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Study the Effects of Power Plant Unit Outages on Maximum Loading in Power System

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ABSTRACT

Taking into account the increasing rate of consumption in power systems, power plants and transmission lines usually works on the edge of stability, and it is possible that with a little increase in load or occurrence of a contingency, the system goes out of stability. In such systems, maximum loading condition is almost determined in such a way that static stability of the system will be maintained not only in normal operation of the system but also in emergency conditions and in case of the occurrence of a contingency for at least one of the components of the system. Regarding the above mentioned factors, recognition and prediction of voltage instability in the system has a significant importance and raising the security of system is of high priority to the system operator. In this paper, using a continuation power flow method and considering single power plant unit outages in power system, we analyze maximum loading of the system. We performed simulations on IEEE 9 and 14-bus test systems.
KEY WORDS: maximum loading, continuation power flow, power plant unit, static voltage stability.

I. INTRODUCTION

The increasingly growth of electricity consumption adds to the complexity of power systems and considering this high consumption, the system works at the proximity of instability. When a crisis, regardless of its origin, takes place in a power system, the voltage of an specific bus declines abruptly, so that leads the whole system towards instability, which in turn leads to voltage collapse. The reason for voltage drop might be due to the increased load demand, outage of lines or power plant units. It should be remembered that voltage instability is mainly a local phenomenon, but voltage collapse occurs in the whole system. In fact, there exist two issues in voltage collapse analysis that are relevant to each other:

a) Maximum loading point (MLP)
b) Point of voltage collapse (POC)

The distance exists between the current operating point and collapse point, which is referred to as stability margin, plays a significant role in analysis of static voltage stability. To examine voltage collapse, we used static voltage stability analysis methods which are based on an iterative power flow solutions. In [1] and [2] the minimum single value computation for Jacobian matrix was used as an index for determining the stability margin. Using eigenvalues of the reduced jacobian matrix for determining weak bus of the system, reference [3] demonstrates modal analysis, which is similar to single values and single vectors for determining the approximation to the point of voltage collapse. But as shown in [4] they are not appropriate indices for predicting the point of voltage collapse, due to their non-linear behavior at the proximity of that point. Reference [5] presents a voltage stability index as an approximation index, to find critical buses of the system. However, it doesn't provide sufficient information concerning the system's stability margin, considering the contingencies. In this paper, using the Continuation Power Flow method (CPF), which somehow resolves the singularity problem of the power flow Jacobian matrix near the critical point [6], we analyze static voltage stability taking into account contingencies. We have considered only power plant unit outages on contingency. It should be mentioned that in this paper, by contingency for power system we just mean the power plant unit outage.

II. ANALYSIS OF STATIC VOLTAGE STABILITY

Over the past several years, analysis of voltage stability based on different methods received continues and increasing attention. System dynamics that affect on voltage stability are usually slow. Therefore, many facets of the

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problem can be effectively analyzed using static methods. A wide range of system conditions might be investigated using static analysis methods, and if they are employed appropriately, it is possible to provide further insight into the nature of the problem and identify key factors that affect on instability. Static methods take picture from the system conditions in various time intervals along the time-domain path. In each of these time intervals, derivatives of state variables (i.e. $x^{\cdot}$) in time $x^{\cdot} = F(\theta, v)$ equation become zero and state variables take values corresponding to a specific time interval. So the general equation of the system is transformed to purely algebraic equations, and thus employment of static analysis methods will be possible [7].

Static analysis methods provide good results concerning the assessment of voltage collapse for the purpose of identification of the system's weak points, key factors affecting on voltage instability, and estimation of reliability margin using methods such as P-V and Q-V curves derived from repeated power flow. So, for a comprehensive study of voltage stability and for the purpose of implementation of preventive measures, identification of critical buses, especially considering the power system contingencies, has special importance.

III. Power System Contingencies

When a crisis, regardless of its origin, occurs in a power system, the voltage of a specific bus declines abruptly and leads the system towards voltage collapse. This might happen due to overloading or occurrence of contingencies. In power system, contingency is referred to an event that has influence on normal operation of the system [8]. Some contingencies that were included are the power plant unit, transmission line or transformer outage or missing a transmission line and a power plant unit simultaneously. Power plant unit and line outage, may lead to overload in a number of lines or deviation of bus voltages from their permissible limits [9].

