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Static Voltage Stability Analysis of Dynamic IEEE 14 Test Bus System

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ABSTRACT: Voltage stability analysis is crucial for ensuring the reliable operation of power systems, especially as they face increasing demands and complexities. Voltage instability is concerned with maintaining appropriate voltage level across all the buses in the power system. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. It's important because voltage instability can lead to voltage sags, swells, or even blackouts, affecting both the power supply and the end-users. In this paper the static voltage stability analysis of Dynamic IEEE 14 bus system was analysed using Power system Analysis Toolbox. (PSAT)

KEYWORDS: Modal Analysis, IEEE 14 Bus system, MATLAB (PSAT)

I. INTRODUCTION

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system under normal operating conditions and after being subjected to disturbances. It's important because voltage instability can lead to voltage sags, swells, or even blackouts, affecting both the power supply and the end-users.

Voltage instability has been given much attention by power system researchers and planners in recent years, and is being regarded as one of the major sources of power system insecurity. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue.

Static Voltage stability analysis is one of the major studies that is carried out during the planning and operation of the power system. The static voltage stability analysis uses a system condition or a snapshot to assess the voltage stability issues.

Several incidences of voltage collapse have been observed, in the past few decades, in different parts of the world. Some of the incidences of voltage collapse are:

- New York State Pool disturbance of September 22, 1970.
- Jacksonville, Florida system disturbance of September 22, 1977.
- Sri Lanka Power System disturbance of May 2, 1995.
- Northern Grid disturbance in the Indian Power System of December 1996.
- North American Power system disturbance of August 14, 2003.
- National Grid System of Pakistan disturbances of September 24, 2006.

National Scenario

- Northern Regional grid security violation, January 2001 leading to 1500mw loss in a generation.
- Northern Regional failure 23rd December 2000.
- Southern Regional grid failure on 13th October 1995.
- Western Regional Grid failure on 10th November 1995.
- Western Regional Grid failure on 9th December 1995.

II. 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.

It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result occurs in the form of a progressive fall or rise of voltages of some buses.

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Voltage stability analysis involves the study of the following parameters:

Voltage Stability Margin: This is a measure of how close the system is to losing voltage stability. It typically refers to how much the load can increase before causing instability.

Load Flow Analysis: This involves calculating the voltage, current, and power flows in a power system under various conditions. It helps identify voltage stability margins.

Voltage Collapse: This occurs when a power system loses its ability to maintain voltage levels, leading to a gradual decline in voltage until it reaches a critical point where the system cannot sustain itself.

III. METHODS OF ANALYSING VOLTAGE STABILITY

Steady-State Analysis: Involves the use of load flow studies to assess the system's ability to maintain voltage stability under steady conditions. Tools like Power Flow Analysis (using methods like Gauss-Seidel or Newton-Raphson) are often employed.

Dynamic Analysis: Evaluates how the system responds to disturbances over time. Time-domain simulations are used to study the system's behavior under transient conditions.

Voltage Stability Indices: These are mathematical measures used to evaluate voltage stability. Examples include the Voltage Stability Index (VSI) and the L-index.

Continuation Power Flow Analysis: A technique used to track the system's voltage stability as the load increases. It involves incremental changes in load and tracking the resulting changes in system stability.

The analysis of voltage stability, for planning and operation of a power system, involves the examination of two main aspects:

How close the system is to voltage instability (i.e. Proximity). When voltage instability occurs, the key contributing factors such as the weak buses, area involved in collapse and generators and lines participating in the collapse are of interest (i.e. Mechanism of voltage collapse).Proximity can provide information regarding voltage

The mechanism gives useful information for operating plans and system modifications that can be implemented to avoid the voltage collapse

IV. STATIC VOLTAGE STABILITY ANALYSIS

Static Analysis: Unlike dynamic analysis, which considers system behavior over time, static voltage stability analysis deals with system behavior at a specific point in time. It examines the system's ability to handle changes in load or generation under steady-state conditions.

Methods of Analysis

Power Flow Analysis: This method involves solving the power flow equations to determine the operating point of the system. Voltage stability can be assessed by examining how voltages and power flows change with increasing load or changes in generation.

Voltage Stability Margin: This is the difference between the current operating point and the point at which the system becomes unstable. It is often analyzed using techniques like the continuation power flow method.

P-V Curve Analysis: This curve represents the relationship between the load (P) and the voltage (V) at a particular bus. By plotting the P-V curve, you can identify the critical point where voltage collapse may occur.

Q-V Curve Analysis: This curve shows the relationship between reactive power (Q) and voltage (V). It helps in understanding how reactive power support impacts voltage stability.

