Identification of Weak Bus using Load Variation

Dhananjay Kumar[1], Shivam Singh Patel[2], Akash Tomar[3], Brijesh Prasad[4]

[1,2,3]Bachelor of Technology, EEE Dept, G L Bajaj Institute of Technology & Management, Gr. Noida, U.P, INDIA
[4]Asst Prof, EEE Dept, G L Bajaj Institute of Technology & Management, Gr. Noida, U.P, INDIA

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Abstract - *Power System may lose stability and cause blackout when operating under stressed loaded condition. In order to protect the power system. It becomes essential to predict and identify the voltage instability. After some damaging blackouts, voltage stability & collapse happening all over the world & across our nation has become a concern problem. The major issue in these problem is the collapse of transmission system which is most suffered by the frequent variations load. In this paper, we focus on the detection of most sensitive node in WSCC 3 MACHINE-9 BUS SYSTEM. For doing the above said we are using PSAT (Power System analysis toolbox) a MATLAB Based Simulink & Simulation toolbox which utilizes Load modelling method for voltage stability analysis and identifying weakest bus. In this work, firstly we have analyzed WSCC 3-MACHINE,9-BUS SYSTEM under the standard test data & after that we have increased load data by 5%,10%,15%,20%, 25%,30%,35%,45% and so on then we have compared all the result with the original power flow results of WSCC 3-MACHINE,9-BUS SYSTEM for finding a most sensitive node.*

***Key Words*: Voltage Collapse, Transmission System, Voltage Instability, Weak bus, Sensitivity.**

1. INTRODUCTION

In recent years, increasing demand and lack of new generation and transmission networks have forced power transmission and distribution systems to operate closer to their security limits. In addition, due to the penetration of renewable energy based distributed generators; distribution systems are becoming more vulnerable to voltage instability problem. As a result, Load Variation as a simplest approach has been proposed to identify weak nodes for protective measures, which helps proper placement of reactive power compensator and distributed generators for enhancement of system stability.

Voltage instability or collapse is believed to be a local load bus problem, which can cause trouble to the entire system and depends mostly on load conditions in the system. As most nodes are not voltage controlled, proper load modelling is more important in a distribution system than in a transmission system.

In load flow, sensitivity terms are used to find which nodes to generate a minimum voltage as compared to other nodes. Sensitive node is the one which is mostly suffered by the changes in load demands. Sensitivity relates to the test's ability to identify positive results. The sensitivity of a test is the proportion of people that are known to have the disease who test positive for it. This can also be written as: Sensitivity = Probability of a positive test, given that the patient is ill.

The task of the transmission network in the Power System is to deliver the power generated in the power plants to the load centres in the network and the interconnected power systems. The transmission of electric power has to take place in the most resourceful way without the transmission network failure. The transmission systems in the present time are becoming increasingly complex & stressed because of growing demand and because of restrictions on installation of new lines. For transmission network security & failure point of view it is quite important to calculate the most sensitive node in the network.

Load modelling for power system stability studies has always been a challenge for a number of reasons. The actual load below sub-transmission level consists of large varieties of components like thermostatic loads, resistive and inductive loads, induction motors, and lighting loads. Furthermore, number and type of loads varies continuously through time as different load components are switched on or off in response to residential, commercial and industrial activities. Other factors like change in weather may also cause highly unpredictable and irregular variations in the nature and amount of load. This statistical nature of load makes it very difficult to establish a load model that is generically applicable for power system studies. To correctly analyze the voltage stability of a power system, suitable dynamic models are usually required based on nonlinear differential and algebraic equations. However, in many cases, static analysis tools can be used to identify influencing factors for long term voltage stability.

Here, we are looking or finding the weak bus in WSCC 3-MACHINE,9-BUS SYSTEM bus system by increasing the test system data by 5%, 10%, 15%, 20%, 25%, 30%, 35%, 45% and so on then we have compared all the result with the original power flow results of WSCC 3-MACHINE,9-BUS SYSTEM for finding a most sensitive node.

2. PSAT: A MATLAB TOOLBOX

PSAT is a MATLAB toolbox for static and dynamic analysis and control of electric power systems.PSAT is a MATLAB toolbox for electric power system analysis and control. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user-friendly tool for network design.

