# Design & Simulation of DFIG Using the Conversion of Grid Voltage with Under Distortion

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**Abstract – This paper presents a direct power control (DPC) strategy for a doubly fed induction generator (DFIG)-based wind power generation system under distorted grid voltage. By analyzing the six times grid frequency power pulsation produced by the fifth and seventh grid voltage harmonic components, In this a novel DPC strategy with proportional integrated (PI) regulator has been proposed to implement the smooth active and reactive power output of DFIG by using wind turbine. The performance analysis of the proposed DPC strategy, including the steady and dynamic state performance, Closed-loop operation stability, and rejection capability for the grid voltage distorted component and back EMF compensation item has been investigated. The availability of the proposed DPC strategy with a PI regulator is verified by experiment results of DFIG system under harmonically distorted grid condition. The simulation is done by using MATLAB/SIMULINK software.**

**Index Terms – DFIG, DC link, Pulse width modulation (PWM), Converters.**

## 1. INTRODUCTION

Power systems are large and complex electrical networks. Although the any power system is generations are located at few selected points and loads are distributed. In their between generations and loads, & there exist transmission and distribution systems. In the power system, & also the system load keeps changing from time to time. The delivered power must meet certain minimum requirements with regards to the quality of the supply. Reactive power compensation is often most effective way that to improve both the power transfer capability and voltage stability. The control of voltage levels is accomplished by controlling the production, absorption and flow of the reactive power control system.

Wind power is the conversion of wind energy in the suitable form of energy, such as using wind turbines to generate electricity & windmills for mechanical power, wind pumps for water pumping, or sails to propel ships. The total amount of economically extractable power available from the wind is considerably more than present human power use from all the renewable energy sources.

Induction generators and motors produce electrical power when their rotor is rotate faster than the synchronous frequency. For the typical four-pole motor operating on a 60 Hz electrical grid frequency, & synchronous speed is 1800 r.p.m. of induction generator. Similar four-pole motor operating on a 50 Hz grid frequency will have synchronous speed equal to 1500 rpm. In normal motor operation, stator flux rotation is faster than the rotor rotation. In this way, the rotor is dragged along behind stator flux, by value equal to slip. In generator operating, a prime mover (turbine, engine) drives the rotor above the synchronous speed. The induction generator stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils & active current is produced in stator coils, and motor is now operating as a generator to the generate the voltage and sending power back to the electrical grid.

## 2. RELATED WORK

Heng Nian et. al. [1] discussed about direct power control (DPC) strategy for a doubly fed induction generator (DFIG)-based wind power generation system under distorted grid voltage. By analyzing the six times grid frequency power pulsation produced by the fifth and seventh grid voltage harmonic components, a novel DPC strategy with proportional integrated (PI) regulator has been proposed to implement the smooth active and reactive power output of DFIG system. The performance analysis of the proposed DPC strategy, including the steady and dynamic state performance, closed-loop operation stability, and rejection capability for the grid voltage distorted component and back EMF compensation item has been investigated. The availability of proposed DPC strategy with a PI regulator is verified by experiment results of DFIG system under harmonically distorted grid condition.

V. Kaarthikeyan et. al. [2] proposed the detail analysis Direct Power Control (DPC) is introduced for the DFIG based wind energy conversion systems under distorted conditions. DFIG is very sensitive to grid disturbances and it experiences many problems such as distorted stator or rotor current, electromagnetic torque and power oscillations. The fifth and seventh order harmonics under distorted condition are analyzed. The harmonics level is reduced by using Vector Proportional Integrated Regulator. The steady state and stability consideration of the proposed regulator has been analysed. With its fast dynamic response, the regulator has full voltage and power control; the smooth real and reactive power output can be achieved. The simulation is performed with two conditions first with VPI enabled, with VPI disabled. Under fault conditions, i.e. distorted conditions, the simulated system is executed with VPI disabled. With this condition, the output voltage, real and reactive power is measured. Simulated results of the distorted system with VPI also discussed. Also with the help of VPI regulator, smooth real and reactive power is achieved. The efficiency of this technique can be improved by combining different type of the regulators, instead of using single regulator.

Reddimi Vijaya Kumar Pura et. al. [3] discussed to give an overview of a prompt power control (DPC) system for a doubly maintained artificiality generator (DFIG) based wind power period structure under bent network voltage. By analyzing the six times system repeat force throb made by the fifth and seventh lattice voltage consonant portions, a novel DPC procedure with FUZZY LOGIC controller has been proposed to execute the smooth dynamic and responsive power yield of DFIG. The execution examination of the proposed DPC procedure, including the reliable and component state execution, close circle operation strength, and release limit for the system voltage deformed fragment and back EMF compensation thing has been investigated.

