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# Transient Stability of Grid Connected SCIG Wind Turbine

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**ABSTRACT:** Fixed speed wind turbine is common problem in wind power plants. In fact, being equipped with a squirrel-cage induction generator (SCIG), they tend to drain a relevant amount of reactive power from the grid, potentially causing voltage drops and voltage instability. Wind power output is proportional to the cube of wind speed, which is time-varying in the real world. Thus, SCIG power fluctuations can lead to over-speed and network instability. As the level of wind energy in modern power systems is increased, there is need for accurate study of transient nature and its effect on both turbine as well as transmission line parameter. Consequently, it is important to analyze the impacts of SCIG on the distribution network and to understand the performance of WT under transient-state conditions. This paper investigates transient stability issues of grid connected SCIG wind turbine. The effect of transient stability issues on transmission line parameter is investigated. Mathematical model of 3 MW grid connected SCIG is simulated in MATLAB.

**KEYWORDS*:*** modelling of wind turbine , stability issues , model of grid conneted induction generator

## I. INTRODUCTION

Indian power sector has installed capacity of 288.6 GW and electricity demand is growing more than 8% annually. This increasing demand has forced researchers to explore the hidden potential of wind energy system so that development of renewable energy in terms of cost-competitiveness, energy-efficiency and predictability will be possible[1]. Renewable energy penetrates about 13% of the total Indian energy installed capacity of 2, 88,664.94 MW of which wind energy contributes about 8.5% with installed capacity of 25,188.39 MW. India is becoming one of the major hubs for renewable energy generation after China, USA and Germany. Among all renewable generation, Wind power generation development has initiated in almost all parts of country[2].Table (1) shows the state wise installed capacity of wind power in India[1].

TABLE 1: STATE WISE INSTALLED CAPACITY OF WIND POWER IN INDIA

| Sr. No. | State | Cumulative Installed capacity as on 31/01/2016 |
|---|---|---|
| 1 | Andhra Pradesh | 1031.40 MW |
| 2 | Gujarat | 3645.40 MW |
| 3 | Karnataka | 2638.40 MW |
| 4 | Kerala | 35.10 MW |
| 5 | Madhya Pradesh | 879.70 MW |
| 6 | Maharashtra | 4450.80 MW |
| 7 | Rajasthan | 3307.20 MW |
| 8 | Tamil Nadu | 7455.20 MW |
| 9 | Others | 4.30 MW |
| Total | | 25188.39 MW |

Wind energy is clean and renewable energy source with an ability to produce electrical energy for stand alone, micro grid and utility grid integrated application. The kinetic energy available in wind is trapped by wind turbines and

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converted to electrical energy using electric generators. Traditionally there are three main types of wind turbine generators. These are DC generators, synchronous generators and asynchronous generators. DC generators need to accompanied with commutators and brushes which require regular maintenance and relatively costly. It is usually use for low power demand application like battery charging where load is close to wind turbine. Synchronous generators are widely used for wind generation technology due to its good performance. But the rotor speed must be kept exactly at the synchronous speed, otherwise synchronism will lose. Synchronous generators tend to have low damping effect so that they do not allow drive train transients to be absorbed electrically. Due to this reason they need additional damping elements mounted on springs and dampers. In addition to this synchronous generators are more complex, costly and prone to failure than asynchronous generators. Asynchronous generators are currently predominant and most useful for wind power generation. They are classified as squirrel cage induction generator (SCIG), and wound rotor induction generator (WRIG). Both generators have their own advantage and disadvantages for wind power application. Based on excitation induction generator are classified as; standalone and grid connected. In the standalone mode, the magnetizing flux is established by a capacitor bank connected to the machine and electrical power generated through it, used for domestic application. In case of grid connected utility, grid generated power is fed to state electricity board for transmission and distribution to the community at large. The mode of grid connected wind power generation is becoming popular and has become quite matured as reliable technology even though wind resource at any site is always uncertain and variable in nature. Grid conneted induction generator found more application as it requires no external excitation. However induction generators draw large transient currents, sometimes more than machine rated current when it is connected to utility grid. Due to this, voltage fluctuations occur in the system and thus the continuity of power generation decreases. Disturbance may be due to fault condition or due to utility grid [3].

