Assessment and Improvement of Transient Stability For 9-Bus Practical Systems

Kamlesh Kumar Bishnoi[1], Lokesh Nagar[2]
[1, 2] Dept of Electrical Engineering
[1, 2] Rajasthan Institute of Engineering and Technology, Jaipur-302026

Abstract- *System stability study is the important parameter of economic, reliable and secure power system planning and operation. Power system studies are important during the planning and conceptual design stages of the project as well as during the operating life of the plant periodically. This paper presents the power system stability analysis for IEEE- 9 bus test system. The fault is created on different busses and transient stability is analyzed for different load and generation conditions. The critical clearing time (CCT) is calculated by using time domain classical extended equal area criterion method.*

I. INTRODUCTION

Electric power system stability analysis has been recognized as an important and challenging problem for secure system operation. When large disturbances occur in interconnected power system, the security of these power systems has to be examined302026. Power system security depends on detailed stability studies of system to check and ensure security. The instability in the power systems manifests itself in different ways (frequency, angle, voltage). The focus of this paper is on transient stability. Therefore, any mention of stability in the manuscript refers to transient stability of the synchronous generators. Transient instability is named as "out-of-step" (OOS) or "pole slipping" in different studies, too. Transient stability means the ability of the system to maintain synchronism with other generators following a large disturbance [4,5], which depends on system pre-fault condition, fault severity, and the fault clearance manner [6]. Transient stability traditionally assesses with rotor angle and speed of the synchronous generators [7].

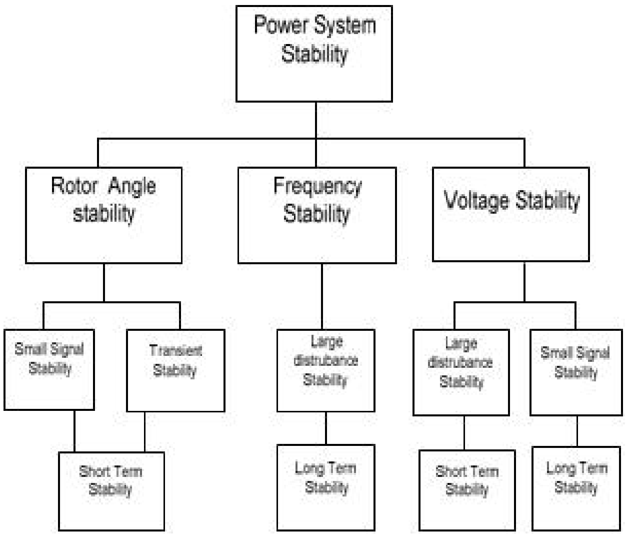
II. POWER SYSTEM STABILITY

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

- Power system is defined as a network of one or more generating units, loads and power transmission lines including the associated equipments connected to it.
- The stability of a power system is its ability to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium.
- Power system stability problem gets more pronounced in case of interconnection of large power networks.

Classification is based on the following considerations:

- physical nature of the resulting instability
- size of the disturbance considered
- processes, and the time span involved



III. ROTOR ANGLE STABILITY

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. Rotor angle instability occurs due to angular swings of some generators leading to their loss of synchronism with other generators. Depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine.

At equilibrium, Input mechanical torque equals output electromagnetic torque of each generator. In case of any disturbance the above equality doesn't hold leading to acceleration/ deceleration of rotors of machines.

IV. TRANSIENT STABILITY

- It includes Losses-generator excitation, transmission,
- switching operations and faults.
- Linearization of system equation is not permitted.
- Studied on the basis of swing.
- Action of Voltage regulators and turbine governor are not included.

FREQUENCY STABILITY

- Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load.
- Frequency instability leads to tripping of generating units and/or loads.
- Frequency stability may be a short-term phenomenon or a long-term phenomenon.

V. VOLTAGE STABILITY

- Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition.
- A system is voltage instable if for at least one bus in the system, the voltage magnitude decreases as reactive power injection is increased.

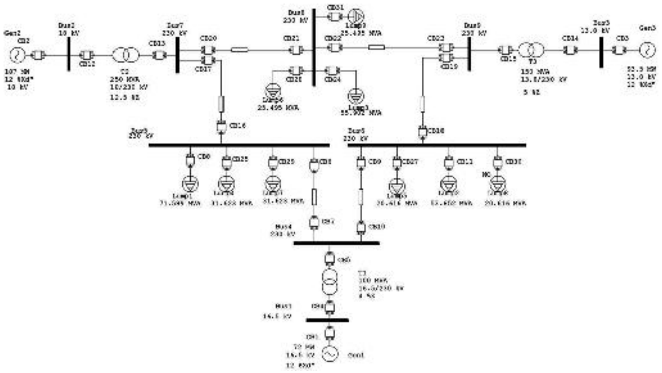
Voltage instability results in progressive fall or rise of voltages of some buses.