Sensitivity Analysis: This involves analyzing how changes in system parameters (like load or generator output) affect voltage stability. Sensitivity indices can help in identifying critical buses or lines that are vulnerable to stability issues.

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Continuation Power Flow: This is an advanced method used to trace the changes in voltage stability as the system load is incrementally increased. It helps in identifying the stability limit and the critical points where the system may become unstable.

Tools and Software
Several tools and software packages can assist with static voltage stability analysis, such as:

Power System Analysis Software (e.g., PSS/E, PowerWorld): These tools can perform detailed power flow and stability studies.
MATLAB/Simulink: For custom analysis and simulations.

DIgSILENT PowerFactory: Another popular tool for power system analysis.
Practical Considerations

1. **Load Models**: Accurate modeling of load characteristics is crucial for reliable stability analysis. Different load models (constant impedance, constant current, constant power) can affect the results.
2. **Reactive Power Compensation**: The presence of reactive power compensators (like capacitors or reactors) can significantly impact voltage stability. Their placement and sizing should be optimized to enhance stability.
3. **System Configuration**: The topology of the power system, including the configuration of transmission lines and transformers, plays a role in stability. Changes in system configuration can affect voltage stability.
4. **Operational Practices**: Operator actions and system control practices, like adjusting generator outputs or switching equipment, are important for maintaining voltage stability during system disturbances.

V. MODAL ANALYSIS

Steps in Modal Analysis for Static Voltage Stability
Formulate the Power Flow Equations:
Start with the power flow equations of the system, which are typically nonlinear. These equations relate the bus voltages to the real and reactive power injections at each bus.

Linearize the Power Flow Equations:
Linearize the power flow equations around a given operating point to obtain the Jacobian matrix. This matrix is essential for understanding how small disturbances affect the system.

Compute the Jacobian Matrix:
The Jacobian matrix consists of partial derivatives of the power flow equations with respect to the system state variables (voltages and angles). This matrix is used to study the system's response to perturbations.

Perform Eigenvalue Analysis:
Calculate the eigenvalues and eigenvectors of the Jacobian matrix. The eigenvalues provide information about the stability characteristics of the system:

Positive Real Eigenvalues: Indicate unstable modes.
Zero Real Eigenvalues: Suggest marginally stable or neutral modes.
Negative Real Eigenvalues: Indicate stable modes.

Analyse the Modal Contributions:
Each eigenvalue is associated with a mode shape, described by its corresponding eigenvector. Analyzing these modes helps in understanding how different parts of the system contribute to voltage stability.

Evaluate Modal Sensitivities:
Assess how changes in system parameters (e.g., load changes, generator outputs) affect the eigenvalues and eigenvectors. This sensitivity analysis helps in identifying critical components or configurations that impact stability.

The Modal analysis of the Jacobian matrix is used to analyze the static voltage stability Nima Amjady et al. (2008)[83] as given in the equation

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$$\begin{bmatrix} \Delta P_{PQ,PV} \\ \Delta Q_{PQ} \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V_{PQ} \end{bmatrix}$$

where,
$\Delta P_{PQ,\ PV}$ is the incremental change in bus real power
ΔQ_{PQ} is the incremental change in bus reactive power
$\Delta\theta$ is the incremental change in bus voltage angle
ΔV is an incremental change in bus voltage magnitude

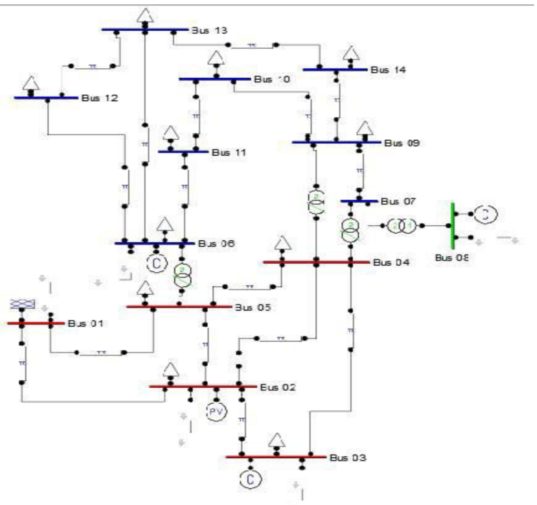
The elements of the Jacobian matrix represent the sensitivities between nodal power and bus voltage changes. Power system voltage stability is largely affected by reactive power. Keeping real power constant at each operating point, the Q-V analysis can be carried out. Assuming $\Delta_{PPQ,PV} = 0$, it follows from the equation
$\Delta Q_{PQ} = [J_{QV} - J_{Q\theta}.J^{-1}_{P\theta}.J_{PV}].\Delta V_{PQ} = J_R.\ \Delta V_{PQ}$
and, $\Delta V_{PQ} = J^{-1}_{R.}\ .\Delta Q_{PQ}$
The Q-V modal analysis can be performed based on the inverse of the reduced Jacobian matrix (J_R^{-1}), and it represents the reduced V-Q Jacobian matrix. Therefore, the bus, branch, and generator participation factors are obtained. Moreover, the stability margin and the shortest distance to instability will be determined.

