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Simulation of Flicker Mitigation by Torque Control of Variable-Speed Wind Turbines with DFIG

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Abstract: With increase of the Electricity demand the energy fulfilment is not possible with the help of conventional Fossil fuels. So, with the increase of wind power penetration into the grid, the power quality becomes an important issue. One important aspect of power quality is flicker since it could become a limiting factor for integrating wind turbines into weak grids, and even into relatively strong grids if the wind power penetration levels are high. There are numerous of factors that affect flicker emission and power oscillations of grid-connected wind turbines including wind characteristics (e.g. turbulence intensity and tower shadow) and type of wind turbine and grid conditions (e.g. short circuit capacity (SCR) and grid impedance angle). In this project a torque control method is proposed by which power fluctuation is reduced using a series of band reject filters (BRFs). All aerodynamic, mechanical and electrical aspects of a wind farm connected to the grid are modelled using Matlab Simulink. Based on the presented model, power fluctuations caused by tower shadow effects can be analyzed and evaluated.

Keywords: SCR, DFIG, FLicker, WTG, IPC, Simulink,etc.

I. INTRODUCTION

Wind energy generation has been noted as the most rapidly growing renewable energy technology. In transmission and distribution system power quality of supply is very importance measure to be considered. So, considering in wind generation system this power quality issues become so much important measure. As the technology developing in the power generation field the wind power generation developing very quickly. To reduce the disturbances produced by variation in wind flow, we use induction generator and connect it directly to the grid system. This induction generator is simple and robust in construction and having reactive power for excitation. However, in induction generators to produce magnetization the reactive power support is required. The major drawback in induction generators is active, reactive power and the terminal voltage varies due to fluctuating wind. The power quality problems can be seen in accordance to wind generation, transmission and distribution system, such as voltage sag, flickers, voltage swells, harmonics etc. As wind-power capacity has increased, so has the need for wind power plants to become more active participants in maintaining the operability and power quality of the power grid. As a result, it becomes necessary to require wind power plants to behave as much as possible as conventional power plants. [1-7]

Wind Energy Conversion System (WECS)

The system to convert the energy present in the wind to useful form of energy is known as WECS. In the past, the power in the wind was harnessed to provide useful mechanical power but in modern world WECS is mainly concentrated on conversion of energy to electrical form. The conversion of the wind energy into the electrical energy depends on several factors like angle of attack, tower height, wind speed, blade length, turbine type, etc. The wind energy conversion system can be distinctly divided into three different parts: aerodynamics, mechanical and the electrical component as shown in figure below.

- Aerodynamics system: The aerodynamics of the WECS system consists of wind blades, turbine hubs, and turbine rotor. The kinetic energy present in the wind is converted into the mechanical energy in this system.
- Mechanical System: The mechanical energy obtained from the kinetic energy is processed in this system. It converts the obtained mechanical energy into appropriate form to feed the electrical system. The mechanical system of the WECS system consists of the low speed shaft, gear box, high speed shaft which is connected to the induction generator.

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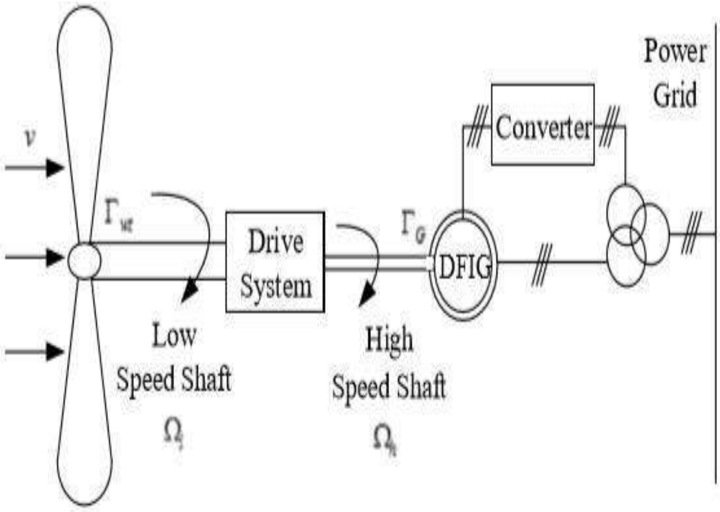

Figure-1 DFIG WECS System

- Electrical system: The mechanical energy is converted into the electrical energy in this part. It consists of the electrical generator, electrical transformers, power converters, grid connection.

Wind turbine can operate with either 1) fixed speed or 2) variable speed. For fixed speed wind turbines, the generator (induction generator) is directly connected to grid. Modern high-power wind turbines are capable of adjustable speed operation and use their doubly-fed-induction generator (DFIG) systems. DFIG based WTs widely used in wind power generation because of its capability of maximizing the energy capture during variable wind condition and controlling P and Q power for better grid integration. The doubly fed induction Generator (DFIGs) have been widely applied for wind farms (WFs) applications because of their advantages such as variable speed constant frequency operation capability and active/reactive power controllability.

II. WIND ENERGY

Wind which is given in the input of wind power plant has own aerodynamics in the system. The wind aerodynamics may change the several parameters of WTG, due to which it can change electrical output of constant power control in WECS. The rapid development of wind power production is evident worldwide. In the wind energy industry, PMSG and DFIG are both well-known generators of topology in the most recent field. Both have their advantages and disadvantages in terms of requirements. Due to the unpredictable nature of wind power large power outages can cause so many power quality issues in the grid connected wind energy system. The integration of Wind energy requires the mitigation of these power quality issues in the system for regulating performance in the system.
To minimize disturbances generated by air flow fluctuations in the power plant the effective IPC control which includes individual pitch angle control and WTG parameters control must be required. The PMSG use in wind energy face several technical challenges and problems in the system. Therefore the use of DFIG based wind power plant is very important and beneficial in the grid connected wind energy system. The wind energy efficiency level is very low and fluctuation plays grid problems and stability issues which causes the major issues in the system.
DFIG's key advantages compared to PMSG are better power management and consistent energy management. DFIG is therefore best known for its research work on wind turbine conversion programs. In wind energy, the rotor speed deviation and torque deviation will create several problems in wind turbines and generators to generate electricity. The basic operating principle of DFIG is to provide both end control using closed-loop controlling for better regulation and constant power management in the system. So the RSC converter and GSC converter is provided at the rotor side of the machine and grid side.[8]

