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Voltage Stability Analysis of Squirrel Cage Induction Generator [SCIG] Integrated Wind Farms

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ABSTRACT: The complexity of the power system and level of integration of Wind energy into the power system has significantly increased, causing voltage instability problem across many power systems. Voltage instability is concerned with maintaining appropriate voltage profile 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. In this paper the voltage stability analysis of Squirrel Cage Induction Generator (SCIG) integrated system was analyzed using Power system Analysis Toolbox.(PSAT)

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

I. INTRODUCTION

The complexity of the power system has increased in response to the economic growth and continuously increasing power demand. Renewable energy (RE) conversion and integration has attracted much attention in recent years and is now a main area of interest in the energy sector. This is informed by the need to address climate change effects because of the perennial exploitation of fossil-fuel for power production and the need to supply the rising demand in energy worldwide .Thus, renewable and sustainable energy alternatives to the traditional fossil fuel-based power generation are being developed and deployed in different parts of the world. Now a days integration of Wind energy has significantly increased, causing voltage instability problem across many power systems. Billions of dollars are committed annually to renewable energy research and development in North America, Europe, Japan, China, Australia, India and Brazil.

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.

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.

Voltage stability analysis: 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

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II. VOLTAGE STABILITY ANALYSIS USING BIFURCATION ANALYSIS

The Voltage stability of a power system can be well analyzed by using bifurcation analysis. The bifurcation analysis gives a quantative and qualitative analysis of the voltage stability of the power system.The following are the types of bifurcation analysis:

- Saddle-node bifurcation point, where two equilibrium coalesce and then disappear, at this point the reduced Jacobian has a zero Eigen value.
- Hopf bifurcation point, where there is an emergence of oscillatory instability, at this point, two complex conjugate Eigen values of reduced Jacobian cross the imaginary axis.
- Singularity induced bifurcation, at this point, y (g) is singular, we know that ~>the inverse of y (g) will become infinity, which is called "singularity induced infinity", where it is not easy to compute and analyze the stability of the system.

Modal or Eigen Value Analysis: Modal analysis can predict voltage collapse in complex power system networks. It involves mainly the computing of the smallest Eigen values and associated eigenvectors of the reduced Jacobian matrix obtained from the load flow solution. The Eigen values are associated with a mode of voltage and reactive power variation, which can provide a relative measure of proximity to voltage instability. Then, the participation factor can be used effectively to find out the weakest nodes or buses in the system.

The stability margin or distance to voltage collapse can be estimated by generating the Q-V curves for that particular bus. Assume that a power system is located at a primary operating point. In this operating point, the relations between main power system quantities (voltage magnitude, voltage angle, injected active power and injected reactive power) can be expressed by power flow equations.

The linearized steady state system power voltage equations are given by,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{q\theta} & J_{qV} \end{bmatrix} \times \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix}$$

ΔP = incremental change in bus real power.
ΔQ= incremental change in bus reactive power injection.
ΔΘ = incremental change in bus voltage angle.
ΔV = incremental change in bus voltage magnitude.
Where the change in active and reactive power are related to changes in angle and voltage. The minimum singular value or the smallest eigenvalue of the Jacobin matrix can be used as distance or proximate indicator to this limit. If the Jacobin matrix models the power flow equations, this singularity will coincide with the point of maximum load ability. But if load behaviors etc. are included (extended Jacobin matrix) the singularity will indicate the point of collapse. If ΔP= 0, the relation between voltage change and reactive power change can be written as

$$\Delta Q = \left[J_{qV} - J_{q\theta} \times J_{P\theta}^{-1} \times J_{PV}\right] \times \Delta V = J_R \times \Delta V$$

At the beginning, load-flow analysis will be performed by using full Newton-Raphson load flow method to obtain the voltage profile, total power losses and Jacobin matrix.

