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Computation of Sensitive Node for IEEE- 14 Bus system Subjected to Load Variation

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Abstract: The load flow analysis is an important method for the power system analysis and designing. This analysis is carried out at each and every state of planning, operation, control and economic scheduling. In this paper, we have focus on the finding of most sensitive node in IEEE- 14 bus systems. Simulation is carried out at PSAT Matlab Toolbox which includes a complete set of user-friendly graphical interface and a Simulink-based editor for one-line network diagrams which utilizes the L-index method and FVSI for voltage stability analysis and sensitive nodes determination. In this project, firstly we have analyzed IEEE- 14 bus system under the standard test data & after that we have increased load data in step of 5%. For finding a most sensitive node, the results are compared with the original power flow results of IEEE- 14 bus system.

Keywords: IEEE-14 Bus, System, Sensitive Node, Reactive Power, PSA

I. INTRODUCTION

The voltage stability is the capability of a power system to maintain steady state voltage at all buses in the system at normal values and after being subjected to a disturbance [1]. A power system becomes unstable, when voltages uncontrollably changes due to the disbalance between load and generation, outage of equipment & lines and failure of voltage control mechanism in the system. The problem of voltage instability occurs mainly due to deficient supply of the reactive power or by an unnecessary absorption of reactive power[2]. Continuous monitoring of the system status is required because the voltage instability affects the satisfactory operation of power system.

Stability of the power systems can be identified through various stability factors. The slow variation in reactive power loading towards its maximum point causes the conventional load flow solution to attain its non convergence point. The ordinary load flow solution does not converge, beyond this point i.e. it forces the system to reach the voltage stability limit prior to bifurcation in the system [3]. The margin calculated from the base case solution to the maximum convergence point in the load flow calculation determines the

loadability maximum at a particular bus in the system. Thus in this system we examined IEEE- 14 system by increasing its reactive loading by 5%, 10%, 15%, 20%, 25%, 30%, 35% and till 40%.

II. METHODS OF FINDING OUT WEAKEST BUS

The Indian electrical infrastructure was generally considered unreliable. It is essential to locate a sensitive node in the

power system in order to avoid the severe disturbances. The critical bus is determined by finding out the maximum acceptable load on the bus. The most critical bus in the system is the bus which can accept smallest maximum load. Line stability index method, Fast Voltage Stability Index (FVSI) and Voltage Collapse Prediction Index (VCPI) are some most important methods which are used to finding out the most sensitive line in the power system [4].

III. INDEX FORMULATION

LSI and FVSI index formulation is discussed here in this subsection as following:

A. *Line Stability Index Formulation*

Based on the transmission concept in a single line M. Moghavvemi's derived a line stability index to find the voltage of an interconnected system in a reduced single line network [4]. In this formulation the discriminator of the voltage quadratic equation is set to be greater or equal than zero to maintain stability. A typical single transmission line where index is derived from is illustrated in Fig. 1:

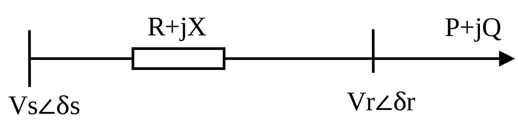

Fig. 1. Single line diagram of a transmission line in the power system

Where,

$V_s\angle\delta_s$, $V_r\angle\delta_r$ are the sending end and receiving end voltages.

R+jX is the impedance of the transmission line

P+jQ is the receiving end apparent power

θ is the line impedance angle

δ is the angle difference between the supply voltage and the receiving end voltage.

The line stability index is expressed by Lmn, proposed by Moghavvemi and Omar (1998) is formulated based on a power transmission concept in a single line. The line stability index Lmn is given by [5],

$$Lmn = \frac{4XQ}{[V_s \sin(\theta - \delta)]^2}$$

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When the stability index Lmn is less than 1, the system is stable and when this index exceeds the value 1, the entire system loses its stability and voltage collapse occurs. Hence the value of Lmn must be lower than 1 to maintain a stable system.

