow program. The paper demonstrates that the approximate solution is more accurate than the basic NR load flow technique. In reference [13], a probabilistic PI method is used for a composite power system to perform the contingency ranking and selection. It shows that the second-level contingency is more accurate and better in computation time. A detailed survey on congestion management has been provided in [14], [15]covering the congestion management methods and the different congestion management issues in the electricity market. The various techniques of congestion management when upgrading from a conventional grid to a smart grid scenario are explained in reference [16]. Reference [17] discusses the different congestion management methods, especially for the distribution networks penetrated by many distributed energy resources. For the system to run safely, the system and physical limitations must be removed as soon as possible [18].

Also, various FACTS devices are used for congestion management in the transmission lines [19]– [21]. In [22], two new congestion techniques are introduced to identify the system's critical transmission lines. For the congestion management of the particular system, DGs and Energy Storage Systems (ESS) are acquainted with the system with the aid of power transfer distribution factors. Many optimization techniques are used for congestion management. The considerable penetration of renewable energy sources and their uncertain nature makes the grid network uncertain, and installing an ESS is suggested to deal with these uncertainties [23]. The Voltage Performance Index (PI_V) and Active Power Performance Index (PI_P) are utilized in this study to rate contingencies on the IEEE 24-bus system using the NR approach. In the study, 5MW charging stations are attached to load bus lines as real loads [24]. Adding real loads to the system will increase the number of losses. DGs are included in the system to compensate for the losses using the Weak Bus placement approach [25].

The total contributions and insights of our work are as follows: (1) Section 1 provides a review of existing surveys in the literature, illustrating the need for our study by examining recent publications and related papers for a better understanding; (2) a thorough review in section 2 of the contingency selection using the NR Load flow solution, detailing the PI_P and PI_V; (3) section 3 of the study covers the experimental section giving in all the minor and significant details about the 24-bus IEEE test system, as well as the voltage limits and the loading margin limits of the load lines in the test system; and (4) all of the experimental results and discussion with tabulated results and graphs are elaborated in section 4; (5) section 5 concludes the work .

2. CONTINGENCY SELECTION USING LOAD FLOW SOLUTION

CA is a “what if” computer software that evaluates, provides, and ranks the implications of any power system contingency unplanned outage condition. A contingency is when a device (such as a generator or transformer) or a small area of the power system fails (for example, a transmission line). For each existing problem defined in a power system, CA does a "power flow" study.

For example, a transmission line that was 85 percent loaded before the contingency event may now be loaded at 120 percent of its MVA rating following the contingency event. A load bus nominal voltage may also fall to 90% of its rated voltage due to the same contingency event. If there is a violation, the changes are noted and calculated according to the severity of the violations or overloads.

Because there are only 3MW charging stations available at the moment. However, as we move towards a green transportation industry, high-capacity charging stations will be required. The paper uses the PI for a 5MW charging station to calculate the IEEE 24-bus system's contingency rating. The PI_V and PI_P are used for the test system, and the overall PI is used to prioritize the contingencies in order of priority. Contingencies are sorted in decreasing order based on the total PI calculation findings, with the highest-valued contingency rated first, followed by the others. This assists in implementing the required safeguards to keep the system safe.

Active Power Performance Index (PI_P)

To measure the degree of line overloads, the Active Power Performance Index is used with the formula:

$$PI_P = \sum_{i=1}^{N_L} (W / 2n)(P_i / P_i^{max})^{2n} \qquad (2.1)$$

$$P_i^{\max} = (V_i * V_j) / X \qquad (2.2)$$

Voltage Performance Index (PI_V)

To determine the outage of voltage magnitude limits, Voltage Performance Index is used with the formula:

$$PI_V = \sum_{i=1}^{N_B} (W / 2n) \left\{ \left(\left| V_i \right| - \left| V_i^{sp} \right| \right) / \Delta V_i^{\lim} \right\}^{2n} \qquad (2.3)$$

The overall formula for the calculation of PI will be formulated as:

$$PI_{Total} = PI_P + PI_V \qquad (2.4)$$

The flow chart for the calculation of PI and PI_{Total} is shown in figure 1. Depending on the importance of a line, contingency can be ranked. If it is not desired to overload a specific line, the weightage of that line is set to a high value.