Many authors and researchers discussed about the transient stability analysis and its mitigation technique. Power system transient stability is related to the ability to maintain synchronism when subjected to a severe disturbance, such as a three phase fault or short circuit on a bus. The resulting system response involves large excursions of the generator rotor angles and is governed by the nonlinear power–angle relationships. Transient stability assessment essentially determines whether the system can reach an acceptable steady-state operating point in post-fault operating stage. Amutha, N.; Kalyan Kumar B[4] discussed the stability of a post-fault power system can be determined by checking the fault-on trajectory at clearing time. If it lies inside the stability region of a desired stable equilibrium point of the post-fault system, then the system is stable. L. Dusonchet, F. Massaro and E. Telaretti[5] discussed about the voltage stability behavior of a fixed speed wind turbine (FSWT) connected to the grid, after a short-circuit fault in the power network. Li Jianlin, Liang Liang, yangshuili, Hui Dong[6] describe about wind power fluctuations and its impact on grid. Mohsen Rahimi and Mustafa Parniani[7] have investigated the dynamic behavior of FSWT under wind speed fluctuations and systems disturbances. Olof Samuelsson and Sture Lindahl[8] briefly explain the on speed stability for induction generator also describes the phenomenon for speed stability and provide a tentative definition. H. Li B. Zhao, C. Yang H.W. Chen Z. Chen [9] discussed the transient models of the wind turbine generation system including the flexible drive train model based on the direct transient stability estimation method. A method of critical clearing time (CCT) calculation is developed for the transient stability estimation of the wind turbine generation system. Walmir Freitas, Andre Morelato, and Wilsun Xu[10] present the issue of short term voltage instability and improvement voltage instability by braking resistor. Daniel Trudnowski[11] mention about the problem of fixed-speed wind-generator based on transient stability studies. This problem of stability is evaluated by Wind Park modeling technique.

This paper presents the study of transient stability issues and its effect on turbine and transmission line parameters. The structure of paper is organized as: Section 2 describes mathematical modeling of wind turbine. Section 3 describes stability issues observed in grid connected squirrel cage induction generator. Section 4 discusses the mathematical modelling of grid connected SCIG wind turbine. Section 5 describes simulation results of modelling of SCIG based on MATLAB-13.

## II.MATHEMATICAL MODELLING OF WIND TURBINE

A wind turbine is rotating machines which capture the power from the wind by means of aerodynamically blades and converts into rotating mechanical power. Mechanical power is transferred by shaft in the form of torque at certain rotation to prime mover. Wind is continuously varying in nature and its velocity depends on height. Greater the height, higher will be available wind power. The blades derives its rotational energy from the kinetic energy of the wind and

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moves the prime mover involving gear system thus converting wind energy to mechanical energy .The yaw motor is used to turn the rotor towards the wind, as wind continuously changes its direction[12].

Wind turbine rotor converts the kinetic energy absorbed from the wind into mechanical energy. The available power $P_{wt}$ is given by

$$P_{wt} = \frac{1}{2}\rho\pi R^2 V^3 = \frac{1}{2}\rho\pi R^2 \left(\frac{R}{\lambda}\right)^3 \omega_R{}^3 \quad (1)$$

Where $\omega_R$ rotor is speed in rad/s and $\lambda$ is the turbine tip speed ratio which is defined by formula

$$\lambda = \frac{\omega_R R}{V} \quad (2)$$

Turbine mechanical power $P_{mech}$ that can be extracted depends on power coefficient $C_P$ or pitch angle $\beta$ is given by

$$P_{mech} = C_P(\lambda\ \beta)P_{wt} = \frac{1}{2}C_P(\lambda\ \beta)\ \rho\pi R^2 \left(\frac{R}{\lambda}\right)^3 \omega_R{}^3 = C_P(\lambda\ \beta)k\omega_R{}^3 \quad (3)$$