The use of wind Power has so many advantages compare to the other conventional sources. The most of the wind power plants are located at remote area where the wind speed is easily available for electricity generation. In today's world wind energy research is going for On-shore and Off-Shore wind power plant in real time use. The role of DFIG based WECS becomes very popular because of following major points:-

1. Power Fluctuation in WECS with variable wind speed
2. Grid parameters regulation problem due to frequency variations

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3. Wind Farm generation uncertainty with different characteristics of wind power plant
4. The voltage disturbance and grid fluctuation in the WECS

Power from the Wind

The location of wind power plant is consider in remote location for maximum wind speed availability and better wind speed characteristics for the wind turbine operation. It will help in the performance control of WTG. The input side of WTG parameters control with turbine side regulations help in the torque and many more mechanical parameters regulations in the system. The load connection with nearby of WTG is very important for the load side parameters control for voltage and currents. The effective WTGs with better power quality control help in the load side HV and LV side line parameters balancing. The variation of remote location WTG with electrical parameters can also be affected the distribution and feeder line parameters in the AC network.
In earlier times when we increase the length of rotor blades them weight is increase. So, due to advancement in technology light weight and strong rotor blades is very useful and conventional to produce power of 1 MW. These are so many advantages feature of use of wind power system. In most of the wind power plant site location is in rural area, island area and marine areas. The energy equipment in these kinds of places are simple and does not require high electrical power.

1. The power system supplies cheap variable voltage for heating purpose and expensive higher voltage for motor and lights.
2. The rural grid system is very weak up to 33 KV system. The grid integration of wind energy conversion system is very difficult, and problem occurs for worker of the plant.
3. These are some time duration is coming where wind energy is not available. That's storage system is necessary for continuous power supply.

The mathematical relation between the power generated form DFIG and wind speed of turbine can be calculated as below:-

$$P_{wind} = \frac{\pi}{8} dD^2 v_{wind}^3$$

The role of DFIG based WECS is very demanding in the recent times. The variation in the grid and line parameters can be controlled using the converter control in the DFIG system. The both side converter control helps in the rotor side parameters control as well as grid side parameters control. The DC bus voltage is not controlled through these converters can be creates several major issues in the system performance in grid side as well as line side parameters. The DC bus voltage regulation is carried out using the Energy storage device in the system. The common DC link capacitor and two layer capacitor based energy storage is very simplified & reliable solution for these kind of unbalancing control. It will also help in the active and reactive power control in the grid side.[1][5][10]

Components of Wind Turbine

The nacelle is the housing for all the electrical and the mechanical components. It contains components like the gearbox, shaft, and electrical generator. The main components of the wind turbine are shown in the figure below and described below: -

Rotor: The turbine rotor extracts the kinetic energy present in the wind. The wind strikes the rotor blades and it starts to rotate which transfers the power to the rotor hub.

Shaft: The hub of the rotor is attached to the low speed shaft. The low speed shaft connects the gear box and the hub of the rotor.
Gearbox: The gearbox changes the speed of rotation of the low shaft and connects to the high-speed shaft. The electrical generator usually runs at the speed faster than the speed of the low speed shaft, so the gearbox changes the speed to appropriate speed for the electrical generator.

Generator: The high-speed shaft provides the necessary mechanical energy for the electrical generator. It than converts the energy into electrical form. The electrical generator used for the DFIG is wound rotor induction generator.

Electronic controller: The controller employed to control various operational parameters of the wind turbine. The direction of the wind turbine, yaw mechanism, voltage, and speed controllers are employed.

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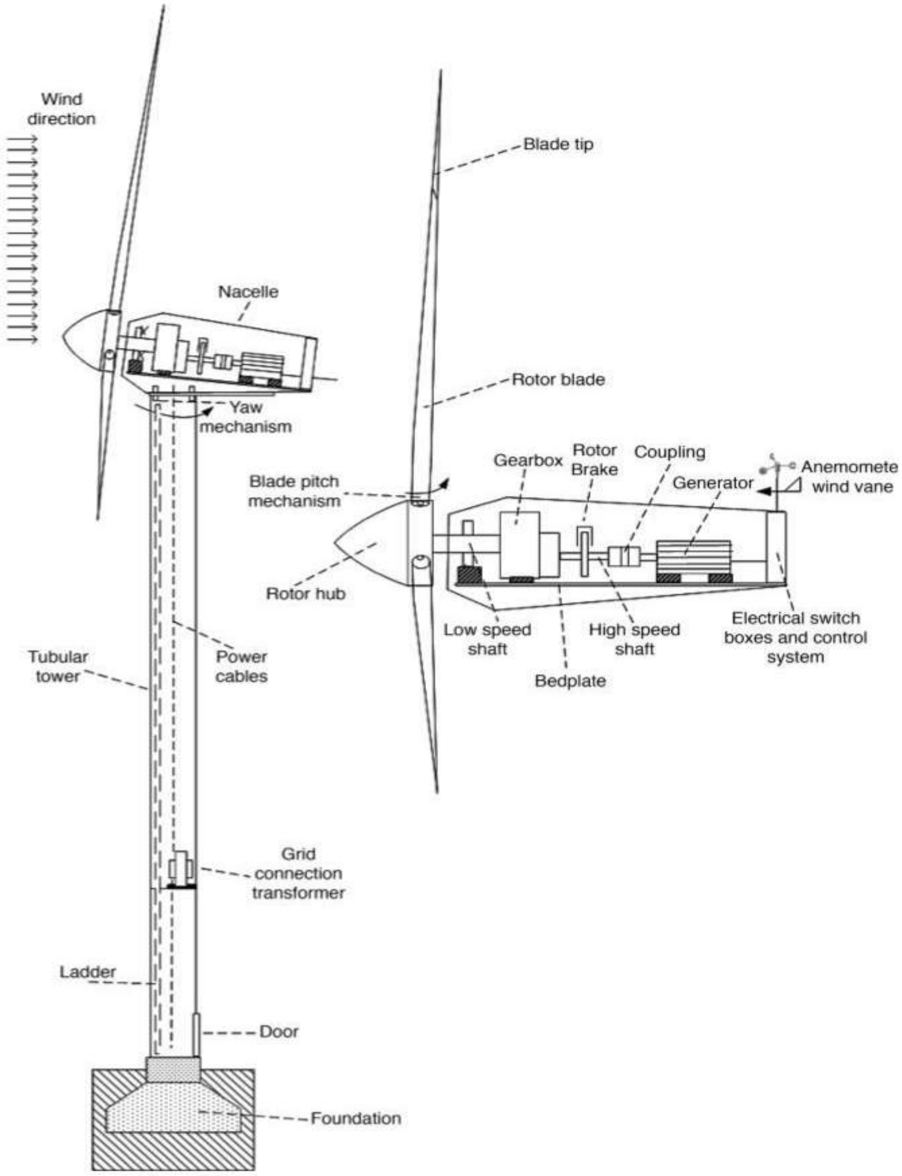