The reduced Jacobin matrix J_R can be calculated from Jacobin matrix

$$J_R = \left|J_{qV} - J_{q\theta} \times J_{p\theta}^{-1} \times J_{PV}\right|$$

The matrix *JR* represents the linearized relationship between the incremental changes in bus voltage (Δ*V*) and bus reactive power injection (Δ*Q*). It's well known that, the system voltage is affected by both real and reactive power variations. In order to focus the study of the reactive demand and supply problem of the system as well as minimize computational effort by reducing dimensions of the Jacobian matrix *J* the real power (Δ*P* = 0) and angle part from the system are eliminated.
$\Delta V = J_R^{-1} \Delta Q$

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The Eigen values and eigenvectors of the reduced order Jacobian matrix *JR* are used for the voltage stability characteristics analysis. Voltage instability can be detected by identifying modes of the Eigen values matrix *JR*. The magnitude of the Eigen values provides a relative measure of proximity to instability. The eigenvectors on the other hand present information related to the mechanism of loss of voltage stability.

There is no need to evaluate all the Eigen values of J_R of a large power system because it is known that once the minimum Eigen values becomes zeros the system Jacobian matrix becomes singular and voltage instability occurs. Thus, the smallest Eigen values of JR are taken to be the least stable modes of the system. The rest of the Eigen values are neglected because they are considered to be strong enough modes. Once the minimum Eigen values and the corresponding left and right eigenvectors have been calculated the participation factor can be used to identify the weakest node or bus in the system.

III. SQUIRREL-CAGE INDUCTION GENERATOR (SCIG)

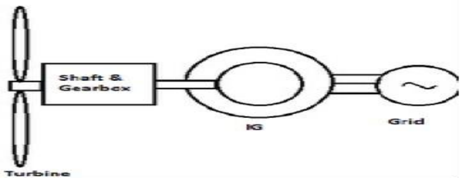

Figure:1. SCIG

As illustrated in Fig., wind turbine is connected to rotor of Squirrel-Cage Induction Generator (SCIG) through a shaft and gearbox. Since SCIG often runs at constant speed, this topology represents a fixed-speed wind turbine system

Operation of squirrel cage induction generator : The SCIG in this WTG concept can only operate within a narrow range of the rotational speed slightly above the synchronous speed. Because of these very small rotational speed variations, this type of WTG is considered to operate at fixed speed. As shown in Figure, each individual WTG consists of a SCIG driven by a wind turbine through a mechanical shaft system and operates at a certain incoming wind velocity. SCIG consumes reactive power and therefore is normally equipped with compensating capacitors for reactive compensation and improving the power factor. Since SCIG is of fixed speed generator, for a particular wind speed, the output active power is fixed as well. Thus, with the increase of wind speed, so does the output power until the nominal power is reached. The wind speed at this moment is called nominal wind speed. Beyond this speed, the pitch angle system will prevent the output power from exceeding the nominal value. That is, when the wind speed is below nominal value, the power capture can vary with the change of wind speed; **when** the wind speed is above nominal value, the pitch angle control system will limit the generated power by changing the pitch angle

IV. SIMULATION RESULTS

The IEEE14 standard test bus system was re modeled by integrating SCIG at bus number1.The Newton Raphson power flow algorithm was executed to determine the voltage profile and the weak bus.The Eigen value analysis was carried out to find the voltage stability and small signal stability of the system.