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow;

2. Optimal power flow;

3. Small signal stability analysis;

4. Time domain simulations;

5. Phasor measurement unit (PMU) placement.

Besides mathematical routines and models, PSAT includes a variety of utilities, as follows:

1. One-line network diagram editor (Simulink library);

2. GUIs for settings system and routine parameters;

3. User defined model construction and installation;

4. GUI for plotting results;

5. Filters for converting data to and from other formats;

6. Command logs.

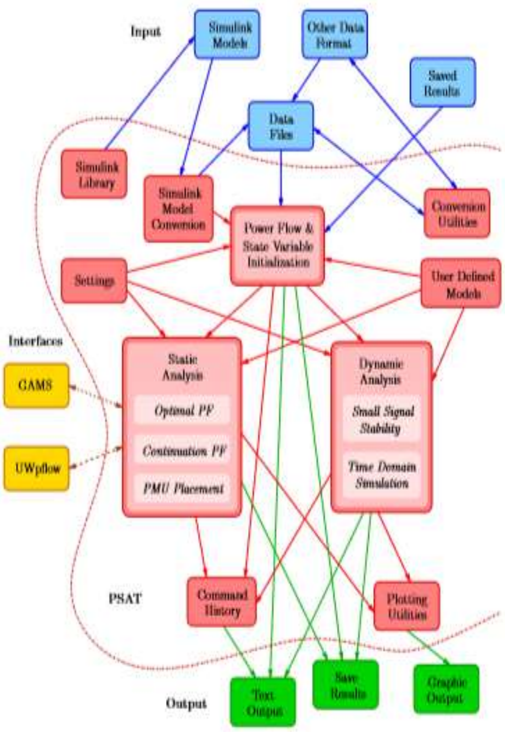

Fig-1: A Synoptic Diagram of PSAT

3. VOLTAGE COLLAPSE AND WEAK BUS

With the increased loading of transmission and distribution lines, voltage instability problem has become a concern and serious issue for power system planners and operators. The main challenge of this problem is to narrow down the locations where voltage instability could be initiated and to understand the origin of the problem. One most effective way to limit down the workspace is to identify weak buses in the systems, which are most likely to face voltage collapse. The weakest bus has been identified as the bus, which lacks adequate reactive power support to defend against voltage collapse. Network configuration, R/X ratio of interconnections, load models, load directions, presence of generators and compensators are most influential factors of the strength of a bus in a transmission system. In turn, identifying weak buses can give correct information for the optimal reactive power planning involved that would decide which buses are the most severe and need to have new reactive power sources installed. Ranking of bus based on strength has also been found useful in determining location for distributed generator to enhance loadability of the system.

Voltage collapse is the process of events accompanying voltage instability leads to a low unacceptable voltage profile in a significant part of the power system.

Voltage collapse phenomenon is characterized by continuous decrease in system voltage. Initially system voltage decreases gradually but later on, it reduces very rapidly.

Some of the contributing factor of voltage collapse are

1. Stressed power system i.e. high active power loading on the system
2. Inadequate reactive power support
3. Load characteristics at low voltage magnitude
4. Response of transformer tap changers, generators exciter limiters to decreasing voltages at load buses.
5. Unexpected relay operation may occur during conditions with low voltage magnitudes.

4. METHODOLOGY AND TEST SYSTEM

This WSCC 9-bus test case represents the Western System Coordinating Council (WSCC) to an equivalent system with nine buses and three generators.

The base KV levels are 13.8 kV, 16.5 kV and 18 kV. The line complex powers are around hundreds of MVA each. As a test case, the WSCC 9-bus case is easy to control, as it has only 3 voltage control devices.

This model comprises of 2 PV buses ,1 slack bus,3 step up transformers and 3 load centres. The whole transmission model has been configured in pi model representation. The given model also consists of excitation systems connected to each bus. The above transmission model is simulation representation in PSAT MATLAB Toolbox.

Since, this model has only 3 voltage control devices, it will be easier to control the performance of system under the condition of voltage collapsing. For testing purpose, we have carried out load variations gradually in terms of 5%,10%,15%...and so on till the condition of starting of divergence of load flow results.