Figure 2 Wind Turbine with different components

III. DFIG

DFIG is Associate in nursing abbreviation for Double Fed Induction Generator, a generating principle wide utilized in wind turbines. It's supported Associate in nursing induction generator with a point in time wound rotor and a point in time connector assembly with brushes for access to the rotor windings. It's doable to avoid the point in time connector assembly, however there are a unit issues efficiently, price and size. A far better different may be a brushless wound-rotor doubly-fed electrical machine.

The doubly-fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower. Thus, in the typical ± 30 % operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. [1-3]

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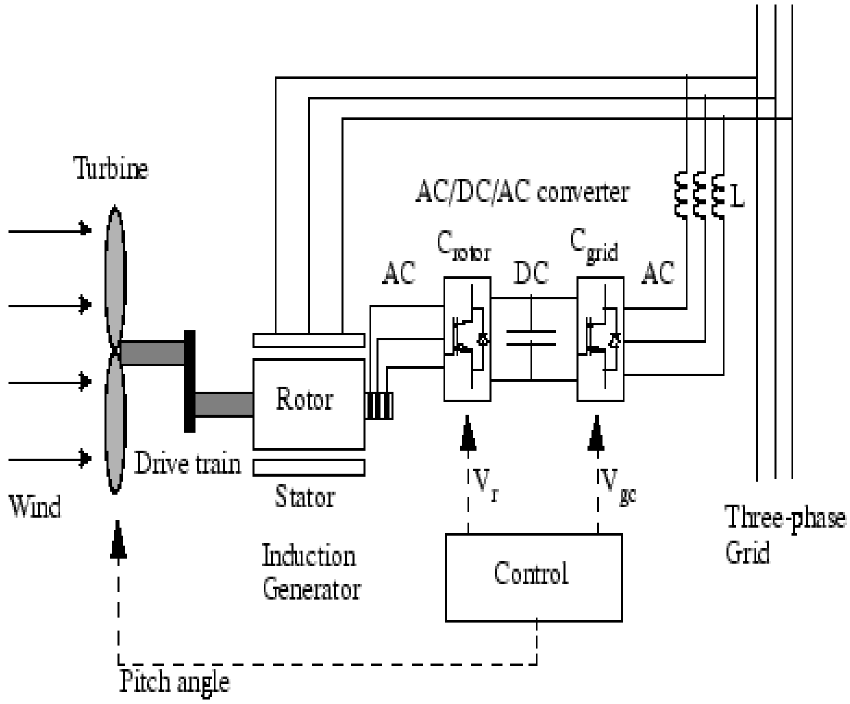

Fig-3 Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

Working Principle of DFIG Wind Turbine

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator basically an induction generator with the three-phase stator winding that is directly connected to the electrical grid and three phase rotor winding which is also connected to the grid via slip-rings and an AC/DC/AC IGBT-based PWM converter.

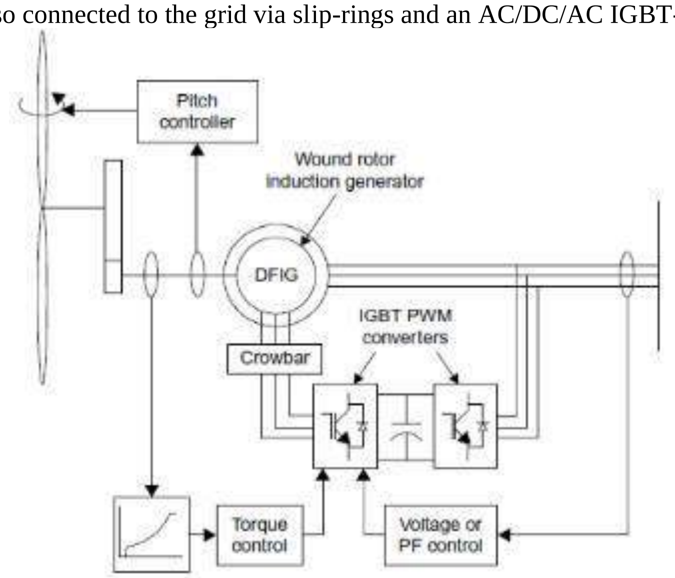

Fig: 4 DFIG wind turbine

The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. Since both the stator and rotor windings of the induction generator are connected to the grid. Where the rotor power is of dissipated as heat energy in DFIG WPPs the power in the rotor circuit is recovered, transformed and sent onwards to the grid through a partial scale back-to-back PEC. The wound rotor only passes on to the grid the slip power of the generator, which is typically about one-third of the total power of the DFIG. For wind speeds lower than 10 m/s the rotor is running at sub synchronous speed. At high wind speed it is running at super synchronous speed. In the super synchronous speed operation mode, the power is delivered to the grid directly by the stator. At the

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same time power flows from the DFIG rotor as well through the PEC through the grid or simply, the rotor supplies power to the grid, “positive resistance is inserted”. But then as the wind speed up still further, the additional power is spilled away by pitching the WPP rotor blades out of the wind.

At low wind speeds when the DFIG must operate at sub-synchronous speeds, the PEC continues to enable the DFIG to generate power because the PEC has a bi-directional power. In such a case, a “negative resistance is inserted “into the rotor circuit to make up the energy defect the PEC may borrow power from the line for the under-speed rotor, which is passes on the stator, still allowing the stator to feed the network with 50 Hz power supply. The stator appears to be supplying 130% of power of the grid. Note that the generator rotor has ‘borrowed’ 30%, leaving the line with 100% for the theoretical lossless DFIG. When the power flow is in the reverse direction, the grid-side PEC will act as a converter and the rotor-side PEC will act as an inverter

WECS Modelling

WECS is the same as solar energy, it converts wind energy into electricity. The wind speed of 12 m/s is the ideal speed for the maximum output from the wind plant. The energy formula for wind energy is given as below:-

$$P = \frac{1}{2}\rho A V^3 \ldots\ldots\ldots\ldots (1)$$

In this equation P indicates the Power, ρ will indicate the air density, wind speed V and A is the swept area of the turbine which is given as below:-

$$A = \pi r^2 \ldots\ldots\ldots\ldots (2)$$

In the wind energy conversion system PMSG and DFIG generators are widely used nowadays. In the DFIG the mathematical modelling is required with several steps of calculations which is described as given in this section. In the general configuration, Park Transformation is used for DFIG modelling in which Stator Flux and Rotor currents are used as state variables.