Various methods have proposed for evaluating the effect of equipment outages. Usual distribution factor-based methods and DC power flow are quick solutions for evaluating active power flow. But none of them can evaluate the reactive power flow due to voltage security analysis. For this purpose, AC Power Flow Methods was used, and gradually seek to accelerate their algorithm through applying some modifications [10].

IV. The Under-Studied Systems

The under-studied systems are two IEEE 9-bus and 14-bus test systems. MATLAB and PSAT softwares were used for simulation [11]. Single line diagram of IEEE 9-bus and 14-bus test system have depicted in Figs. 1 and 2 in PAST software environment.

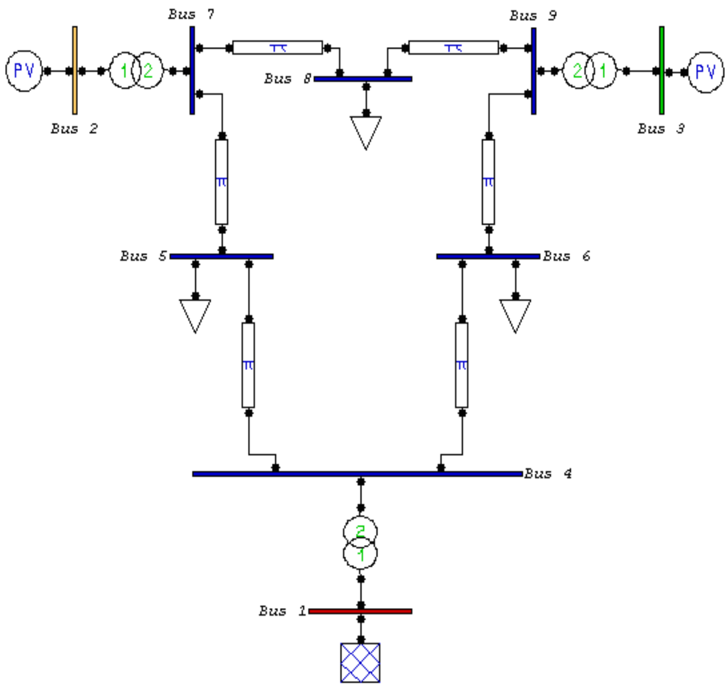

Fig. 1 Diagram of IEEE 9-bus test system simulated with PAST

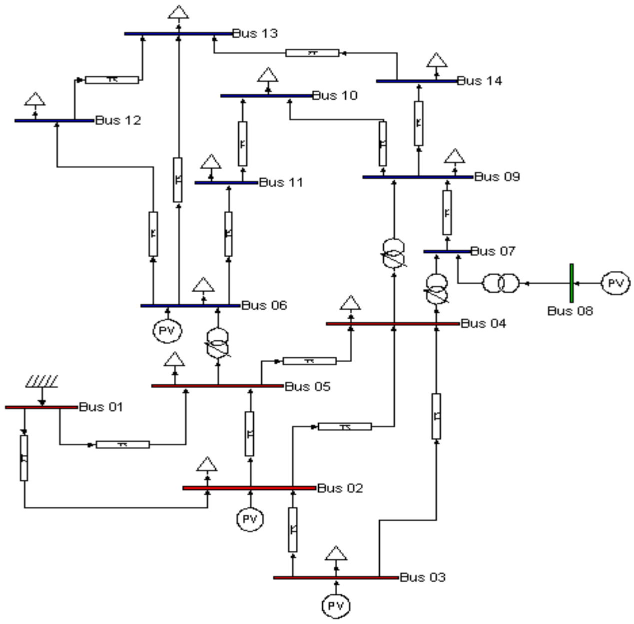

Fig. 2 Diagram of IEEE 14-bus test system simulated with PAST

V. SIMULATION RESULTS

To examine static voltage stability under different loading conditions, at first we performed continuation power flow, using PAST software, for normal condition of the system which all the component of the system are employed accurately. Then upon power plant unit outage, continuation power flow program is executed for the new structure and the obtained results are evaluated. This simulation is evaluated for three cases.