Where

$$k = \frac{1}{2}\rho\pi R^2 \left(\frac{R}{\lambda}\right)^3 \quad (4)$$

The mechanical torque is given by

$$T_m = \frac{P_{mech}}{\omega_R} = \frac{C_P(\lambda\ \beta)P_{wt}}{\omega_R} \quad (5)$$

From equation (5), the relationship between mechanical torque $T_m$ and rotor speed $\omega_R$ is given. The mechanical torque in equation (5) is calculated assuming an ideal rotor disk. Mathematically when rotor speed increases, mechanical torque decreases.

## III.STABILITY ISSUES OF GRID CONNECTED SCIG

Power system stability is ability of system, for given initial condition, to regain the state of operating equilibrium after being subjected to physical disturbance. A severe voltage sags due to fault causes increase in speed of turbine and generator rotor. In this case rotor may accelerate to high speed which later on becomes uncontrollable. This is the generator counterpart to induction motor stalling which is referred as voltage instability. Fixed speed induction generator like squirrel cage when connected to grid, it leads to stability issues. Generally following types of stability issues are being observed during grid connected SCIG wind turbine [8].

a) Rotor angle stability
b) Voltage stability
c) Frequency stability

**Rotor angle stability:** When the induction generator subjected to fault, its rotor may accelerate and reach high steady-state speed far from that corresponding to the frequency of the system. The stability of induction generator can be analyzed by considering torque versus rotor speed curve. Speed of rotor should not exceed the critical value for maintaining the stable operation. If the rotor speed goes beyond the threshold value then rotor angle also increases thus torque produced reduces.

**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. An induction generator draws a large amount of reactive power from the system if it accelerates to a high speed, which could result in voltage collapse. The voltage sag due to fault reduces the capability of induction generator to deliver active power to grid and thus reduces the terminal voltage. If the speed increase is too high, the generator may not return to the prefault state. The mechanical torque of the turbine will decrease when the turbine speed increases, and the turbine may reach the steady state at elevated speed. This state is not desirable since it is accompanied by reduced active power, increased reactive consumption, and depressed voltages near the generating unit.

**Frequency Stability:** Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. The problem of frequency stability will be occurred only when synchronization with grid fails.

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### IV.MODELLING OF GRID CONNECTED SCIG

Fig.2 shows the complete model of grid connected squirrel cage induction generator with point of common coupling. When the induction generator is used along with the grid connected system it has inherent advantages of cost effectiveness and robustness. However the induction generator requires reactive power for magnetization. During normal operation voltage and current are varied due the change in wind speed so overall active power and terminal voltage are significantly affected. As the wind speed is variable, the power in wind turbine is proportional to cube of wind speed, the generated power in wind is varies significantly. When Induction generator connected to wind farm with wind turbine then generator demands large reactive power from grid for excitation. The biggest drawbacks induction generator is its requirement of reactive power as it delivers active power only. As result, it draws heavy inrush current.