Continuation Method

Continuation power flow-based voltage stability techniques are based on the reformulation of the load flow equation and application of predictor and corrector techniques with local parameterization to plot the trajectory of the PV curve. The continuation power flow method is used to analyze the power system where the load changes continuously from the base case to a critical point. This method yields accurate results and is used to determine the critical buses that may lead to voltage insatiability.

Continuation Power Flow Diagram
ALGORITHM FOR VOLTAGE STABILITY ANALYSIS

Step 1: The power flow based on the Newton Raphson method is executed for the Dynamic IEEE 14 test bus system and the power flows are obtained.
Step2: From the power flow result, those buses with poor voltage profile is considered as the weak buses.
Step 3: The Continuation Power Flow algorithm is executed on the Dynamic IEEE 14 test bus system.
Step 4:The PV Curves are obtained from the Continuation Power Flow and the maximum Loading Limit is obtained.
Step 5: The dynamic components are discarded and the above procedure is repeated.



The plot of voltage magnitude at various buses is shown in figure 5.6. From the voltage profile, it is evident that buses 4,5,9,10 and 14 have less voltage magnitude and so they are considered to be weak bus which may provoke voltage instability.

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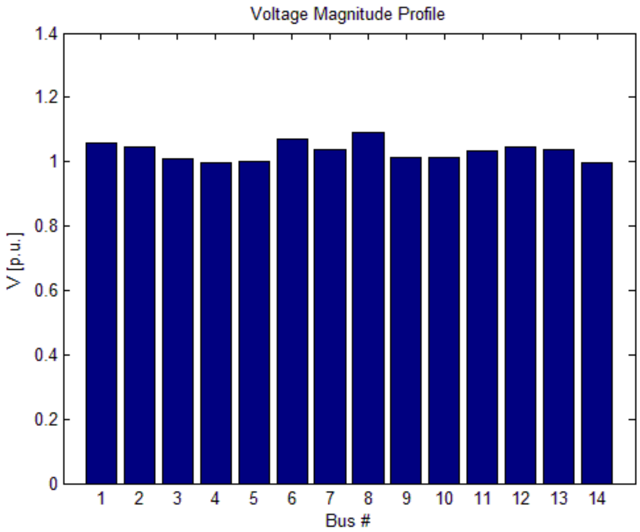
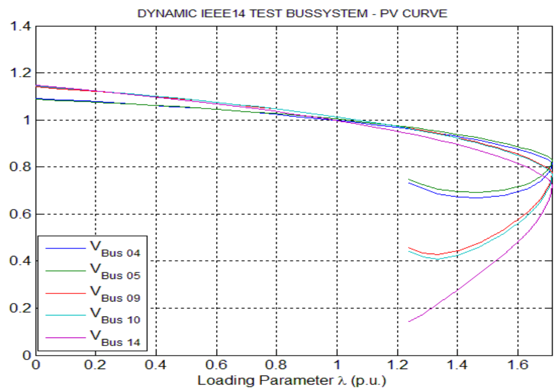


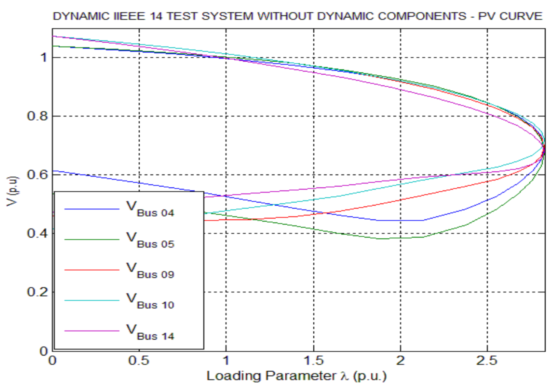
Voltage Magnitudes of Dynamic IEEE14 bus System

STUDY OF THE EFFECT OF DYNAMIC COMPONENTS ON THE MAXIMUM LOADABILITY LIMIT

To determine the maximum Loading margin the CPF program is executed.



PV Curve of Dynamic IEEE14 bus System



PV Curve of Dynamic IEEE14 bus System with Dynamic Components Discarded.

