Comparative Analysis of Different Power Delivery Systems Using Voltage Stability Index

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***Abstract*— Comparative analysis of different power delivery systems using voltage stability indices are of significant importance in current scenario of interconnected power systems. While analyzing transmission systems generally resistances of lines are neglected in different voltage stability indices therefore the same index cannot be used for a distribution system. Moreover, Newton-Raphson load flow method which is used for a transmission system analysis, does not converge for a distribution system. In the present work, three power delivery systems IEEE 30-bus transmission system, a 36-bus real time Indian semi-transmission systems and the IEEE 69-bus distribution system are considered to test the existing voltage stability index. For Transmission system and semi-transmission system NR load flow method and for Distribution system Teng's method of load flow is used. A voltage stability index [2] is used, as it is, for transmission system whereas for distribution system resistance value for lines is also taken into consideration in the same index. The maximum load- ability of all the buses for all the systems considered, were calculated one-by-one. The bus having least loading-ability is considered as weakest. The proposed method is efficient and gives additional information about collapse phenomenon and maximum load-ability.**

***Index Terms*—Distribution systems, Transmission systems, Semi-transmission system, Maximum Load-ability, Voltage stability index.**

I. Introduction

Voltage stability is the ability of a power system to maintain adequate magnitude of voltage at buses, so that when nominal load at the system is increased, actual power transferred to the load will increase. As real power is key variable to the rotor angle stability analysis, reactive power is central to voltage stability analysis [5]. Reactive power is easier to generate but difficult to transmit. Deficit of reactive power either locally or globally causes the voltage profile to become poor and with increase in loading voltage collapse [1] occur. Several incidences of instability and collapse have been observed throughout the world leading to major system breakdown. It has been observed as slow phenomenon in several cases and also fast phenomenon in few cases.

Voltage stability is analyzed as static as well as dynamic phenomena. Static voltage stability is mainly associated with reactive power imbalance. Thus, the loading-ability of bus in a system depends on the reactive power support, which the bus can receive from the system. Both real and reactive power losses increase rapidly as the system approaches the maximum loading point on voltage collapse point. It is therefore essential that reactive power must be available locally. For dynamic voltage stability, appropriate modeling is required. Dynamic cases occur when changes are very fast and the analysis is performed online.

For conducting voltage stability [6] studies there are various methods. The most commonly used method is based on P-V or Q-V curves together with the characteristics of the system and is especially useful for conceptual analysis of voltage stability of radial systems or longitudinal transmission lines. Another method is to calculate voltage stability index for a desired bus which gives an indication of impending voltage collapse at that bus. For static voltage stability analysis of an interconnected system, power flow model is generally considered. It has been proved that near system maximum load-ability point, the load flow diverges and Newton-Raphson load flow Jacobian becomes singular. This also implies that the least eigen value of the Jacobian approaches to zero. Furthermore it has been also shown that under certain assumptions, there is a direct relationship between the singularity of the load flow Jacobian and the singularity of the system dynamic state Jacobian.

For assessing the voltage stability of a system, proximity indicators are also used to know how close the system is to the voltage instability point.

In the present work, voltage stability [8] is analyzed for transmission system as well as for distribution systems. It has been observed that for distribution systems, Newton-Raphson method of load flow does not converge and the analysis becomes difficult. Therefore several other methods like Backward-Forward sweep method, Das-Kothari method [3], Teng's method [4], are used for the purpose of voltage

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stability analysis. Several voltage stability indices have also been reported in the literature which give the voltage collapse for weak area clustering and a ranking of buses based on maximum load-ability. Factors involved are deficit of reactive power, loads regaining their output even during transformer OLTC (On-Line Tap Changing Ratio) operation and operation of generator current limiters.

In this work, a Fast Voltage Stability Index (FVSI) as suggested by Musirin et. al [2] has been used to analyze different power delivery systems. FVSI referred to a line is formulated as the measuring instrument in predicting the voltage stability condition in the system. The proposed method is very simple and it could speed up the computation. The FVSI has been referred to a line. The current equation has been derived to form the voltage or power quadratic equations and the discriminent of the roots of voltage or power quadratic equation is set to be greater than zero. This causes the roots of the quadratic equations to be imaginary which in turn causes voltage instability leading to voltage collapse. The line index that is evaluated close to 1.00 will indicate limit of voltage instability.

II. Line Voltage Stability Index

Consider a two-bus test system as shown in figure-1. The line voltage stability index is derived as given in [2] except the last approximation because the value of resistance is high in distribution system.