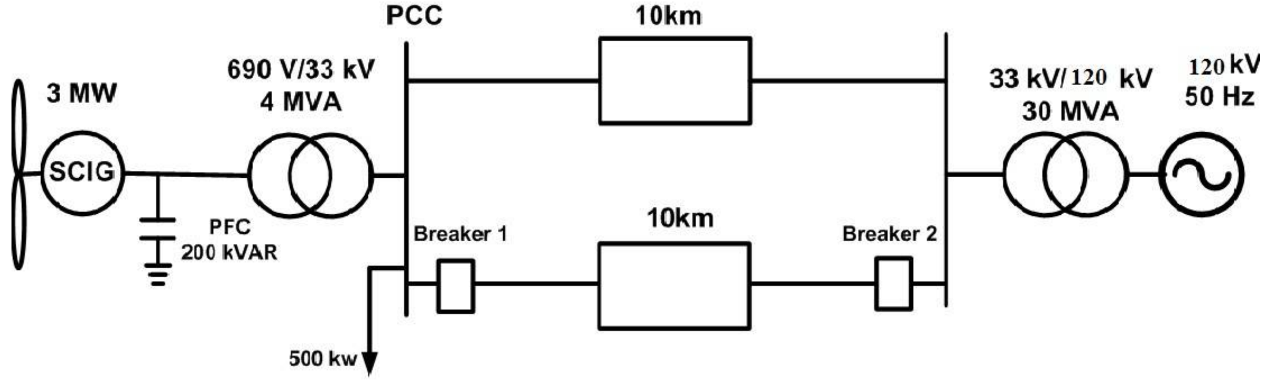


Fig.1 Grid connected SCIG with PCC

From the static equivalent circuit diagram of SCIG, the developed electromotive force is given by

$$E = jI_m X_m = -I_r \left(\frac{R_r}{s} + jX_r\right) \quad (6)$$

$$I_m = I_s + I_r \quad (7)$$

$$V_s = E + I_s(R_s + jX_s) \quad (8)$$

$$P_{mech} = 3I_r^2(R_r/s) \quad (9)$$

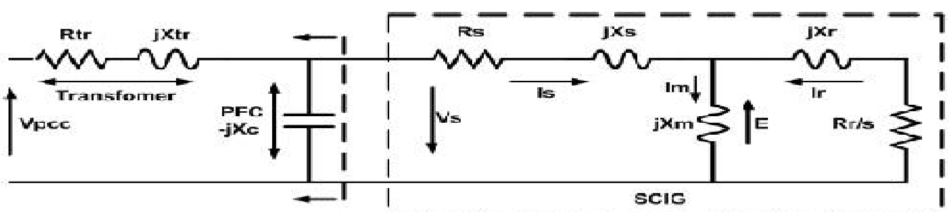


Fig 2 Equivalent circuit diagram of SCIG

E is electromotive force,
$I_m$ is magnetizing current, $I_s$ is stator current and $I_r$ is rotor current.
$R_s$ & $R_r$ are stator and rotor resistances; $X_s$ & $X_r$ are stator and rotor secondary leakage reactance's; $X_m$ is magnetizing reactance ,$P_{mech}$ is input mechanical power , S is slip. All the rotor parameters are converted to equivalent stator parameter. By considering the voltage equivalent and small variation range of slip, we can conclude that

$$V_r \cong \frac{I_r}{IsIX_m} K_s \quad (10)$$

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Where

$$K_s = \sqrt{M^2 + N^2} \quad (11)$$

$$M=-(s R_s X_r + s R_s X_m + X_s R_r + R_r X_m) \quad (12)$$

$$N=(R_s R_r - s X_s X_r - s X_m X_s - s X_r X_m) \quad (13)$$

Thus from the equation (3) and (9) we get

$$I_r = \sqrt{\frac{C_P(\lambda\,\beta) k \omega_R{}^{3\,2}}{3R_r}} \quad (14)$$

Where s is slip ratio

$$s = \frac{\omega_s - \omega_R}{\omega_s} \quad (15)$$

From the (10), (14) & (15) we get

$$V_s \cong K_r \sqrt{\frac{\omega_R{}^3}{\omega_s - \omega_R}} \quad (16)$$

Where $\omega_s$ synchronous speed is $K_r$ is defined as

$$K_r = \frac{k_s \sqrt{\omega_s k C_P(\lambda\,\beta)}}{\sqrt{3} R_r X_m} \quad (17)$$

From equation (16) we can observe voltage behaviour of SCIG against the $\omega_R$. It is clear that when the rotor speed is varied, terminal voltage of SCIG decreases. Voltage and frequency can be re-established after a disturbance with support of power grid itself. To wait for the voltage to re-establish after the fault has been cleared in case of weak grid interconnection is not reliable because there is always risk of voltage instability initiated by the disturbance. As induction generator draw heavy large transient current several times more than rated current when they are connected to utility grid. These causes' severe voltage fluctuations which are considered to be one of the biggest issues for wind power generating systems. All these issue are classified in various parameters namely called as voltage instability, current instability, rotor speed, pitch angle variance due to variable speed. All these parameters also affects on mechanical and electrical torque as it mainly depends on pitch angle.