3. EXPERIMENTAL SECTION

The flow chart in Figure 1 depicts the test system's step-by-step contingency evaluation. The 24-bus IEEE system used for the contingency evaluation is shown in Figure 2. The test system is comprised of 10 generator buses with 32 generating units ranging from 12MW to 400MW, 13 load buses linked by 38 lines, and one slack bus with a 100 MVA base.

The transmission system supports two voltage levels, 138kV and 230kV. Figure 2 depicts the 230kV system in the upper half, while the 138kV system is shown in the lower half, with 230/138kV transformer stations on buses 11, 12, and 24. To maintain rated voltage under transient conditions, two voltage correcting devices, a Synchronous Condenser and a Reactor, are coupled at bus 14 and bus 6, respectively.

The flow chart described in figure 1 was programmed in MATPOWER MATLAB Software. For every time a transmission line is weighted out of the system for the contingency calculation, the individual bus voltages and power flows are calculated using the NR load flow technique. For PI_V calculation, a margin of ±5% is kept for assigning minimum and maximum voltage limits on the line, i.e., 0.95 pu and 1.05 pu, respectively. It is also possible that any line can become overloaded with the outage of any of the lines. That congested line scenario accounts for the calculation of the PI_P index. The above two PIs are used to calculate the line contingencies and are explained in the next section.

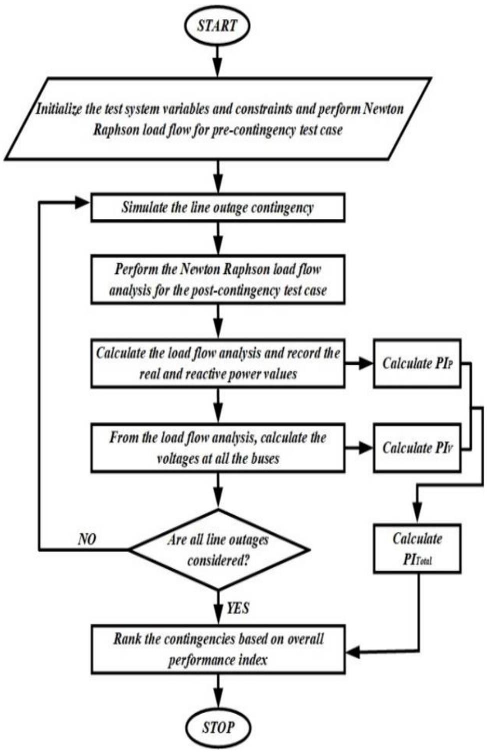

Figure 1: Flowchart for the work

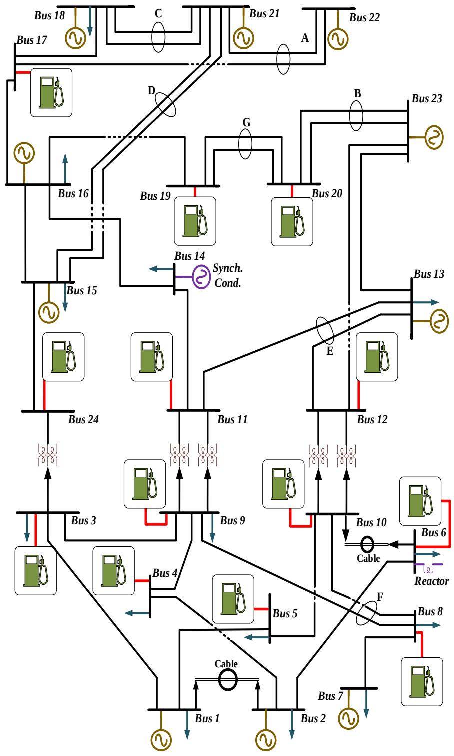

Figure 2: 24-bus Test System

4. RESULTS AND DISCUSSION

As depicted in figure 2, the system demonstrates the placement of 5MW charging stations at the load buses with NO DGs connected to the system. For the sake of simplicity, the charging stations are connected to the system as actual loads.