The PV curves for the dynamic IEEE14 bus system and the dynamic component discarded system are shown in the figures. From the CPF result of the dynamic IEEE14 bus system with the dynamic components included and the PV

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Curve, it is evident that the maximum loading margin is 1.787 p.u. Whereas in the case of the dynamic component discarded system the maximum loadability limit is 2.8277 p.u. So it is evident that the introduction of dynamic components into the power system reduces the Voltage stability Margin significantly.

VI. CONCLUSION

In this paper , the voltage stability analysis of Dynamic IEEE 14 bus was carried out based on Static voltage stability analysis using Modal and Continuation power flow technique. Power system Analysis Tool Box (PSAT) on MATLAB 2014 was used for analyzing the voltage stability of the IEEE14 bus and it was identified that the system does not possess voltage stability.

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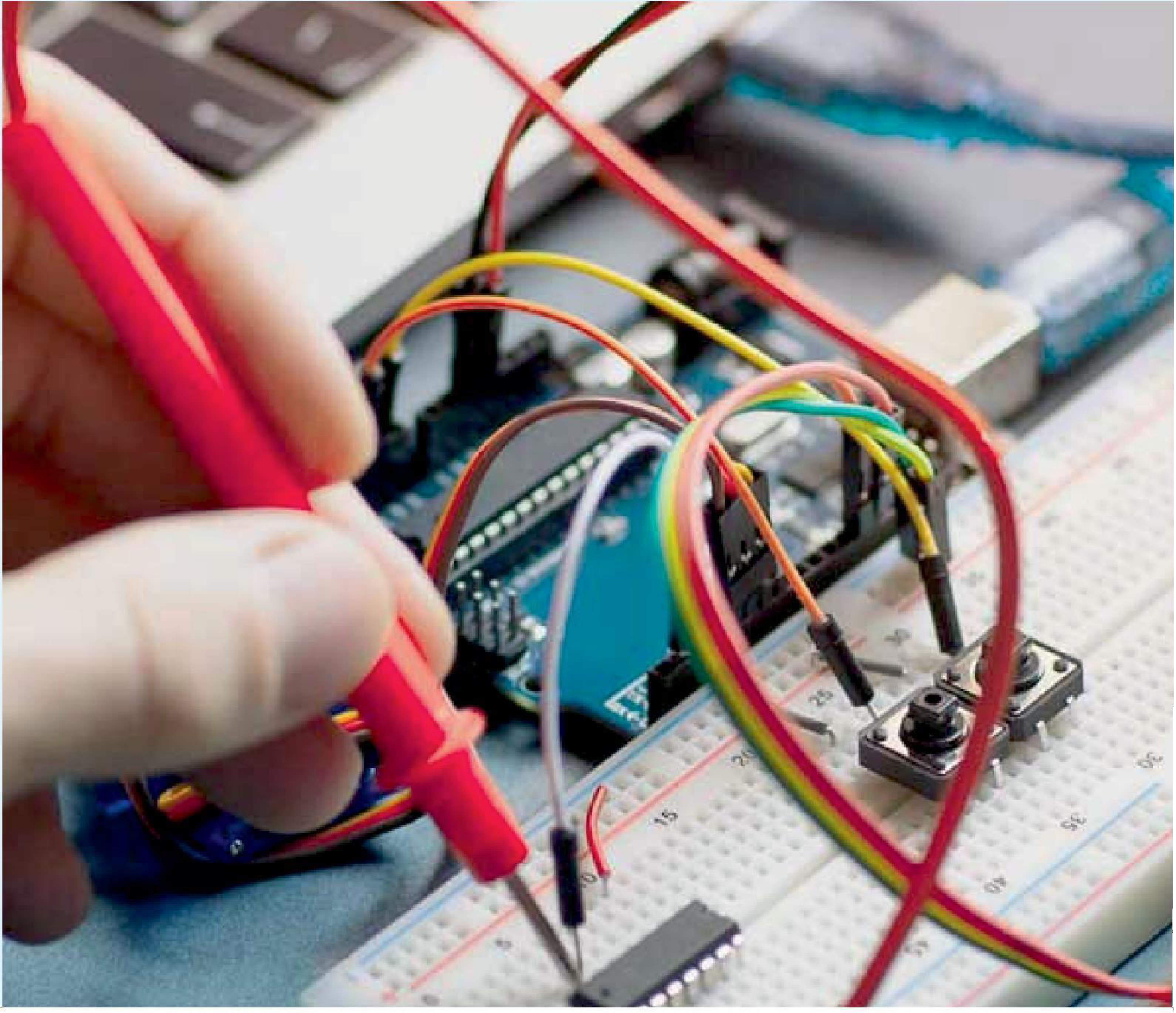

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