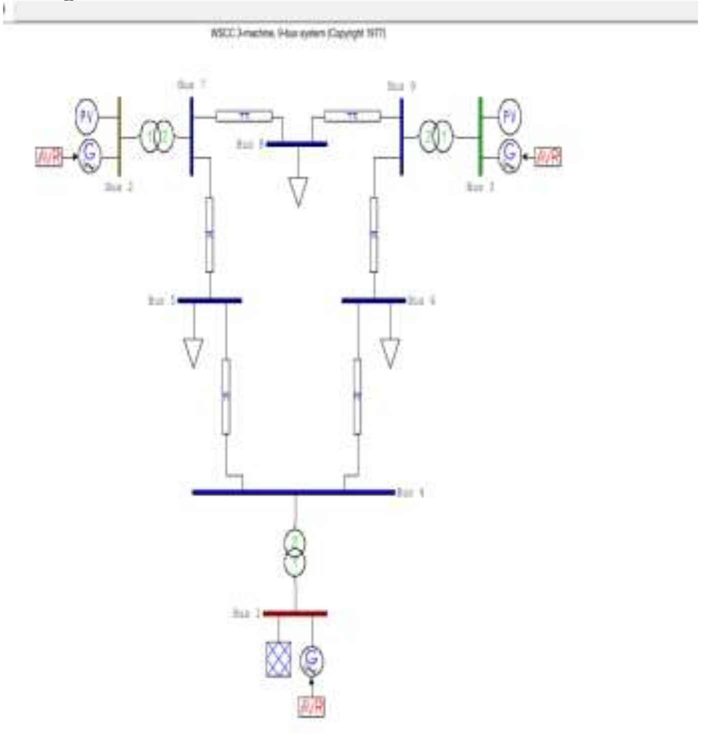

Fig-2: WSCC 3 Machine 9 Bus System Model

Sometimes, power system is operated at higher load than expected. In such situations, the extra load may cause voltage collapse. Inclusion of additional shunt capacitive compensation may be used to alleviate this situation. We follow below mentioned steps in the alleviation process.

1. First add more load as desired to the specified bus.

2. Solve the load flow equations using fast Newton Raphson's load flow method.

3. Determine whether a converged solution is obtained or not.

4. If the solution is converged, then there is no need for capacitive compensation.

5. If there is no feasible solution for the power flow equations, then corrective action is taken by providing reactive power injection computed by iterative method.

6. If necessary select an appropriate value of additional capacitive compensation to enhance voltage stability at the desired bus.

7. Go to step 2 and repeat steps 2 to 6.

Here, all the buses are kept at their base voltages as mentioned above. We will gradually vary the load at each of the load Centre's one by one or all of them gradually.

Initially, the transmission system is loaded very lightly. Now we will gradually increase the load to that point at which the power flow equations start diverges. Assume that total value of load initially is 3 pu.

5 RESULTS AND DISCUSSIONS

Case -1 When total load is nearer to 3 pu

NETWORK STATISTICS

Buses: 9

Lines: 6

Transformers: 3

Generators: 3

Loads: 3

SOLUTION STATISTICS

Number of Iterations:	4
Maximum P mismatch [p.u.]	1.68E-14
Maximum Q mismatch [p.u.]	1.49E-14
Power rate [MVA]	100

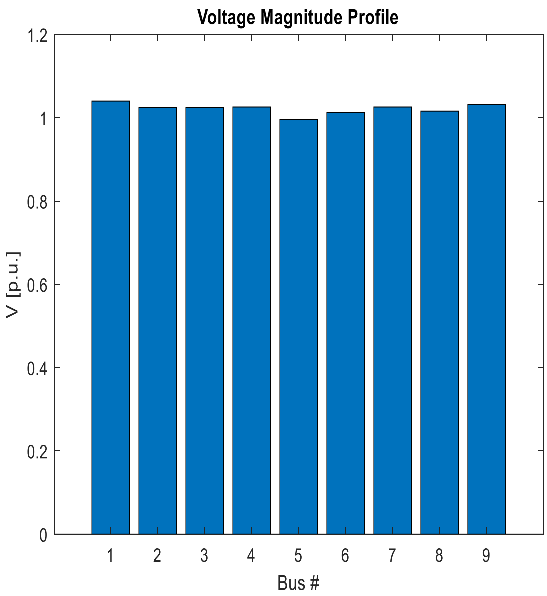

Fig-3: Voltage profile at 3pu load

LINE FLOW

Table-1

From Bus	To Bus	Line	P Flow	Q Flow	P Loss
			[p.u.]	[p.u.]	[p.u.]
Bus 9	**Bus 8**	1	0.242	0.031	0.0008
Bus 7	**Bus 8**	2	0.764	-0.008	0.0047
Bus 9	**Bus 6**	3	0.608	-0.181	0.0135
Bus 7	**Bus 5**	4	0.866	-0.084	0.023
Bus 5	**Bus 4**	5	-0.407	-0.387	0.0025
Bus 6	**Bus 4**	6	-0.305	-0.165	0.0016
Bus 2	**Bus 7**	7	1.63	0.066	0
Bus 3	**Bus 9**	8	0.85	-0.109	0
Bus 1	**Bus 4**	9	0.716	0.270	1.11E-16