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VOLTAGE PROFILE OF IEEE 14 BUS SYSTEM WITH SCIG

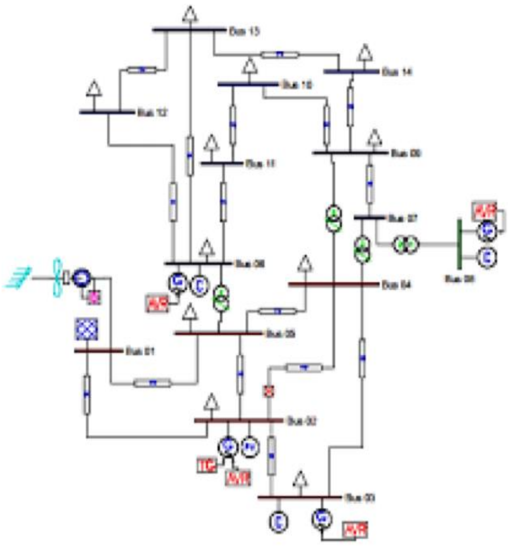

Fig.2. IEEE14 TEST BUS SYSTEM WITH SCIG WIND FARM INTEGRATED

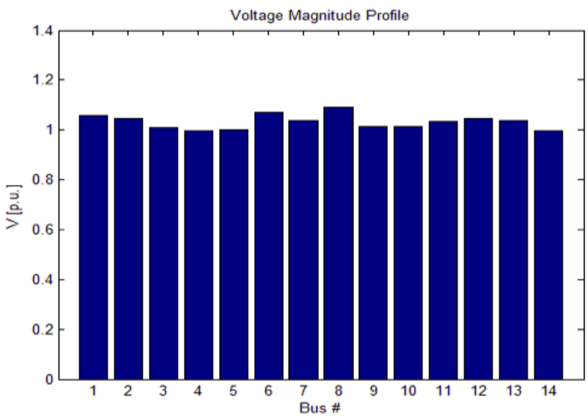

Fig.3. VOLTAGE PROFILE OF IEEE14 BUS WITH WEGRATED WITHISCIG

From the Voltage profile plot of the IEEE14 bus system it is identified that bus number 14 is the weakest bus.

The real power and reactive power injection at all the buses are plotted and shown below. The p[lot is obtained by using the PSAT software.

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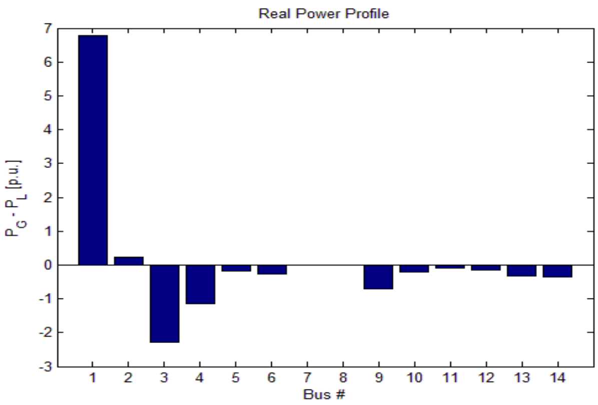

Fig.4. REAL POWER PROFILE OF IEEE14 BUS INTEGRATED WITH SCIG:-

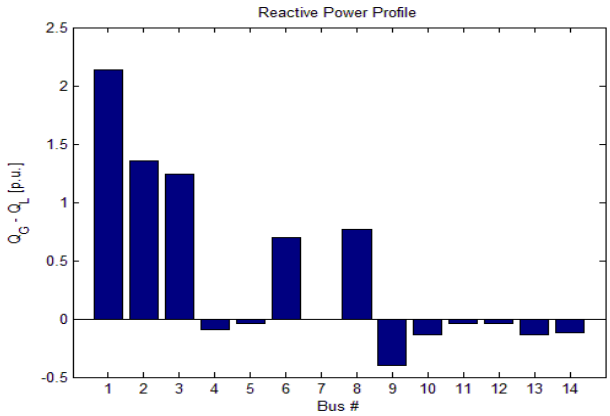

Fig.5. REACTIVE POWER PROFILE OF IEEE14 BUS INTEGRATED WITH SCIG

V. EIGEN VALUE ANALYSIS

The Eigen value analysis was carried out on the SCIG wind integrated power system and the following result was obtained.

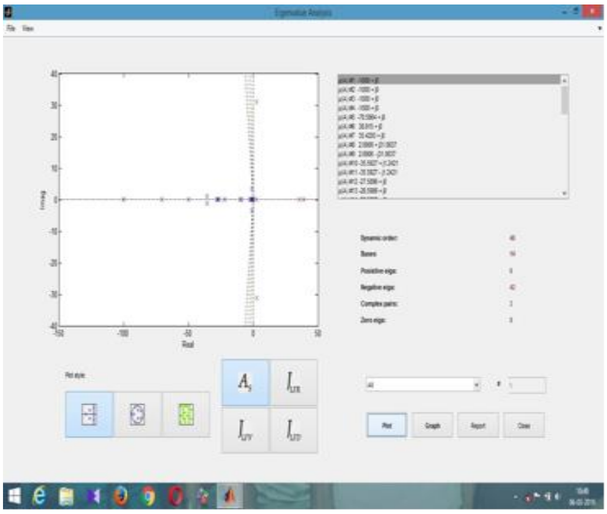

Fig.6. EIGEN VALUE ANALYSIS OF IEEE14 BUS INTEGRATED WITH SCIG

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The Eigen value analysis was carried out using the PSAT , it is evident that there are six positive Eigen values indicating that the IEEE14 test bus system integrated with SCIG does not possess Voltage stability. The Eigen value also shows the presence of three complex pairs indicating that the system may possess small signal instability.