## V. RESULTS AND DISCUSSION

The mathematical modelling of SCIG is simulated in MATLAB. Figure 4 shows the MATLAB simulink model of grid connected squirrel cage induction generator wind turbine. The dynamic model of fixed speed SCIG wind turbine consisting of 3MW induction generator is connected to grid through 4 MVA transformers with point of common connection.

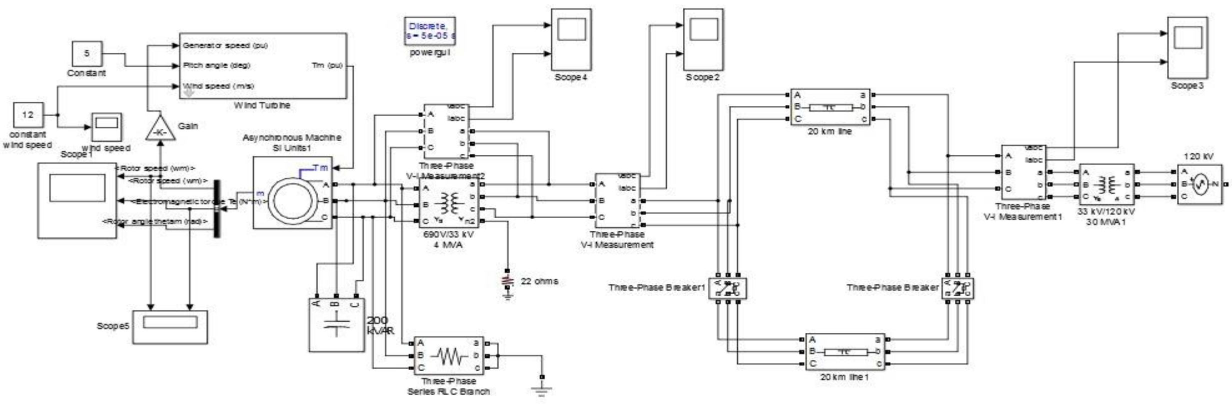


FIG.3 MATLAB simulink model of grid connected SCIG wind turbine

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Based on mathematical modelling grid connected SCIG is simulated and results are observed. Wind is continuously varying so rotor speed gets changed due to varying nature of wind speed. The equation (16) represents the relation between terminal voltage and rotor speed. The transmission line parameters which are mostly affected are voltage, current, rotor speed and torque. The changes in rotor speed have adverse effect on terminal voltage that brings to system into unstable mode. Fig. 5 shows the relationship between the terminal voltage and rotor speed.