POWER FLOW RESULTS

Table-2

Bus	V	P gen	Q gen	P load	Q load
	[p.u.]	**[p.u.]**	**[p.u.]**	**[p.u.]**	**[p.u.]**
Bus 1	1.04	0.71641	0.270	0	0
Bus 2	1.025	1.63	0.066	0	0
Bus 3	1.025	0.85	-0.108	0	0
Bus 4	1.0257	-6.7E-15	3.91E-15	0	0
Bus 5	0.995	-2.2E-15	1.41E-14	1.25	0.5
Bus 6	1.012	-1.9E-15	3.05E-15	0.9	0.3
Bus 7	1.025	1.68E-14	1.2E-14	0	0
Bus 8	1.015	-7.5E-15	-3.9E-15	1	0.35
Bus 9	1.032	7.29E-15	1.49E-14	0	0

Case-2 when total load is 8.299 pu

NETWORK STATISTICS

Buses: 9

Lines: 6

Transformers: 3

Generators: 3

Loads: 3

SOLUTION STATISTICS

Number of Iterations: 7

Maximum P mismatch [pu.] 1.68E-13

Maximum Q mismatch [pu.] 6.04E-14

Power rate [MVA] 100

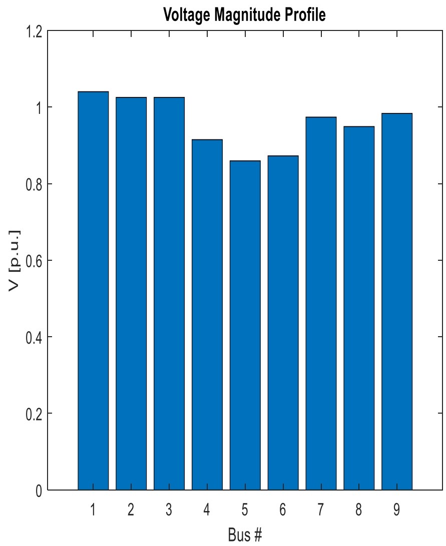

FIG-4: Voltage profile at 8.299 pu lo

Table-3

LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss
			[p.u.]	[p.u.]	[p.u.]
Bus 9	Bus 8	1	0.952	0.185	0.013
Bus 7	Bus 8	2	1.790	0.209	0.031
Bus 9	Bus 6	3	-0.102	0.775	0.038
Bus 7	Bus 5	4	-0.160	0.754	0.028
Bus 5	Bus 4	5	-2.989	0.351	0.137
Bus 6	Bus 4	6	-2.939	0.594	0.237
Bus 2	Bus 7	7	1.63	1.209	8.88E-16
Bus 3	Bus 9	8	0.85	1.064	-1.4E-15
Bus 1	Bus 4	9	6.304	4.441	8.88E-16

POWER FLOW RESULTS

Table -4

Bus	V	P gen	Q gen	P load	Q load
	[p.u.]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.04	6.30418	4.441	0	0
Bus 2	1.025	1.63	1.209	0	0
Bus 3	1.025	0.85	1.064	0	0
Bus 4	0.867	-1.7E-13	6.04E-14	0	0
Bus 5	0.813	1E-13	1.24E-14	2.8	0.5
Bus 6	0.805	1.14E-13	5.5E-15	2.79	0.3
Bus 7	0.956	1.31E-14	-2.2E-15	0	0
Bus 8	0.929	4.88E-15	3.55E-15	2.7	0.35
Bus 9	0.965	9.09E-15	-5.9E-15	0	0

Case-3 When total load is 8.3 pu

NETWORK STATISTICS

Buses: 9

Lines: 6

Transformers: 3

Generators: 3

SOLUTION STATISTICS

Number of Iterations: 9

Maximum P mismatch [p.u.] 0.12964

Maximum Q mismatch [p.u.] 0.04029

Power rate [MVA] 100

Table -5

Bus	V	P gen	Q gen	P load	Q load
	[p.u.]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.04	6.412	5.057	0	0
Bus 2	1.025	1.62	1.409	0	0
Bus 3	1.025	0.849	1.3123	0	0
Bus 4	0.838	-0.013	0.0040	0	0
Bus 5	0.795	0.0058	0.0007	2.3	0.5
Bus 6	0.750	0.0101	0.00026	3.15	0.3
Bus 7	0.944	0.00097	-6.2E-05	0	0
Bus 8	0.912	0.00049	1.57E-05	2.85	0.35
Bus 9	0.951	0.000608	-0.00013	0	0