The equations in the d-q axis role model for the DFIG mathematical modelling is shown below:-

$$\varphi_{ds} = L_{ss} i_{ds} + L_m i_{dr} \ \ldots\ldots\ldots\ldots (3)$$
$$\varphi_{qs} = L_{ss} i_{qs} + L_m i_{qr} \ \ldots\ldots\ldots\ldots (4)$$
$$\varphi_{dr} = L_m i_{ds} + L_{rr} i_{dr} \ \ldots\ldots\ldots\ldots (5)$$
$$\varphi_{qr} = L_m i_{qs} + L_{rr} i_{qr} \ \ldots\ldots\ldots\ldots (6)$$

The above equations are used for stator and rotor side fluxes calculations. The flux calculations show that it relates to the self-inductance and currents of both sides of the DFIG machine.

$$V_{ds} = -R_s i_{ds} - \omega_s \varphi_{qs} - \frac{1}{\omega_B} p(\varphi_{ds}) \ \ldots\ldots. (7)$$
$$V_{qs} = -R_s i_{qs} + \omega_s \varphi_{ds} - \frac{1}{\omega_B} p(\varphi_{qs}) \ \ldots\ldots. (8)$$
$$V_{dr} = -R_r i_{dr} - (\omega_s - \omega_r)\varphi_{qr} - \frac{1}{\omega_B} p(\varphi_{dr}) \ \ldots. (9)$$
$$V_{qr} = -R_r i_{qr} + (\omega_s - \omega_r)\varphi_{dr} - \frac{1}{\omega_B} p(\varphi_{qr}) \ \ldots (10)$$

The above equations show the voltage values for the d-q axis format for stator and rotor side in the DFIG. The resistance values and leakage inductance values are also used for calculations. The above calculations show that the voltage values of stator and rotor sides are depending on the self-inductance of stator & rotor sides and the currents of stator rotor sides. From the above calculations, the self-inductances for the stator and rotor side is derived as given below:-

All above equations are used for mathematical modelling of DFIG for different types of variables as discussed in the above section. These calculations are also helpful for designing the state variables and parameters calculation in the Matlab simulation model of DFIG. Later on, the grid side parameters are also tuned in the system as per the output parameters of the DFIG generator. Several parameters are used for the calculations of a grid side but for the simulation, in Matlab, the grid side voltage and currents are important to be tuned as per the rotor side output voltage and currents in the modelling.[2][4][8]

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IV. SIMULATION AND RESULTS

MATLAB Simulation of DFIG

In this project work, we have developed the MATLAB simulation of a DFIG system connected with a grid network. The simulation results analysis of DFIG output power and grid side voltage are shown in this project work. The system parameters used for DFIG in this project are also represented in the table. The proposed system in this project of the DFIG simulation model will present the DFIG modelling with an electrical grid network.