- Large scale effect of voltage instability leads to Voltage collapse. It is a process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system.
- The driving force for voltage instability is usually the loads.
- Voltage stability problems are also experienced at terminals of HVDC links connected to weak ac systems.

VI. SYSTEM SIMULATION AND LOAD FLOW ANALYSIS

In order to determine the stability status of the power system for each contingency of any disturbance occurs in power system, many stability studies are defined . Power system stability analysis may involve the calculation of Critical Clearing time (CCT) for a given fault which is defined as the maximum allowable value of the clearing time for which the system remains to be stable. The power system shall remain stable if the fault is cleared within this time. However, if the fault is cleared after the CCT, the power system is most likely to become unstable. Thus, CCT estimation is an important task in the transient stability analysis for a given contingency. In this paper for the Transient Stability Analysis, an IEEE 9 Bus system is considered.

Critical clearing time (CCT) in a way measures the power systems Transient stability. It denotes the secure and safe time margin for clearing the contingency, usually three-phase ground-fault. The larger the value of CCT, the power system has ample time to clear the contingency. CCT depends on generator inertias, line impedances, grid topology, and power systems operating conditions, fault type and location. For a single machine infinite bus power system, CCT calculation is straightforward.



Fig

Fig. Single Line Diagram of 9 Bus test system

The single line diagram (SLD) of the simulated test system on ETAP is shown in Fig. For this test system generator and load parameters are given in appendix. The total generation is 313MW and total load is 312.5MW. The test system contains 6 lines connecting the bus bars in the system with the generator connected to network through step-up transformer at 230kV transmission voltage.

It is good practice to have periodic and updated load flow study for every installation. The purpose of load flow study is

i. To calculate bus voltage levels to compare to equipment ratings and distribution system operating requirements

ii. To calculate branch current flows for comparing it to equipment capacity ratings and protective device trip levels.

Table.1 Load Flow Report

Bus No.	Bus KV	Voltage Mag. (%)	Voltage Angle	Gen. (MW)	Gen. (MVAR)	Load (MW)	Load (MVAR)
1	16.5	100.0	1.0	73.831	9.738	0	0
2	18.0	100.0	0.3	155.00	92.091	0	0
3	13.8	100.0	-0.2	85.00	41.951	0	0
4	230	98.140	-4.2	0	0	0	0
5	230	98.837	-4.2	0	0	123.847	49.550
6	230	98.824	-4.2	0	0	89.245	29.736
7	230	99.132	-4.1	0	0	0	0
8	230	98.864	-4.1	0	0	99.214	34.780
9	230	99.005	-4.1	0	0	0	0

Table.2CCT for different generation – loading conditions

Cases	Fault Bus	CCT(sec)
1	Bus 1	0.361209
2	Bus 2	0.31683
3	Bus 3	0.317586

For the above mentioned generation – loading conditions, load shedding was performed till the system frequency stability is regained.

Depending upon the type of plant there can be many load flow cases to study. The objective is to identify the best and worst operating conditions. Several load flow solution algorithms used in industry such as Gauss-Seidel, Newton-Raphson and current injection. There is requirement of at least one swing bus in the network for all the Load flow solution algorithms. The utility point of service is always modeled as swing bus.

The result of load flow analysis when all generators and loads are operating at rated power is given in Table.1. Calculation of critical clearing time (CCT) by using EEAC for different generation and loading condition at the different fault locations are shown in Table. 2.

This CCT is then used to operate the circuit breakers near the faulted bus and hence the corresponding generators are removed from the system. This creates the generation – load imbalance and hence the system frequency is affected.

When the frequency of the system crosses the permissible limit after the fault has occurred, the frequency protection scheme is activated. The frequency stability of the system is enhanced using Load Shedding.

VII. CONCLUSION

The Critical Clearing time (CCT) i.e. the maximum allowable value of the clearing time for which the system remains to be stable is calculated for a given fault. System frequency and voltage is analyzed for different loading conditions and faults on busses. The excess amount of load has to be shredded to maintain system stability. There are many different approaches that have been proposed for transient stability prediction over the spectrum of published material following a variety of concepts and methodologies. Each of these methodologies possesses certain advantages and disadvantages. Considering the importance of stability phenomena, it seems that a combination of separate methods could be a more effective solution

REFERENCES

[1] D. P. Kothari, I. J. Nagrath, "Modern Power System Analysis", India: Tata McGraw-Hill Publishing Company Limited, 2003. Pp.433-510.

[2] S. Das, B.K. Panigrahi, Prediction and control of transient stability using system integrity protection schemes, IET Gener. Transm. Distrib. 13 (8) (2019) 1247–1254.

[3] L. Zhu, D.J. Hill, C. Lu, Hierarchical deep learning machine for power system online transient stability prediction, IEEE Trans. Power Syst. 35 (3) (2020) 2399–2411May.