A. Case one: the results of continuation power flow analysis without considering power plant unit outage

In this case, V- λ curve of the system were produced by applying continuation power flow on IEEE 9-bus test system and critical regions are identified. Considering Fig. 3, it is observed that system loading reaches to the value of λmax=2.53 p.u.

It is shown as well in Fig. 4 that buses 4, 5, 6 and 8 have the most loading and hence, have less security margin than other buses. Bus 5, with the voltage of magnitude 0.57 p.u. identified as the weakest bus. In this system, we have 7.97 p.u. active power consumption and 3.16 p.u. reactive power consumption at maximum loading point, which is distributed over load's buses. Continuation power flow is applied again on IEEE 14-bus test system and critical regions are identified. In Figs. 5 and 6 it is shown that buses 14, 5, 4 and 9 have the most loading compared to other buses.

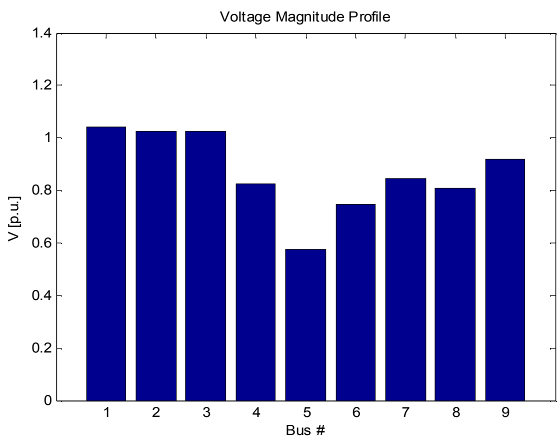

Fig. 3 Voltage magnitude profile for all buses in case one for IEEE 9-bus test system

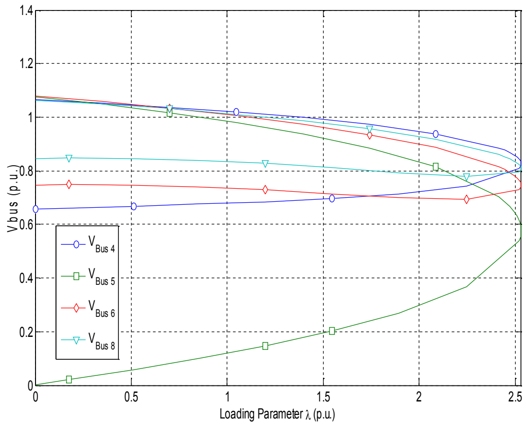

Fig. 4 V-λ curves of critical buses in case one for IEEE 9-bus test system

As we can see, bus 14, is identified as the weakest bus, in which voltage declines abruptly with the increase of power demand and exposes to further static instability. Moreover, at maximum loading point, λmax=2.82 p.u. is calculated. Fig. 7 shows as well that in the bus voltages connected to the power plant unit, no appreciable changes occur with the increase of load, and the voltage of these buses has a constant profile. In this system, we have 1024 MW active power consumption and 322 MW reactive power consumption at maximum loading point which is distributed over 11 load buses.

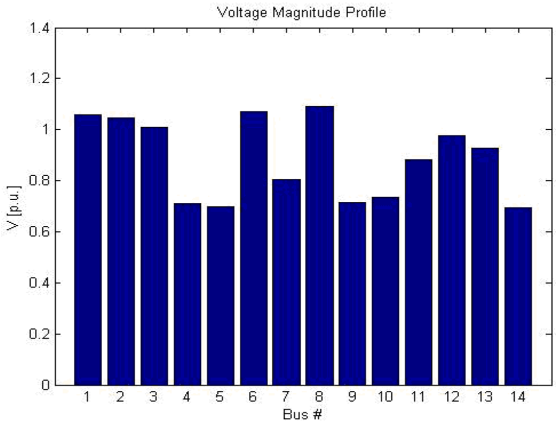

Fig. 5 Voltage magnitude profile for all buses in case one for IEEE 14-bus test system