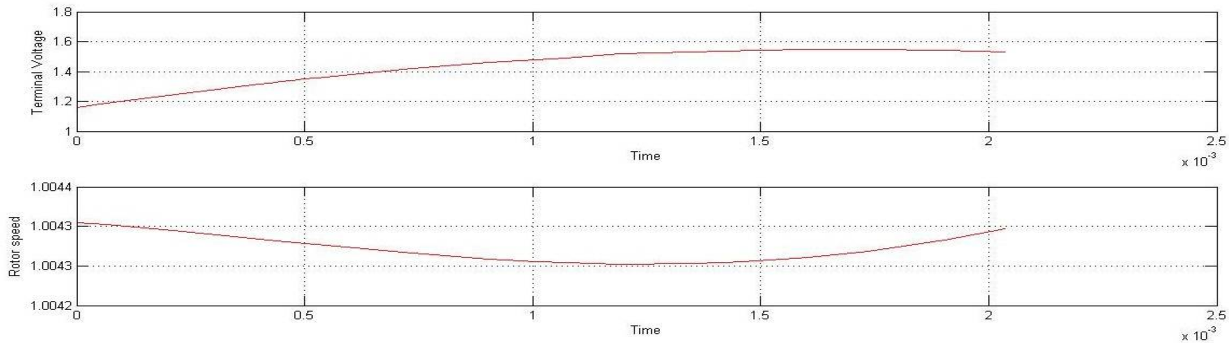


FIG.4 Relationship between terminal voltage and rotor speed

The change in voltage level in grid also deviate the rotor angle which will cause angle stability problem. The voltage and angle stability problem both will cause complete system unstable. Our power stations consist of many generators connected to grid once the stability of any one of the generating unit's gets disturbed then stability of other generating also will get disturbed. Various parameters affected by transient stability due to grid connected SCIG wind turbine systems observed in MATLAB simulink are voltage, rotor speed, and torque, mechanical and nominal power. Voltage and current profile of grid connected SCIG wind turbine systems during starting of induction generator is shown in fig.5. In this case both voltage and current are affected by transients occurring in grid due to heavy loading or may be sudden fault on systems.

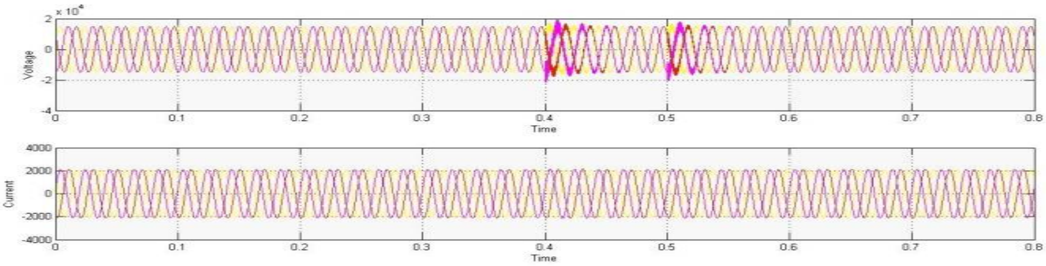


Fig. 5 Voltage and current profile

Figure 6 gives the magnitude waveform of transient voltage in receiving end.

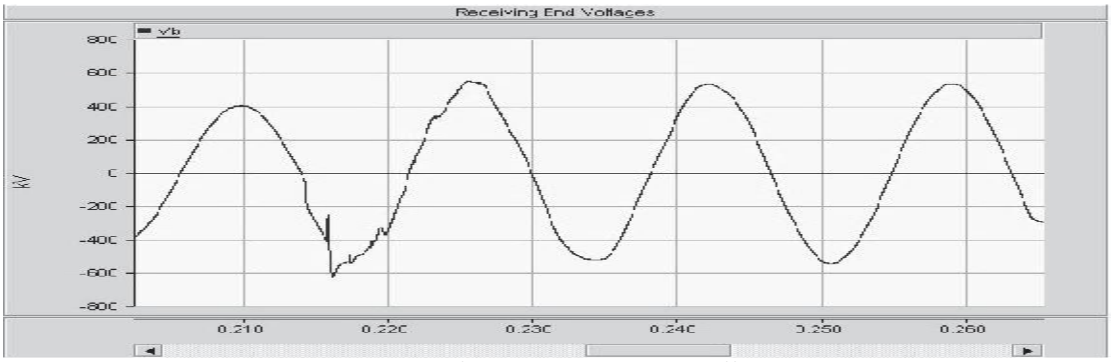


Fig. 6 Phasor Magnitude of receiving end voltage affected by transients

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Similarly the other factors which are affected by the transients are shown in fig 7 and 8. Fig.7 shows the mechanical power and nominal power measured when wind turbine is connected to the systems.