B. FVSI Formulation

It is calculated using reactive power flow as,

$$FVSI = \frac{4Z^2 Q_r}{V_s^2 X_r}$$

The value of evaluated index close to 1 indicates that the particular line is near to instability point. The critical bus is determined by finding out the maximum permissible load on the bus. The most critical bus in the system is the bus which can bear smallest maximum load [6].

IV. DETERMINATION OF MOST CRITICAL LINE WITH REFERRED TO A BUS USING INDEX

Step 1: Reactive load at a bus is gradually increased keeping all other loads keep constant.

Step 2: Load flow is done using PSAT to find out the active and reactive power transmitted at the receiving end for a particular load.

Step 3: Maximum Active and reactive power that can be transferred to a particular bus is calculated using the given formula.

Step 4: L-INDEX and FVSI is calculated at each load knowing power transmitted using load flow.

Step 5: This is repeated for each bus and indices are calculated for each line associated with bus.

Step 6: The line having maximum value of the stability indices at highest loadability point is the most critical line with respect to that bus.

V. TOOL USED

PSAT is a Matlab toolbox for the electric system analysis and control. PSAT includes power flow, optimal power flow, continuation power flow, small signal stability analysis and time domain simulation. All operations can be evaluated by mean of graphical user interfaces (GUI) and Simulink- based library provides an user friendly tool for network design. PSAT contains the power flow routine, which also takes care of states variable initialization. Once the power flow has been completed, further static and (/or) dynamic analysis can be executed [7]. 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.

In the proposed solution we are experimenting with IEEE-14 bus system. For doing so we are using PSAT a Matlab based Simulink & Simulation tool used for Power System Analysis.

VI. IEEE 14 Bus System and Input Data

Here we have designed a Simulink model of IEEE- 14 bus system with base MVA is 100 and base voltage 69 KV. It consists 14 transmission lines, 11 static loads and 4 transformers and has used following standard test data:

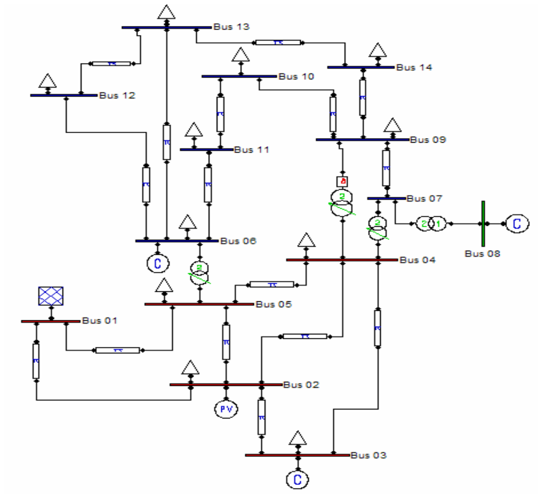

Fig.:3. IEEE 14 Bus System

TABLE I- LINE DATA FOR IEEE 14 BUS SYSTEM

B/W BUSES	LINE IMPEDANCE		HALF LINE CHARGING SUSCEPTANCE (p.u.)
	R (p.u.)	X (p.u.)	
1-2	0.01938	0.05917	0.02640
2-3	0.04699	0.19797	0.02190
2-4	0.05811	0.17632	0.01870
1-5	0.05403	0.22304	0.02460
2-5	0.05695	0.17388	0.01730
3-4	0.06701	0.17103	0.0064
4-5	0.01335	0.04211	0.0
5-6	0.0	0.25202	0.0
4-7	0.0	0.20912	0.0
7-8	0.0	0.17615	0.0
4-9	0.0	0.55618	0.0
7-9	0.0	0.11001	0.0
9-10	0.03181	0.08450	0.0
6-11	0.09498	0.19890	0.0
6-12	0.12291	0.25581	0.0
6-13	0.06615	0.13027	0.0
9-14	0.12711	0.27038	0.0
10-11	0.08205	0.19207	0.0
12-13	0.22092	0.19988	0.0