Section 3 of the report gives a quick overview of the IEEE 24-bus system. The pre-contingency analysis case is referred to as the base case CA. The NR analysis is employed for the study's post-contingency analysis. Because there are 13 load lines in the system, there are 13 charging stations [25], as illustrated in figure 2. The performance indexes, such as PI_P and PI_V, are also calculated with only one line outage at a time. Because the system has 38 lines, the pre-and post-contingency analysis is performed 38 times for PI calculation.

From the contingency analysis, it is calculated that neither of the bus or lines is over-rated or under-rated from its base MW value. So, table 1, Columns 2 & 3, illustrates the PI_P results and contingency ranking based on the pre-and post- contingency analysis evaluation. It can be seen that the outage of line 15-24 results in the highest value of PI_P, and hence it is ranked first for the contingency evaluation. Also, the outage of line 17-18 results in the lowest PI_P value, and, accordingly, is ranked as the last in the contingency evaluation. The pre and post contingency analysis evaluation for the overall PI_V calculation is shown in Table 1, in columns 4 & 5, with the contingency ranking. It can be seen that the outage of line 6-10 results in the highest value of $PI_{V,}$ and hence it is ranked first for the contingency evaluation. Also, the outage of line 17-18 results in the lowest PI_V value, and accordingly, is ranked as the last in the contingency evaluation.

Both PIs are summated, and ranking is based on the calculated overall PI value. Table 1, columns 6 & 7, displays the overall calculated PI values for the specific case where NO DG is connected to the system. Table 1 outlines the lines' overall contingency ranking, where the outage of line 6-10 is ranked first. It can be inferred from the study that the outage of line 6-10 is the most vulnerable in the system and should be given the highest priority in the cases of a blackout or worn-out situation. Also, outage of line 17-18 is ranked last, which means it is the least affected line in the system.

5. CONCLUSION

In the study, we use MATLAB MATPOWER software to complete the CA and ranking of IEEE 24-bus system adopting the NR Load Flow approach. As the list of potential contingency cases for the test system is so extensive, the strategy of contingency selection is essential, as it eliminates a substantial number of contingency instances and focuses on the most severe contingency scenario. Clearly, the interruption of line 6-10 will have the most impact, whereas line 17-18 would have the least.

Table 1: Overall Contingency Value and Ranking

Outage Line	Power_ PI Value	Power_ PI Ranking	Voltage_ PI Value	Voltage_ PI Ranking	Overall PI Value	Contingency Ranking
1-2	1.96	29	2.88	26	28.88	29
1-3	1.96	31	3.15	9	12.15	12
1-5	2.03	22	2.80	34	36.80	30
2-4	2.00	23	3.56	5	8.56	6
2-6	2.14	11	2.79	35	37.79	24
3-9	1.96	30	2.97	16	18.97	25
3-24	3.02	2	4.19	4	8.19	3
4-9	2.06928	18	2.938	19	21.938	22
5-10	1.96622	28	2.905	2	4.905	28
6-10	2.48980	4	25.8968	1	26.8968	**1**
7-8	2.30729	5	4.6058	3	7.6058	4
8-9	1.99482	24	2.8898	23	25.8898	27

8-10	1.98535	26	3.1206	11	14.1206	14
9-11	2.04979	20	3.1658	8	11.1658	10
9-12	2.12005	13	3.3774	7	10.3774	7
10-11	2.10579	15	2.9082	21	23.9082	21
10-12	2.20176	7	2.8608	32	34.8608	16
11-13	2.04224	21	2.9962	15	17.9962	18
11-14	2.06546	19	3.0302	13	16.0302	15
12-13	1.97000	27	2.9458	17	19.9458	26
12-23	2.29423	6	3.0066	14	17.0066	8
13-23	2.16385	8	2.9454	18	20.9454	13
14-16	2.77851	3	3.5072	6	9.5072	5
15-16	2.12328	12	2.924	20	22.924	17
15-21	2.14975	9	2.8644	30	32.8644	19
15-21	2.14975	10	2.8644	31	33.8644	20
15-24	3.07116	1	6.65	2	8.65	2
16-17	2.09841	16	3.1448	10	13.1448	9
16-19	2.08814	17	3.096	12	15.096	11
17-18	1.86229	38	2.7056	38	40.7056	**38**
17-22	2.11363	14	2.8678	29	31.8678	23
18-21	1.93179	36	2.8888	24	26.8888	34
18-21	1.93179	37	2.8888	25	27.8888	35
19-20	1.94961	34	2.872	27	29.872	32
19-20	1.94961	35	2.872	28	30.872	33
20-23	1.95714	32	2.7462	37	39.7462	36
20-23	1.95714	33	2.7462	36	38.7462	37
21-22	1.99239	25	2.8438	33	35.8438	31