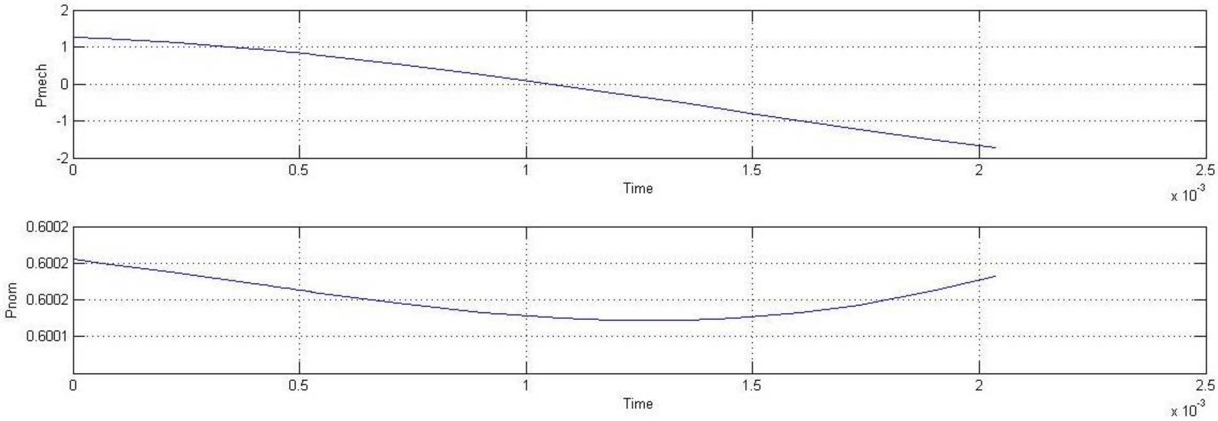


Fig. 7 Mechanical and nominal power

Due to sudden drop in voltage of grid connected system along with wind turbine, the rotor angle and rotor speed changes abruptly shown in fig. 8 The electromagnetic torque produced by the induction generator is proportional to square of terminal voltage .Hence the torque of generator also gets disturbed.

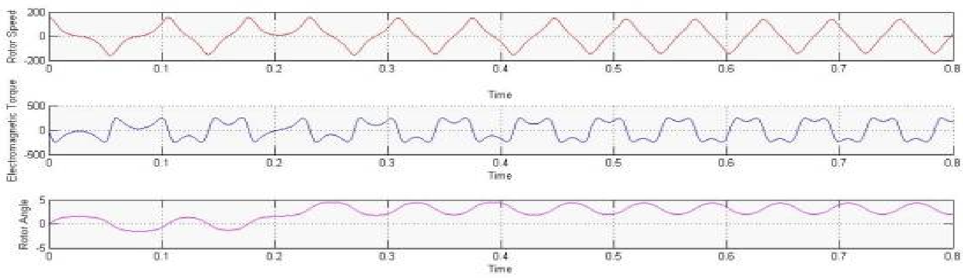


Fig .8 Rotor speed, electromagnetic torque and rotor angle

## VI.CONCLUSION

In wind energy systems one of the popular type used is squirrel-cage induction generator due to its simplicity, reliability, low weight, low cost, and low maintenance cost. One of the main disadvantages of the wind farms that equipped with this type of generators is the transient stability problem. Power stations consist of many generators connected to grid once the stability of any one of the generating unit's gets disturbed then stability of other generating also will get disturbed. It is found that when fixed speed wind turbine generator like SCIG is equipped with grid, system voltage, rotor angle and frequency get disturbed during fault condition. Based on the analytic approach of the physical equivalent circuit of the SCIG WT from the PCC, wind turbine and transmission line parameter that are affected by SCIG transient stability was investigated.

In this paper the main focus is given on the study of transients' stability of grid connected SCIG wind turbine and its effect on different parameters of systems. We investigated the different parameters of grid connected SCIG systems through MATLAB / simulink. From the mathematical modeling and MATLAB simulation results, it is observed that the parameters like voltage, current, rotor speed and its angle are affected mostly. As the other parameter like torque and power depends on voltage and current so these factors also reduced and get affected drastically.

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From the modelling of wind turbine, it is found that the system voltage at PCC is interconnected with pitch angle of wind turbine. So in future if we extend this work and apply some suitable controller technique so that the transient stability may be improved. The devices like FACTS, BR, and DVR can be suitable to improve the transient stability of grid connected SCIG wind turbine. But these devices are costly and their performance is complicated. The new technique known as fuzzy logic controller is also suitable for improving transient stability of grid connected SCIG which is cost effective and will give better performance.

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