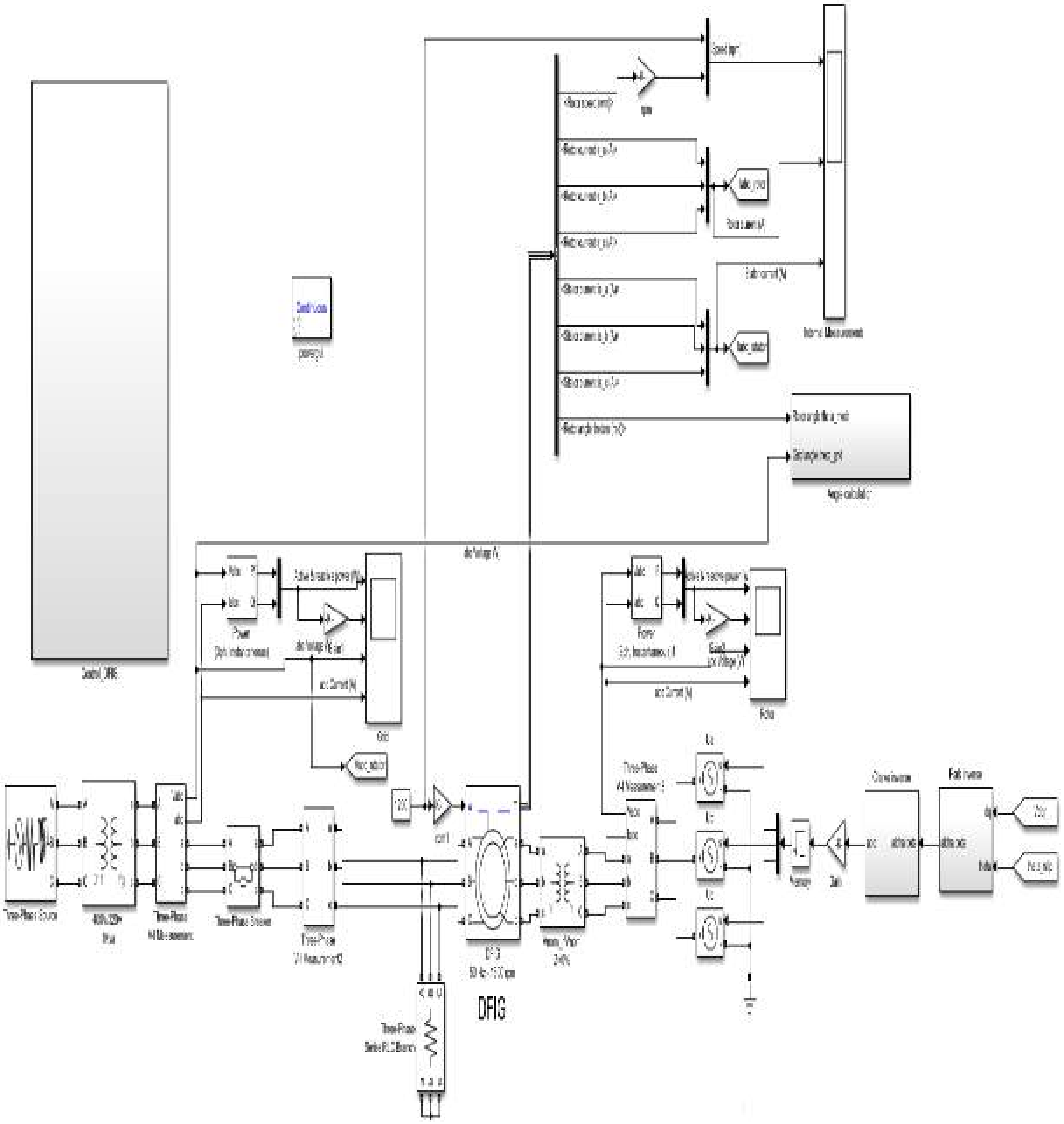

Fig 5- Matlab Simulation of Grid Connected WECS using DFIG

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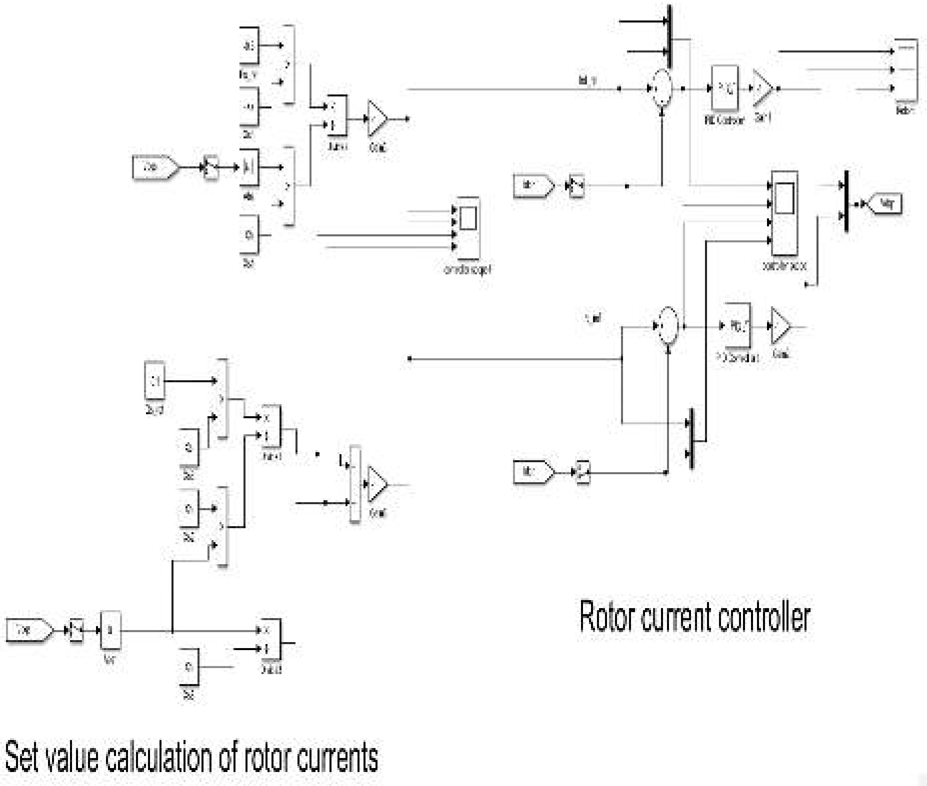

Fig 6- Simulation of Rotor Side Current Control of DFIG

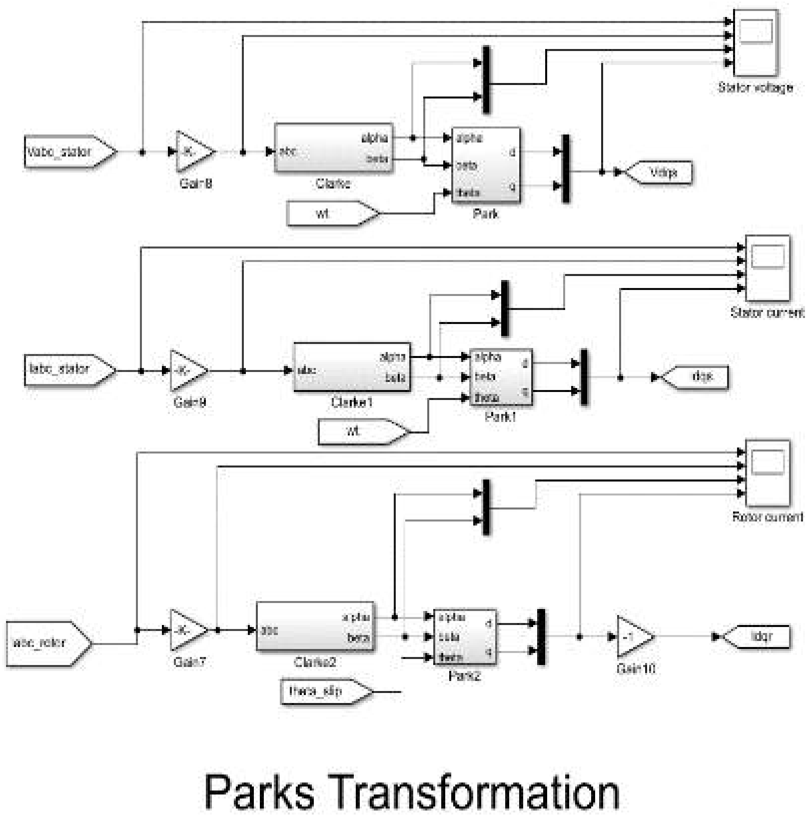

Fig 7- Simulation of Park Transformation for DFIG Control

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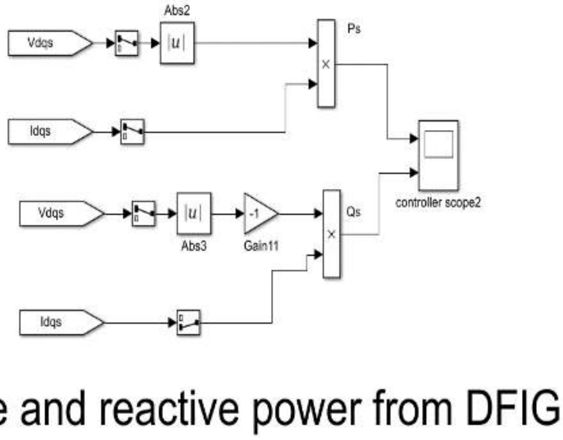

Fig 8- Simulation of Active & Reactive Power Control of DFIG

The simulation model of the DFIG model with converter control is shown in the above diagram of the DFIG operating principle with RSC and GSC converter controlling. Both the converters provide rotor side and grid side parameters controlling in the proposed grid-connected system. In the RSC converter, AC to DC conversion is done using an IGBT switching device. Within the rotor, aspect converter switching operation of switching tool IGBT/Diode is controlled via rotor connected converter which provides rotor side parameters control in DFIG. DC voltage that is produced by RSC is controlled through the DC link Capacitor balancing.