VI. CONCLUSION

In this paper , the voltage stability analysis of SCIG was carried out based bifurcation technique. Power system Analysis Tool Box (PSAT) on MATLAB 2014 was used for analyzing the voltage stability of the IEEE14 bus system integrated with SCIG.It was identified that the system does not possess voltage stability and also the system may encounter small signal instability when loaded.

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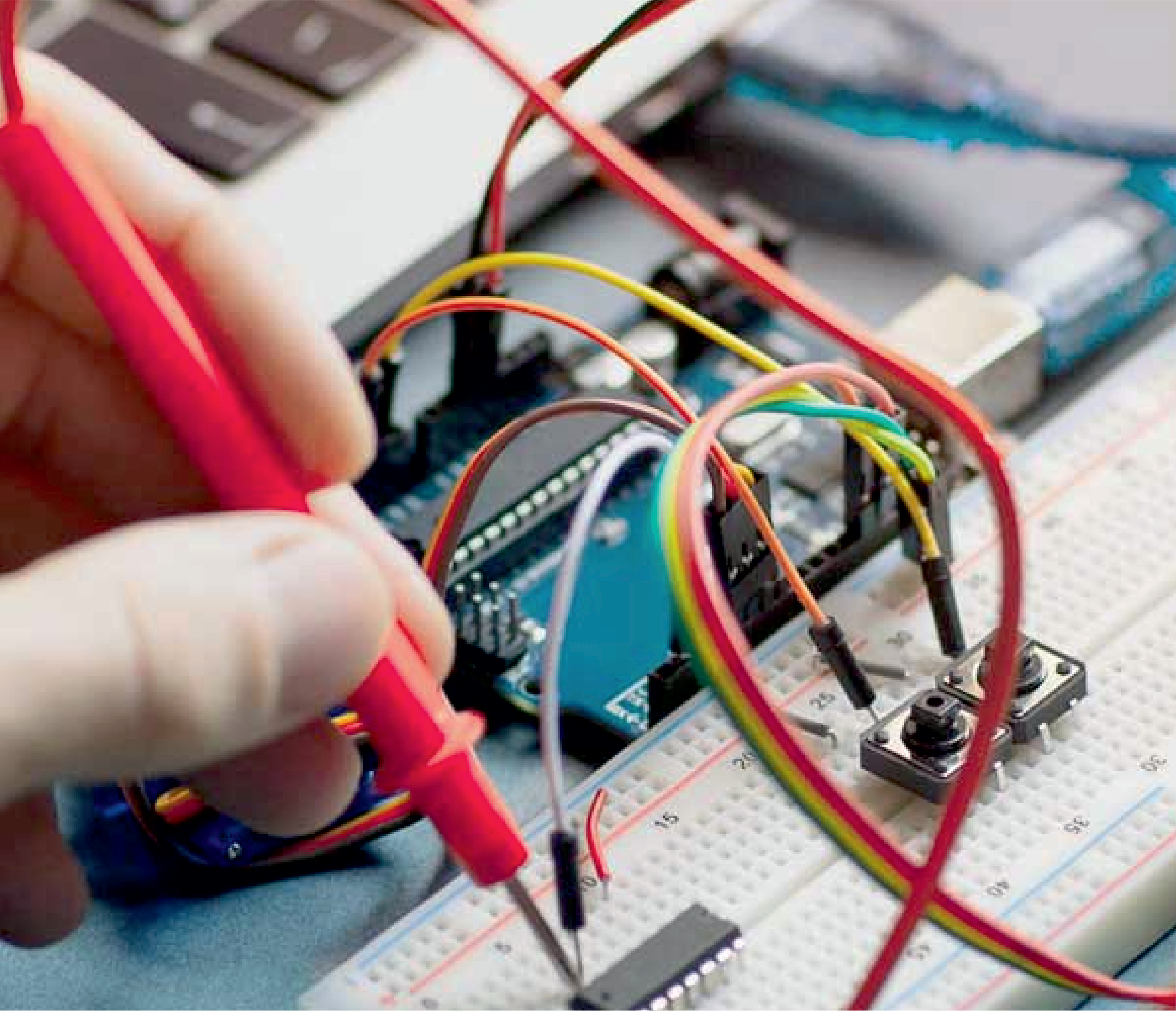

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