6. References

[1] Pillay, S. Prabhakar Karthikeyan, and D. P. Kothari, “Congestion management in power systems - A review,” International Journal of Electrical Power and Energy Systems, vol. 70, pp. 83–90, 2015, doi: 10.1016/j.ijepes.2015.01.022.

[2] A. Narain, S. K. Srivastava, and S. N. Singh, “Congestion management approaches in restructured power system: Key issues and challenges,” The Electricity Journal, vol. 33, no. 3, p. 106715, Apr. 2020, doi: 10.1016/j.tej.2020.106715.

[3] S. Nandini, P. Suganya, and Lakshmi. K.M, “Congestion Management in Transmission Lines Considering Demand Response and FACTS Devices,” Int J Innov Res Sci Eng Technol, vol. 3, pp. 682–688, 2014.

[4] V. K. Tumuluru and D. H. K. Tsang, “A Two-Stage Approach for Network Constrained Unit Commitment Problem With Demand Response,” IEEE Trans Smart Grid, vol. 9, no. 2, pp. 1175–1183, Mar. 2018, doi: 10.1109/TSG.2016.2580578.

[5] H.-M. Chung, C.-L. Su, and C.-K. Wen, “Dispatch of generation and demand side response in regional grids,” in 2015 IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC), Jun. 2015, pp. 482–486. doi: 10.1109/EEEIC.2015.7165210.

[6] M. B. Nappu and A. Arief, “Network Losses-based Economic Redispatch for Optimal Energy Pricing in a Congested Power System,” Energy Procedia, vol. 100, pp. 311–314, Nov. 2016, doi: 10.1016/j.egypro.2016.10.183.

[7] H. Emami and J. A. Sadri, “Congestion management of transmission lines in the market environment,” International Research Journal of Applied and Basic Sciences, vol. 3, no. S, pp. 2572–2580, 2012, [Online]. Available: www.irjabs.com

[8] A. J. Wood, B. F. Wollenberg, and G. Sheble, “Power System Security,” in Power generation, operation, and control, 2013, pp. 296–349.

[9] B. Stott, O. Alsac, and A. J. Monticelli, “Security Analysis and Optimization.,” Proceedings of the IEEE, vol. 75, no. 12, pp. 1623–1644, 1987, doi: 10.1109/PROC.1987.13931.

[10] J. A. Refaee, M. Mohandes, and H. Maghrabi, “Radial basis function networks for contingency analysis of bulk power systems,” IEEE Transactions on Power Systems, vol. 14, no. 2, pp. 772–778, 1999, doi: 10.1109/59.761911.

[11] D. Devaraj, B. Yegnanarayana, and K. Ramar, “Radial basis function networks for fast contingency ranking,” International Journal of Electrical Power and Energy Systems, vol. 24, no. 5, pp. 387–393, 2002, doi: 10.1016/S0142-0615(01)00041-2.

[12] N. M. Peterson, W. F. Tinney, and B. Donald, “Iterative linear AC power flow solution for fast approximate outage studies,” IEEE Transactions on Power Apparatus and Systems, no. 5, pp. 2048–2056, 1972.

[13] A. M. Al-Shaalan, “Contingency selection and ranking for composite power system reliability evaluation,” Journal of King Saud University-Engineering Sciences, vol. 32, no. 2, pp. 141–147, 2020.