TABLE II- TAP SETTING VALUES FOR TRANSFORMERS

TRANSFORMERS	BETWEEN BUSES	TAP RATIO
1	5 - 6	0.932
2	4 - 9	0.969
3	4 - 7	.978

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TABLE III- BUS DATA FOR IEEE 14 BUS SYSTEM

BUS No.	GENERATION		LOAD	
	REAL (MW)	EACTIVE (MVAR)	REAL (MW)	REACTIVE (MVAR)
1	232.4	-16.9	0.0	0.0
2	40	42.4	21.7	12.7
3	0.0	23.4	94.2	19.0
4	0.0	0.0	47.8	3.9
5	0.0	0.0	7.6	1.6
6	0.0	0.0	11.2	7.5
7	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0
9	0.0	0.0	29.5	16.6
0	0.0	0.0	9.0	5.8
11	0.0	0.0	3.5	1.8
12	0.0	0.0	6.1	1.6
13	0.0	0.0	13.5	5.8
14	0.0	0.0	14.9	5.0

VII RESULTS

After feeding these data to the bus system model, we have obtained power flow results using Newton-Rapshon method and using these data we would we changing the load data by 5%, 10% and so on up-to 40% which are connected at bus no.: 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 & 14 respectively.

After changing the load values 5% we have performed power flow analysis and have tabulated the results & have repeated the process for 10% change in load value, then 15% and so on up-to 40% whose power flow result is tabulated below (See Table IV).

TABLE –IV CHANGE IN VOLTAGES

Bus no.	Voltage Change (p.u.)							
	5 %	10 %	15%	20 %	25%	30%	35%	40%
1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
2	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045
3	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
4	.99587	.99573	.99559	.99595	.99531	.99517	.99502	.99488
5	1.0011	1.0010	1.0009	1.0008	1.0007	1.0006	1.0005	1.0004
6	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
7	1.0290	1.0286	1.0282	1.0278	1.0274	1.0269	1.0265	1.0261
8	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
9	.99994	.99913	.99832	.9975	.99668	.99585	.99502	.99418
10	1.0012	1.0005	.99986	.99918	.99668	.99585	.99502	.99418
11	1.0297	1.0294	1.0291	1.0287	1.0284	1.028	1.0277	1.0273
12	1.042	1.0417	1.0413	1.0410	1.0407	1.0404	1.0401	1.0398
13	1.0284	1.0278	1.0272	1.0266	1.0261	1.0255	1.0249	1.0248
14	.96146	.95897	.95646	.95394	.9514	.94885	.94628	0.9437

TABLE V –CALCULATION OF MOST SENSITIVE NODE

us no.	Voltage Change (p.u.)										
	0%	5 %	10 %	15%	20 %	25%	30%	35%	40%	Avg	Diff
V1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0
V2	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	0
V3	1.o1	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	0
V4	.99601	.99587	.99573	.99559	.99595	.99531	.99517	.99502	.99488	.99546	.ooo5
V5	1.0012	1.0011	1.0010	1.0009	1.0008	1.0007	1.0006	1.0005	1.0004	1.008	.0004
V6	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	0
V7	1.0294	1.0290	1.0286	1.0282	1.0278	1.0274	1.0269	1.0265	1.0261	1.0310	.00163
V8	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	0
V9	1.0007	.99994	.99913	.99832	.9975	.99668	.99585	.99502	.99418	.92414	.0765
V10	1.0019	1.0012	1.0005	.99986	.99918	.99668	.99585	.99502	.99418	1.0008	.00102
V11	1.0301	1.0297	1.0294	1.0291	1.0287	1.0284	1.028	1.0277	1.0273	1.02879	.0014
V12	1.043	1.042	1.0417	1.0413	1.0410	1.0407	1.0404	1.0401	1.0398	1.04103	.00126
V13	1.0289	1.0284	1.0278	1.0272	1.0266	1.0261	1.0255	1.0249	1.0248	1.0262	.00267
V14	.96393	.96146	.95897	.95646	.95394	.9514	.94885	.94628	0.9437	.95386	.01006

After obtaining the power flow results for each percentage change in load we have made a table of the voltage profile at each change and have taken out average of each change. After getting the average, we have subtracted the average power flow value to original power flow result. The voltage at the bus where the difference is the most is considered as the most sensitive node (as shown by Table V).