[4] H. Hooshyar, M. Savaghebi, A. Vahedi, Synchronous generator: past, Present and Future, AFRICON 2007, Windhoek, 2007, pp. 1–7.

[5] S.M. Mazhari, N. Safari, C.Y. Chung, I. Kamwa, A hybrid fault cluster and thévenin equivalent based framework for rotor angle stability prediction, IEEE Trans. Power Syst. 33 (5) (2018) 5594–5603 Sept.

[6] S. Afsharnia, A. Vahedi, Modeling & simulation of electric machinery, Persian Book, Tehran University Press, 2005.

[7] D.R. Gurusinghe, A.D. Rajapakse, Post-disturbance transient stability status pre- diction using synchrophasor measurements, IEEE Trans. Power Syst. 31 (5) (2016) 3656–3664 Sept.

[8] A.D. Angel, P. Geurts, D. Ernst, M. Glavic, L. Wehenkel, Estimation of rotor angles of synchronous machines using artificial neural networks and local PMU-based quantities, Neurocomputing 70 (16–18) (2007) 2668–2678.

[9] J. Lv, M. Pawlak, U.D. Annakkage, Prediction of the Transient Stability Boundary Based on Nonparametric Additive Modeling, IEEE Trans. Power Syst. 32 (6) (2017) 4362–4369 Nov.

[10] M. Abedini, M. Davarpanah, M. Sanaye-Pasand, S.M. Hashemi, R. Iravani, Generator out-of-step prediction based on faster-than-real-time analysis: concepts and applications, IEEE Trans. Power Syst. 33 (4) (2018) 4563–4573 July.

[11] H.E.A. Talaat, Predictive out-of-step relaying using fuzzy rule-based classification, Electric Power Syst. Res. 48 (3) (1999) 143–149.

[12] A.R. Sobbouhi, A. Vahedi, "Blinder out-of-step relay study in transient instability, 10th Power System Protection and Control Conference (PSPC), Tehran university, Iran, 2016 Jan.

[13] E. Farantatos, R. Huang, G.J. Cokkinides, A.P. Meliopoulos, A predictive generator out-of-step protection and transient stability monitoring scheme enabled by a dis- tributed dynamic state estimator, IEEE Trans. Power Deliv. 31 (4) (2016) 1826–1835.

[14] H. Yaghobi, Out-of-step protection of generator using analysis of angular velocity and acceleration data measured from magnetic flux, Electric Power Syst. Res. 132(10) (2016) 19–21 Mar.

[15] R. Dubey, S.R. Samantaray, Wavelet singular entropy-based symmetrical fault-de- tection and out-of-step protection during power swing, IET Gener. Transm. Distrib.7 (10) (2013) 1123–1134 Oct.

[16] T. Amraee, S. Ranjbar, Transient instability prediction using decision tree tech- nique, IEEE Trans. Power Syst. 28 (3) (2013) 3028–3037.

[17] B. Shrestha, R. Gokaraju, M. Sachdev, Out-of-Step protection using state-plane trajectories analysis, EEE Trans. Power Deliv. 28 (2) (2013) 1083–1093. Apr.

[18] A. Manunza, Out-of-Step condition and torsional stress of synchronous generators, M2ec Plann. Syst. Conf. (2007).

[19] Protection System Response to Power Swings, NERC System Protection and Control Subcommittee, August2013.

[20] P. Kundur, Power System Stability and Control, McGraw-Hil1, New York, 1994.

[21] Y. Li, Z. Yang, Application of EOS-ELM with binary jaya-based feature selection to real-time transient stability assessment using PMU data, IEEE Access 5 (2017) 23092–23101.

[22] [21] M. Li, A. Pal, A.G. Phadke, J.S. Thorp, Transient stability prediction based on ap- parent impedance trajectory recorded by PMUs, Int. J. Electr. Power Energy Syst. 54 (2014) 498–504.

[23] H. Hosseini, S. Naderi, S. Afsharnia, New approach to transient stability prediction

[24] of power systems in wide area measurement systems based on multiple-criteria decision making theory, IET Genera. Transm. Distrib. 13 (21) (2019) 4960–4967.

[25] J. Yan, C. Liu, U. Vaidya, PMU-based monitoring of rotor angle dynamics, IEEE Trans. Power Syst. 26 (4) (2011) 2125–2133 Nov.

[26] T. Guo, J.V. Milanovic, Probabilistic framework for assessing the accuracy of data mining tool for online prediction of transient stability, IEEE Trans. Power Syst. 29 (1) (2014) 377–385.

[27] Y. Tang, F. Li, Q. Wang, Y. Xu, Hybrid method for power system transient stability prediction based on two-stage computing resources, IET Gener. Transm. Distrib. 12(8) (2018) 1697–1703.