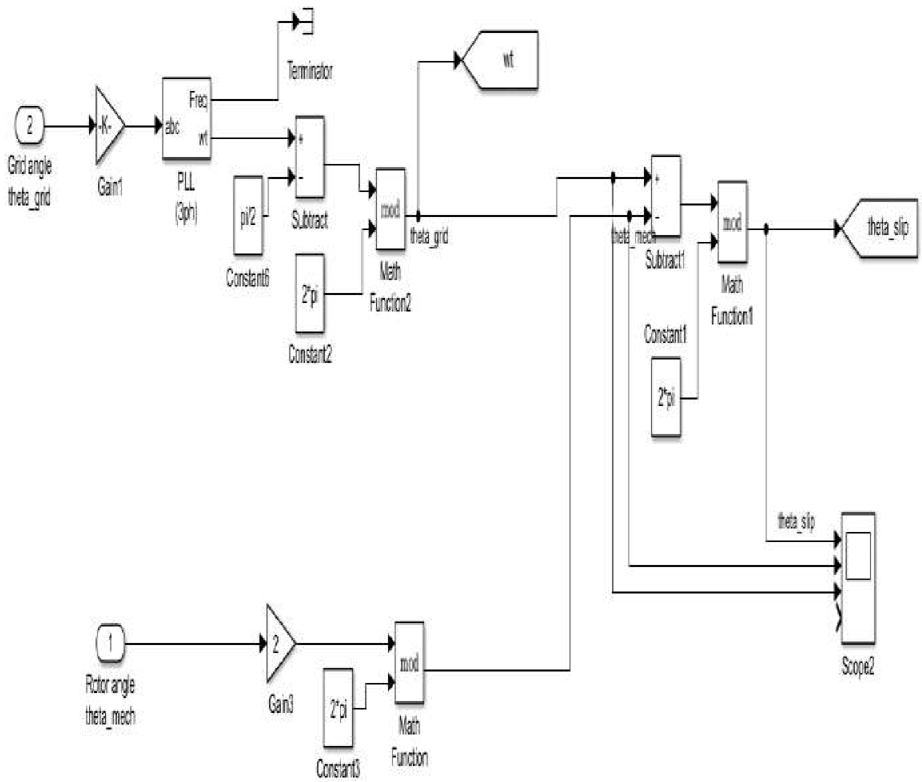

Fig 9- WECS Angle Calculation modelling

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Simulation Results

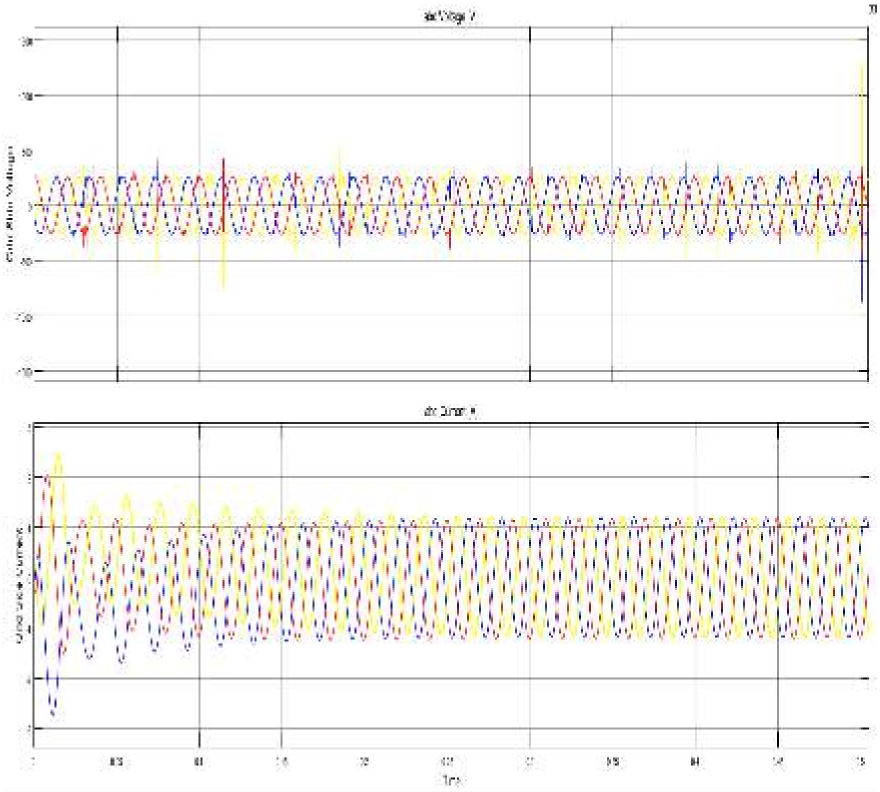

Fig 10- Simulation Results of Grid Side Voltage & Current of DFIG

In figure 10 we can observe flicker in instantaneous grid side voltage and grid side current. As compare to grid side voltage less flicker occur in grid side current.