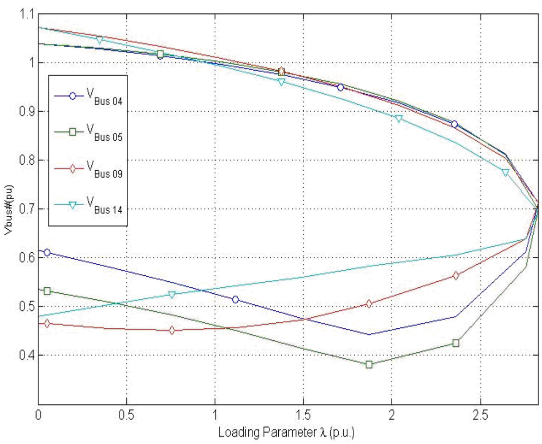

Fig. 6 V-λ curves of critical buses in case one for IEEE 14-bus test system

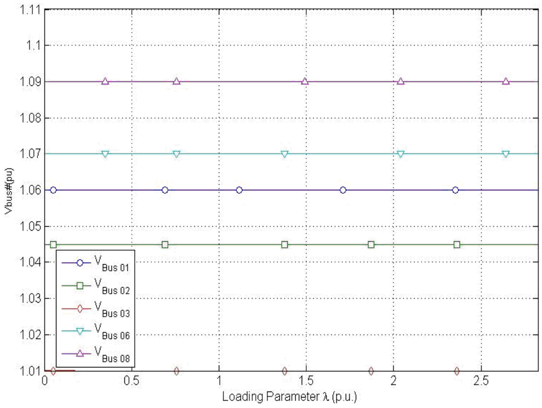

Fig. 7 V-λ curves of buses connected to power plant unit in case one for IEEE 14-bus test system

B. Case two: the results of continuation power flow analysis upon power plant unit outage connected to bus 2 in IEEE 9-bus test system

In this case, considering Figs. 8 and 9, it has shown that buses 5, 7, 2 and 8 have the most loading compared to other buses. Maximum loading is at λmax=1.81 p.u. which in comparison to without production unit outage λmax=2.53 p.u. is reduced. Moreover, upon power plant unit outage connected to bus 2, maximum loading of the system has reached to the value of λmax=2.18 p.u.

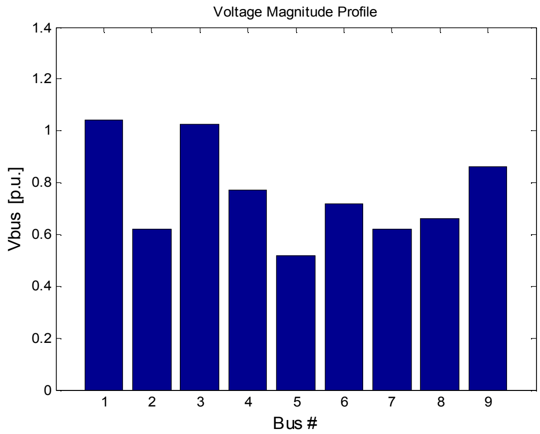

Fig. 8 Voltage magnitude profile for all buses in case two for IEEE 9-bus test system

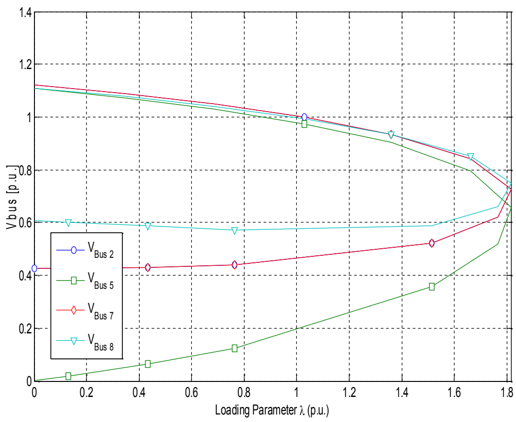

Fig. 9 V-λ curves of critical buses in case two for IEEE 9-bus test system

C. Case three: the results of continuation power flow analysis upon power plant unit outage connected to bus 8 in IEEE 14-bus test system

In this case, the power plant unit connected to bus 8 exits from the system and by applying continuation power flow analysis repeatedly on the new system, the critical regions within the system will be identified. In Figs. 10 and 11 it is shown that buses 9, 7, 8 and 14 are the most critical buses compared to other buses. In this case, bus 9 is a critical bus in which voltage declines further with the increase of flow demand and system exposes to static collapse. Moreover, maximum loading point is at λmax=2.44 p.u. which in comparison to the case one is reduced.