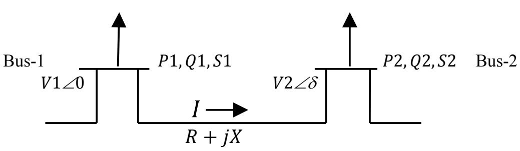

Fig 1. Single line diagram of a two bus test system.

The following equation is suggested by musirin [2], we get the following value of V_2

$$V_2^2 - \left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1V_2 + \left(X + \frac{R^2}{X}\right)Q_2 = 0 \qquad \ldots(1)$$

The roots for V_2 will be

$$V_2 = \frac{\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1 \pm \sqrt{\left\{\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1\right\}^2 - 4\left(X + \frac{R^2}{X}\right)Q_2}}{2}$$

To obtain real roots for V_2, the discriminant is set greater than or equal to zero, i.e.

$$\left\{\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_1\right\}^2 - 4\left(X + \frac{R^2}{X}\right)Q_2 \le 1 \qquad \ldots(2)$$

Or, $\frac{4Z^2Q_2X}{(V_1)^2(R\sin\delta + X\cos\delta)^2} \le 1$ …(3)

No further approximation is done as in the [2] because in distribution system 'R' cannot be negligible. Equation(3) can be used as line voltage stability index.

III. Test Systems

An IEEE-30 bus transmission system, IEEE 69-bus distribution system and 36-bus real time Indian semi-transmission system is considered for analysis purpose with modified data. A MATLAB program is developed. Bus having least value among maximum load-ability limit list has been determined. This least load-ability limit of the bus will decide the weakest bus in whole transmission system and this is the location for the proper placement of a FACTS device [7,10] or capacitor bank.

A single line diagram of an IEEE 30-bus Transmission System is shown in Fig.2. The IEEE 30-bus transmission system considered here; consist of 6 generators, 41 transmission lines and 20 loads. With the help of computation, we have tabulated the given data of IEEE 30 bus transmission system and calculated maximum load-ability limit. Bus 1 is considered as a slack bus. Bus 1, 2, 5, 8, 11, 13 is considered as generator bus.

Fig 3 shows the single line diagram of IEEE-69 bus distribution system [24]. This IEEE-69 bus distribution system is radial type distribution feeder having voltage 12.66KV and apparent power 100MVA. It is having 9 load levels almost dynamic in nature and duration is approximately 8541 hours. There are two capacitors located in the system.

Single line diagram of 36 bus equivalent of Western region EHV Indian system is shown in Fig 4. This system consists of 9 generator bus and 9 transformers consuming total active and reactive powers of 4657 MW and 1789 MVAR through 69 transmission lines. It is also having 4 shunt compensators and 16 reactors. There are 69 number of loads connected in the whole system.