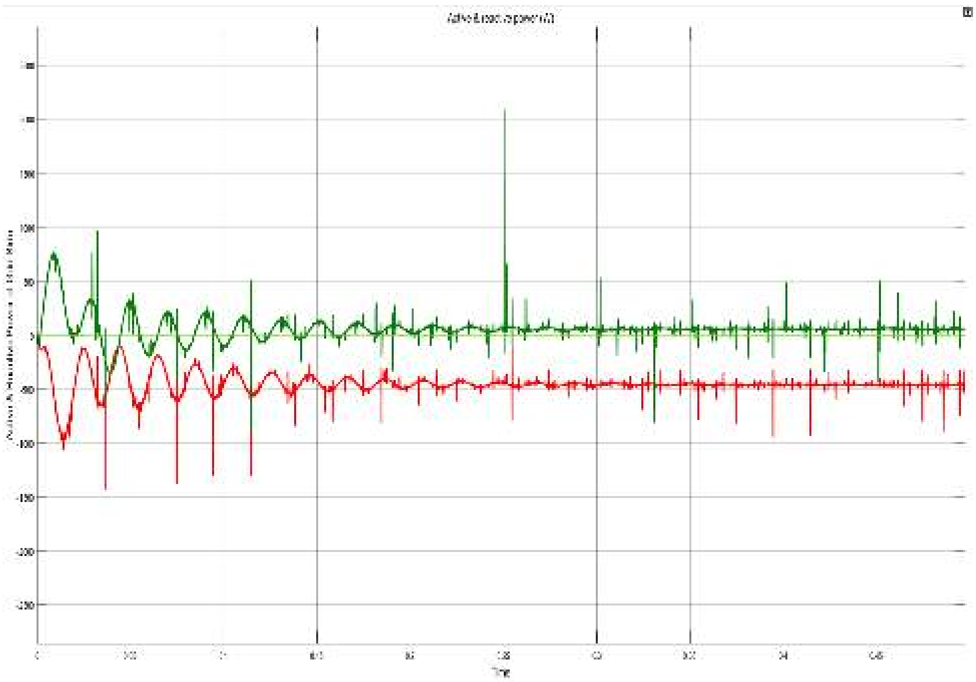

Fig 11- Simulation Results of Grid Side Active & Reactive Power of DFIG

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In figure 11 we can observe fluctuation in active and reactive power at grid side. As active and reactive power are function of voltage and due to flicker occur in grid side voltage, we can also observe it in active and reactive power at grid side.

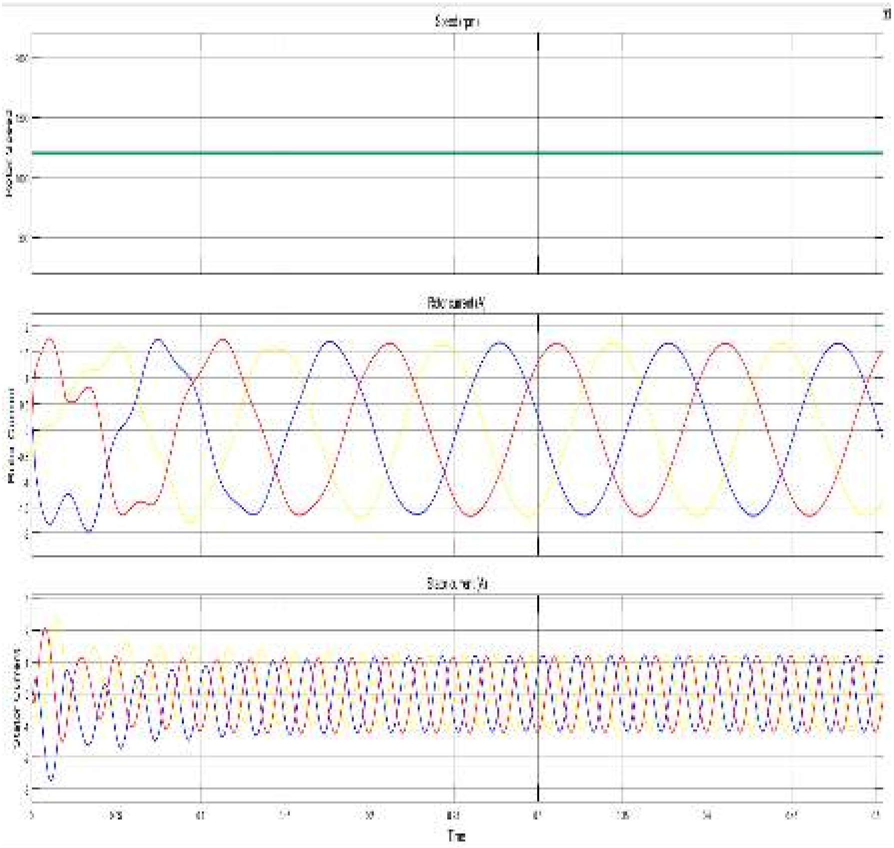

Fig 12- Simulation Results of WECS based DFIG Parameters

In figure 12 the rotor speed of DFIG is taken as 1200 RPM. We can observe flicker in rotor current and stator current.

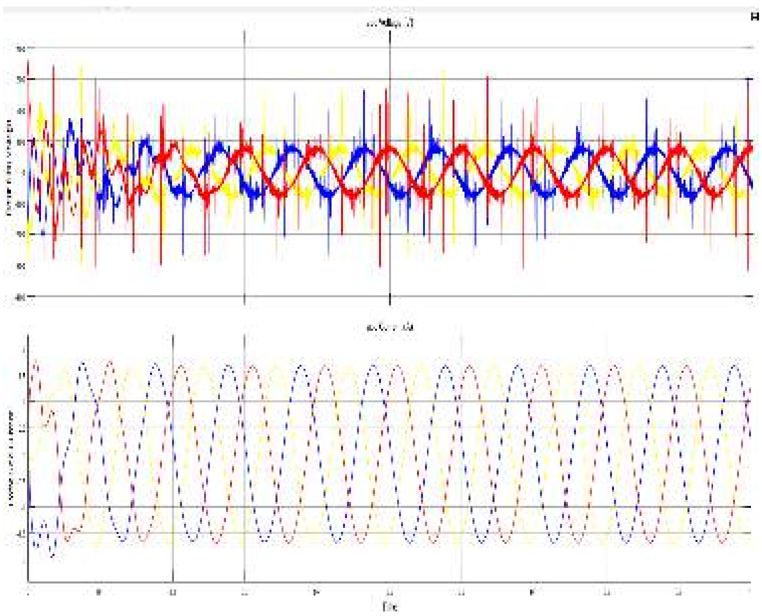

Fig 13- Simulation Results of Rotor Side Parameters

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In figure 13 we can observe fluctuation in instantaneous Voltage and current at rotor side. Here we can see that as compare to voltage flicker occur in current is less.