[14] N. I. Yusoff, A. A. M. Zin, and A. bin Khairuddin, “Congestion Management in Power System—A Review,” in 2017 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), 2017, pp. 22–27. doi: 10.1007/978-981-15-7994-3_39.

[15] A. Kumar, S. C. Srivastava, and S. N. Singh, “Congestion management in competitive power market: A bibliographical survey,” Electric Power Systems Research, vol. 76, no. 1–3, pp. 153–164, 2005, doi: 10.1016/j.epsr.2005.05.001.

[16] S. Gumpu, B. Pamulaparthy, and A. Sharma, “Review of Congestion Management Methods from Conventional to Smart Grid Scenario,” International Journal of Emerging Electric Power Systems, vol. 20, no. 3, pp. 1–24, 2019, doi: 10.1515/ijeeps-2018-0265.

[17] S. Huang, Q. Wu, Z. Liu, and A. H. Nielsen, “Review of congestion management methods for distribution networks with high penetration of distributed energy resources,” in IEEE PES

Innovative Smart Grid Technologies Conference Europe, 2014, pp. 1–6. doi: 10.1109/ISGTEurope.2014.7028811.
[18] Y. Wang, Z. Sun, Z. Yan, L. Liang, F. Song, and Z. Niu, "Power transmission congestion management based on quasi-dynamic thermal rating," Processes, vol. 7, no. 5, p. 244, 2019, doi: 10.3390/pr7050244.
[19] K. Thekdi, V. Varnamiya, and D. Desai, "Congestion Management in Transmission Lines using FACTS Devices," International Journal of Engineering Research & Technology (IJERT), vol. 8, no. 1, pp. 17–21, 2019.
[20] T. T. Nguyen and F. Mohammadi, "Optimal placement of TCSC for congestion management and power loss reduction using multi-objective genetic algorithm," Sustainability, vol. 12, no. 7, pp. 1–15, 2020, doi: 10.3390/su12072813.
[21] N. Padmini, P. Choudekar, and M. Fatima, "Transmission congestion management of IEEE 24-Bus test system by optimal placement of TCSC," in 2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems, ICPEICES 2018, 2018, pp. 44–49. doi: 10.1109/ICPEICES.2018.8897421.
[22] E. Dehnavi, F. Aminifar, and S. Afsharnia, "Congestion management through distributed generations and energy storage systems," International Transactions on Electrical Energy Systems, vol. 29, no. 6, pp. 1–12, 2019, doi: 10.1002/2050-7038.12018.
[23] V. K. Prajapati and V. Mahajan, "Reliability Assessment and Congestion Management of Power System with Energy Storage System and Uncertain Renewable Resources," Energy, 2020, [Online]. Available: https://doi.org/10.1016/j.scitotenv.2019.135907
[24] S. Aggarwal, M. Bajaj, and A. K. Singh, "Analysis of Electric Vehicle Charging Station Allocation in Deregulated Electric Power System," in 2020 IEEE 9th Power India International Conference (PIICON), Feb. 2020, pp. 1–6. doi: 10.1109/PIICON49524.2020.9113022.
[25] S. Aggarwal and A. K. Singh, "Impact analysis of electric vehicle charging station integration with distributed generators on power systems," International Journal of Circuit Theory and Applications, vol. 49, no. 6, pp. 1811–1827, Jun. 2021, doi: 10.1002/cta.2974.

Biographies

Ms. Surbhi Aggarwal received the bachelor's degree in Electrical and Electronics Engineering from UPTU in 2015, the master's degree in Power Systems from Thapar University in 2017, and currently pursuing the doctorate degree in Electric Vehicles from National Institute of Technology Delhi, respectively.

Dr Amit Kumar Singh received the bachelor's degree in Electrical and Electronics Engineering from UPTU in 2007, the master's degree in Power and Energy Systems Engineering from NIT Silchar in 2009, and doctorate degree in Electrical Engineering from IIT Patna, respectively. He is currently working as an Assistant Professor at the Department of Electrical and Electronics Engineering, NIT Delhi. His research areas include Power System Restructuring /Deregulation, Electricity Market, Distributed Generation, Renewable Energy, Security Analysis, Fault Detection, Operation and Control of Power Systems, Smart Energy Network.