According to the table V, we observed that bus no. 9 and 14 are the most sensitive node due to having more difference in change in voltages. Now we can use the graphical method which shows that at which bus voltage has lowest value. We use CPF and plot the graph of voltage against its loading parameter λ (Fig. 4).

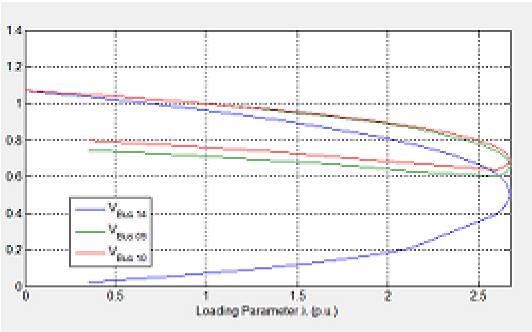
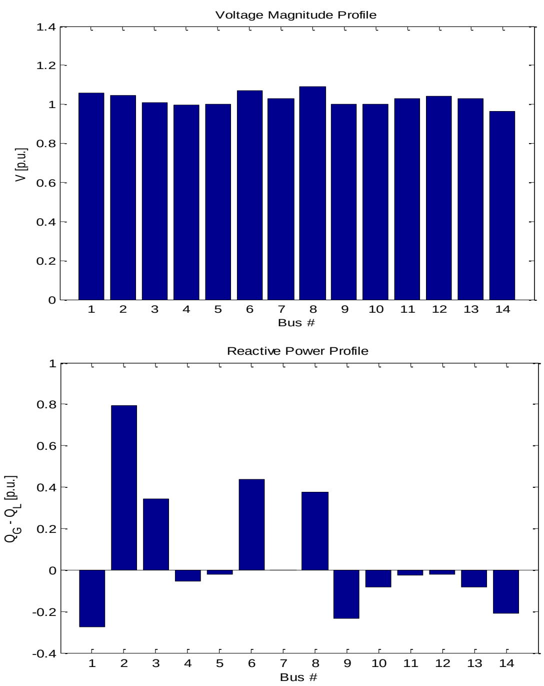


TABLE VI- VOLTAGE STABILITY INDEXES

Line	L-INDEX	FVSI
14-9	.11675	.1152
14-13	.2234	.22332
13-12	.02602	.05332
13-6	.113909	.11309
12-6	.06494	.064921
10-9	.009822	.0096617
10-11	.0947	.0947024
4-5	.05178	.05178
4-2	.04397	.04390
4-3	.15725	.1507
5-2	.05558	.055528
5-1	.08968	.0897
2-3	.010925	.010907
1-2	.08904	.088902

Fig. 4 Voltage Against Loading Parameter

VOLATAGE PROFILE AND REACTIVE POWER GRAPHS



Voltage index profile between various lines of the system is also calculated using LSI and FVSI methods. The formulated data of voltage index profile is given in Table VI.

VIII CONCLUSION

From above discussion and results it is clear that bus 9 and 14 have the lowest value of voltages. Firstly reactive load has been increased by 5%, 10%,15%,20%,25%,30%,35% till 40 %. Voltage sensitivity analysis is carried out and after calculating and referring the graphs it is cleared that bus 9 and 14 are most critical buses and when subjected to change in load may result in voltage collapse. Line stability is determined by L-index and FVSI. Line (13-14) has higher value of L-INDEX and FVSI .That why line (13-14) is most critical line.

Hence a special protection method could be applied on these buses to prevent voltage collapse.

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