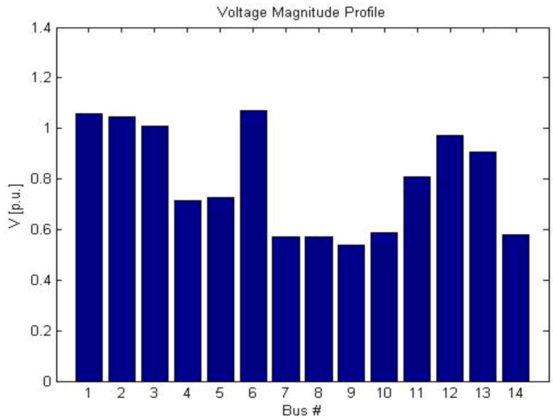

Fig. 10 V-λ curves of critical buses in case three for IEEE 14-bus test system

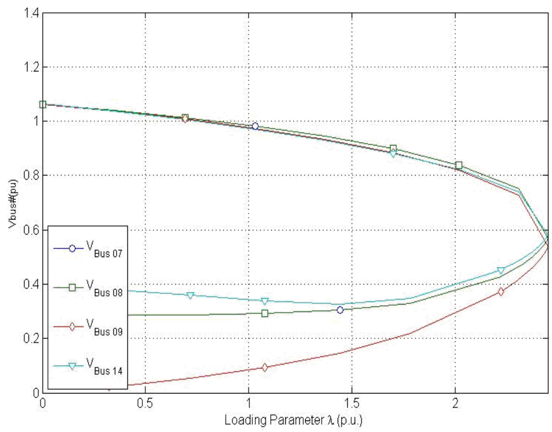

Fig. 11 V-λ curves of critical buses in case three for IEEE 14-bus test system

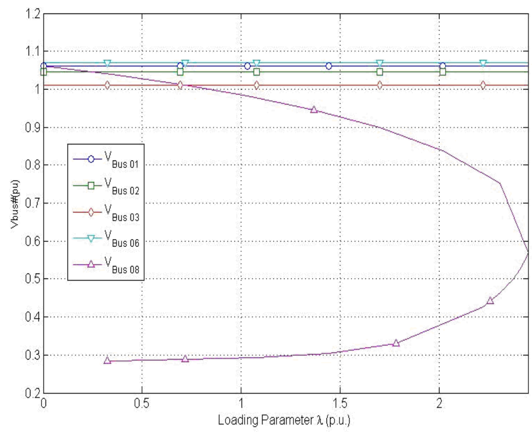

Fig. 12 V-λ curves of buses connected to power plant unit in case three (with bus 8 power plant unit outage) for IEEE 14-bus test system

The total amount of active and reactive power consumption of load buses at maximum loading point, is 887 MW and 278.9 MW respectively which is reduced in comparison to the first case, and it indicates that the interruption of production unit causes the reduction of total power consumption in load buses and it somehow causes the reduction of maximum loading point, increased voltage drop in buses, and more proximity to collapse. It can be seen as well in Fig. 12 that due to the interruption of power plant unit connected to bus, the voltage of this bus decreases significantly but voltages of buses that power plant unit is connected to them, is a constant profile like the first case.

VI. CONCLUSION

In this paper, for analyzing the maximum loading from the static point of view, we studied the effects of power plant unit outages by applying continuation power flow method in IEEE 9 and 14-bus test systems. The results reveal that the occurrence of contingency for the power plant unit in a power system, together with gradual increase of load, causes increasing voltage drop in buses, decreasing maximum loading point and more closeness of buses to instability and finally collapsing the system. Of course it must be emphasized that the effect of this contingency on various points of the system that the occurrence of each one of these factors, causes a shift in the location of critical buses in the power system, so identification of those system regions that come under the influence of this contingency has a special importance in the power systems.

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