POWER FLOW RESULTS

Table-6

LINEFLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss
			[pu.]	[pu.]	[pu.]
Bus 9	**Bus 8**	1	13.589	7.918	1.236
Bus 7	**Bus 8**	2	-9.873	1.0755	0.843
Bus 9	**Bus 6**	3	-12.22	-14.923	5.7941
Bus 7	**Bus 5**	4	1.182	5.7957	1.1822
Bus 5	**Bus 4**	5	-6.5E-12	2.84E-12	5.03E-13
Bus 6	**Bus 4**	6	24.89	133.72	24.898
Bus 2	**Bus 7**	7	1.475	0.513	6.66E-16
Bus 3	**Bus 9**	8	0.0846	-9.279	8.88E-16
Bus 1	**Bus 4**	9	7.05E-06	18.77	0

Case-4 when total load is 8.7 pu

SOLUTION STATISTICS

Number of Iterations:	9
Maximum P mismatch [p.u.]	45.96991
Maximum Q mismatch [p.u.]	171.4815
Power rate [MVA]	100

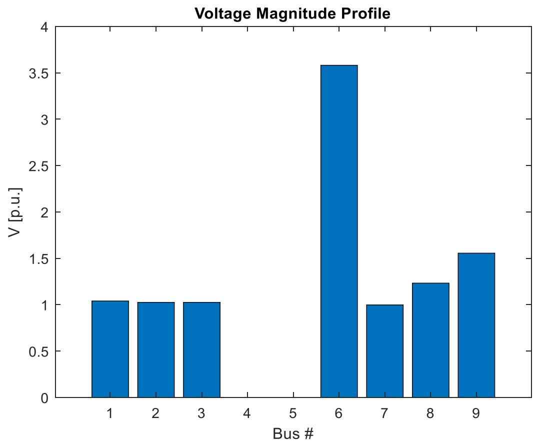

Fig-5: Voltage profile at 8.7p.u. load

POWER FLOW RESULTS

Table-7

Bus	V	P gen	Q gen	P load	Q load
	[pu.]	[pu.]	[pu.]	[pu.]	[pu.]
Bus 1	1.04	7.05E-06	18.77	0	0
Bus 2	1.025	1.476	0.513	0	0
Bus 3	1.025	0.084	-9.279	0	0
Bus 4	0.000001	2.88E-05	-3E-05	0	0
Bus 5	0.000001	2.950	0.500	2.95	0.5
Bus 6	3.581	45.969	171.48	3.05	0.3
Bus 7	0.997	-10.167	6.502	0	0
Bus 8	1.232	1.064	8.377	2.7	0.35
Bus 9	1.55	1.276	7.077	0	0

- As we carry out variations in load demand with slight changes, we see the variations in value of voltages across each bus. When load demand is kept at very low value (for eg. -load of 3.15 pu) with respect to Maximum generation capacity, the voltages at each bus are approximately nearer to **1** pu.
- But as we increase the load demand to 8.2996 pu, limiting violations in voltages and reactive power are out of reach and when load demand reaches to value of 8.3 pu, limiting violations in voltages occur

and so reactive power flow also violates (as voltages and reactive power flow are directly related to each other).

- Now consider the performance of the system when total value of load is 8.7 pu. Both reactive power and voltage profile at bus no 4 and 5 becomes zero. So, it can be inferred from above the two plots of voltage profile and reactive power plot that both are proportional to each other.
- When power flow solutions converge, the voltage profile is almost nearly constant, but as the loadability on the system is gradually increased voltage at each bus is different from each other.

6. CONCLUSIONS

From above reports, it is clear that the voltage profile is weak at bus 4 & bus 5 when subjected to load more than 8.29906 pu which may result in voltage collapse. Hence a special protection scheme should be applied on these buses to prevent voltage collapse.

So, by using above described load model weakest bus can be easily selected out. We have seen that power flow also conventionally called as load flow equations easily converges when total load is kept below 8.299 pu but as load is increased beyond this particular value of 8.299 pu load flow equations starts diverges out and voltages at bus 4 and 5 becomes lower. when load is 8.7 pu bus voltages at 4 and 5 becomes zero.

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