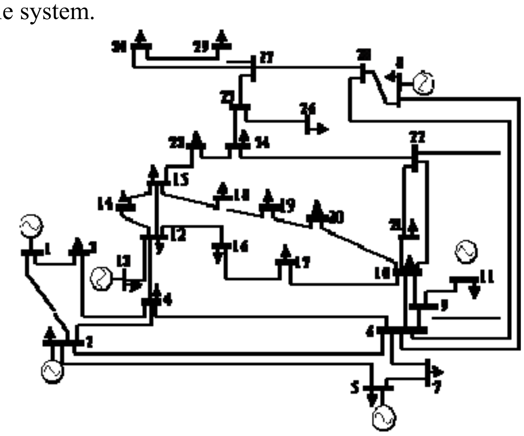

Fig 2: Single Line Diagram of Standard IEEE 30 bus test system

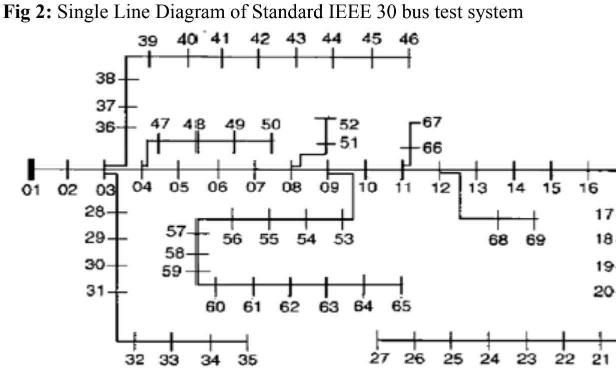

Fig 3: Single Line Diagram of IEEE-69 bus distribution system

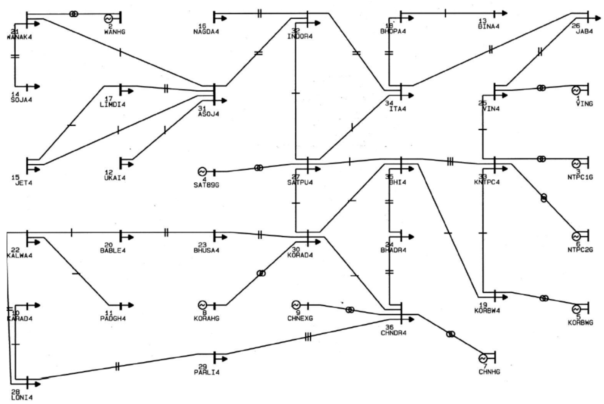

Fig 4: Single line diagram of 36 bus equivalent of Western region EHV Indian system

IV. Results And Discussion

In Voltage Stability Index Method, maximum load-abilities were calculated for each load bus and the bus having least values were considered as weakest bus. The load flow did not converge up to 100 iterations for certain buses. However, the load flow converged within 500 iterations for the some buses. But this happened for only some buses so those buses are considered as inadmissible. The weakest bus found this way may be considered as the optimum location for the placement of a FACTS device. The simulation results for IEEE -30 Bus test and 36 Bus Indian Transmission System are given in table I and table III respectively.

On other hand, IEEE-69 bus distribution system is used, in which the stability is calculated by Teng's method [22]. The simulation result of this system is given in table II.

TABLE I
MAXIMUM LOAD-ABILITY LIMIT CALCULATION FOR IEEE-30 BUS TEST SYSTEM

Bus number	Maximum Load-ability limit	Voltage Index	Voltage Magnitude
8	82.3	0.9998	0.7784
12	87.3	0.9975	0.6625
19	60.9	0.9976	0.6710
20	28.5	0.9936	0.7079
21	57.2	0.9997	0.7480
23	34.6	0.9990	0.6492
24	31	0.9894	0.6617

TABLE II
MAXIMUM LOAD-ABILITY LIMIT CALCULATION FOR 36 BUS INDIAN TRANSMISSION SYSTEM

Bus number	Maximum Load-ability limit	Voltage Index	Voltage Magnitude
10	476.9	0.9955	0.0824
	0	0.9417	1.4905
	-114	0.9998	1.4905
12	598.7	0.9165	0.7572
	0	0.9193	1.2787
	-2470	0.9999	2.0065
13	598.8	0.9156	0.8494
	0	0.9193	1.2942
	-836	0.9999	1.6090
20	735.8	0.7011	.8854
	0	1.0000	1.4609
	In negative, all values goes to 1.0000		
22	640.4	0.8915	0.6201
	0	0.9861	1.5143
	-24.3	0.9999	1.5256
23	703.4	0.7087	0.9935
	0	0.9513	1.3867
	-54	0.9992	1.4061
28	554	0.8286	0.7418
	0	0.9629	1.4928
	-72	0.9996	1.5248

TABLE III
MAXIMUM LOAD-ABILITY LIMIT CALCULATION FOR IEEE-69 BUS TEST SYSTEM

Bus number	Maximum Load-ability limit	Voltage Index	Voltage Magnitude
65	173.9	0.9997	0.8854
64	176.5	0.9997	0.8861
61	207.4	0.9998	0.8892
63	282	0.9999	0.8884
62	286.4	0.9922	0.8888
60	478.7	0.9999	0.8980
59	687.2	0.9993	0.9048

V. Conclusions

Comparative analysis of different power delivery systems considered is performed using Fast Voltage Stability Index. When loads are increased maintaining power factor, maximum load-ability limit increased exceptionally high crossing the temperature limits of line, which in turn represents no voltage collapse. Keeping real power constant when reactive power is increased, voltage stability based load-ability limit will be less than or equal to temperature based line limits and hence complete analysis is performed, for this case to suggest the illness of the system. Positive and negative signs for reactive power represent the presence of load and generator respectively or requirement of the same and up to which value balance can be maintained. Different power delivery systems behaved differently for the same voltage stability index. Non-linearity in index was found in distribution system, semi-transmission system and very large transmission systems. For the same buses different values of voltage collapse point were noted showing non-linearity of the index. In spite of non-linearity in the index used it is found efficient to analyze the illness and maximum load ability of different systems.

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