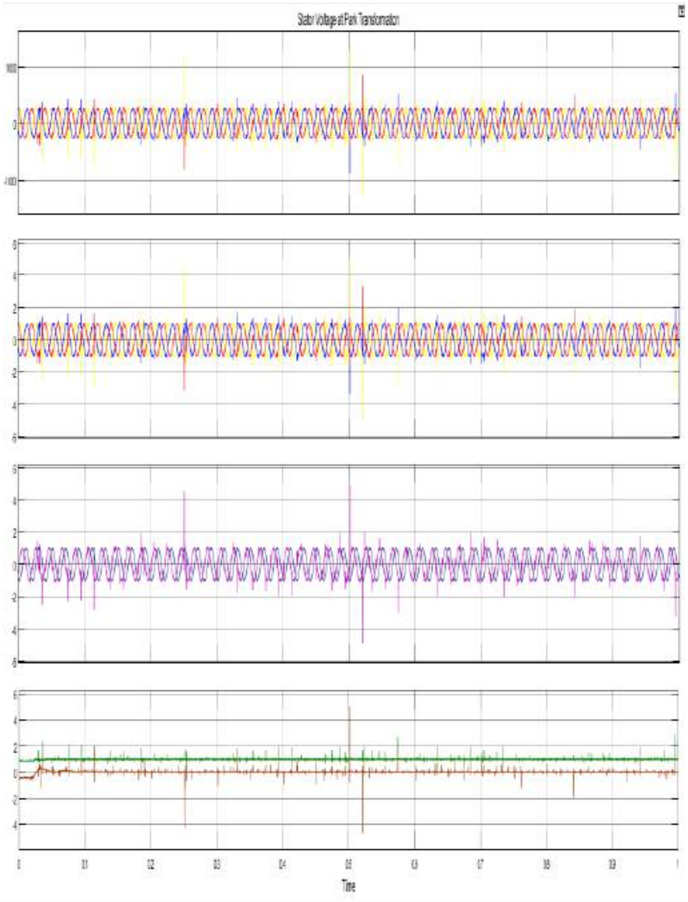

Fig 14- Park Transformation Values of Stator Voltage during Park Transformation

Figure 14 shows park Transformation of stator Voltage, In this 1st and 2nd result shows flicker in instantaneous voltage of stator side. 3rd result is of Clarke transformation in which instantaneous voltages abc is converted in to alpha and beta. 4th result shows park transformation in which alpha beta is converted in to dq.

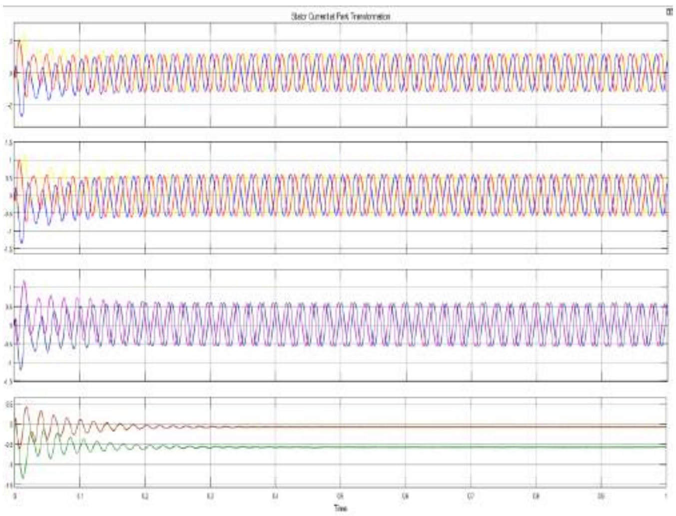

Fig 15- Simulation Results of Stator Currents during Park Transformation

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Figure 15 shows park Transformation of stator Current, In this 1st and 2nd result shows flicker in instantaneous current of stator side. 3rd result is of Clarke transformation in which instantaneous current abc is converted in to alpha and beta. 4th result shows park transformation in which alpha beta is converted in to dq.

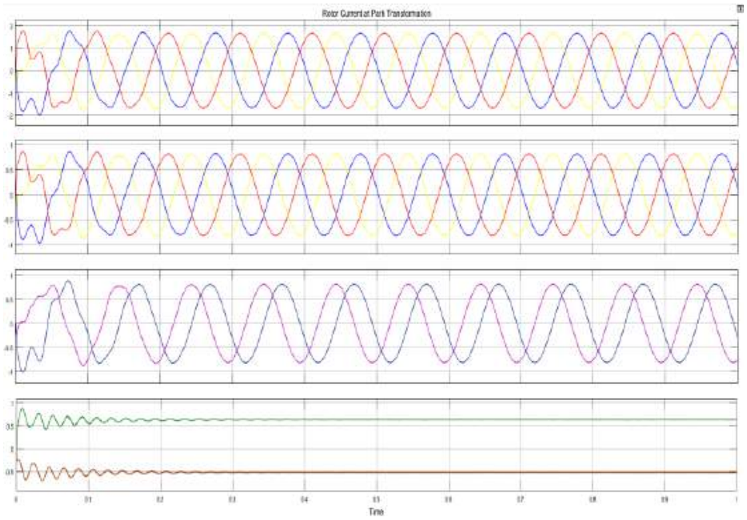

Fig 16- Simulation Results of Rotor Currents during Park Transformation

Figure 16 shows park Transformation of Rotor current, In this 1st and 2nd result shows flicker in instantaneous current of stator side. 3rd result is of Clarke transformation in which instantaneous current abc is converted in to alpha and beta. 4th result shows park transformation in which alpha beta is converted in to do.

V. CONCLUSION

During the work of this project, I have learned the role of Wind energy sources as a prominent alternative to conventional energy sources. Therefore after solar, the wind becomes a popular renewable energy source in the entire world. I also understand the drawbacks of the synchronous generator of torque-speed control in the plant. Which help me to work and research on DFIG based wind energy conversion systems. During the work of this project on the DFIG wind power plant, the modelling and simulation suggest that in the upcoming years DFIG generators are replaced by the synchronous generator in the wind energy conversion system. Various parts of this project have been surveyed and implemented during this project work, also made a Simulink test model realize the project objectives. Change in load does not affect the voltage at the point of common coupling. Also, it stops harmonics injection into the grid from switching load. We can see from the output of WTG without any control strategies, there is fluctuation in electrical quantities. During the energy generation from wind energy, the excess power from the system is used for storing backup and it will be used in the peak load demand conditions. The simulation of DFIG based WECS with electrical grid connected network as successfully shown with results.

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