## 3. PROPOSED DPC MODEL OF DFIG UNDER DISTORTED GRID VOLTAGE

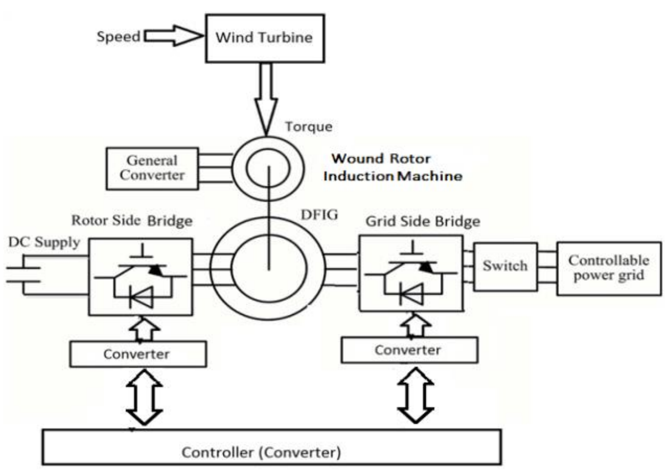


Fig. 1 Proposed DPC scheme of DFIG under distorted grid voltage.

Main sub-systems of model for direct power control of doubly fed induction generator under distorted grid voltage mainly consist of -

1. Wind Turbine Doubly Fed Induction Generator system

2. Voltage and Reactive Power Control Systems

a) Rotor side converter control system

b) Grid side converter control system

3. Pitch angle control system

3.1 Wind Turbine Doubly Fed Induction Generator systems

The wind turbine and the doubly-fed induction generator are shown in Figure 2.

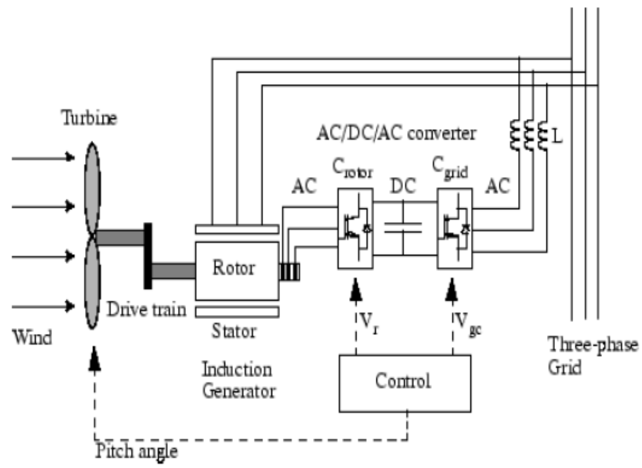


Fig. 2 Wind Turbine Doubly Fed Induction Generator system

The AC/DC/AC converter is divided into two component first is the rotor side converter ($C_{rotor}$) and second is the grid side converter ($C_{grid}$). $C_{rotor}$ and $C_{grid}$ are Voltage Sourced Converters that use forced commutated power electronic devices for (IGBT's) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as a DC voltage source. A coupling inductor L is used to the connect $C_{grid}$ to the grid side. The three phase rotor winding is connected to $C_{grid}$ by slip rings and brushes and the three phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generated the pitch angle of the system command and the voltage command signals $V_r$ and $V_{gc}$ for the $C_{rotor}$ and $C_{grid}$ are respectively in order to control the power of the wind turbine control, the DC bus voltage and the reactive power or the voltage at the grid terminals.

3.2 Modelling of Voltage and Reactive Power Control Systems

Operating Principle of The Wind Turbine Doubly-fed Induction Generator

For understanding of operation of DFIG we need to describe the flow of active and reactive power which has been shown in the following figure 3

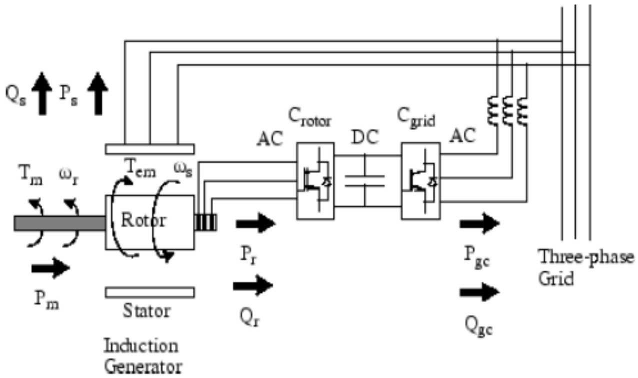


Fig 3 Power flow diagram of Wind Turbine Doubly Fed Induction Generator

$P_m$ -Mechanical power captured by the wind turbine and transmitted to the rotor

$P_s$ -Stator electrical power output

$P_r$ -Rotor electrical power output

$P_{gc}$ -Electrical power output

$Q_s$ -Stator reactive power output

$Q_r$ -Rotor reactive power output

$Q_{gc}$ -Reactive power output

$T_m$ -Mechanical torque applied to rotor

$T_{em}$ -Electromagnetic torque applied to the rotor by the generator

$\omega_r$ -Rotational speed of rotor

$\omega_s$ -Rotational speed of the magnetic flux in the air gap of the generator, this speed is named synchronous speed.

J -Combined rotor and wind turbine inertia coefficient

$C_{rotor}$ -Rotor side converter control system

$C_{grid}$ -Grid side converter control system

### 3.3. Control Method

A. Rotor side converter control For DFIG

The voltage or the reactive power at grid terminals is controlled by the reactive current flowing in the converter $C_{rotor}$ . The converter operates in the stator-flux qd-reference frame the rotor current broken down into an active power in the q-axis. A reactive power in the d-axis component, when speed of the wind speed changes there will be a change in the active and reactive power of the generator also. As (actual P) that is actual active power of the generator is compared with reference value of P (ref P) which is determined by the wind speed. The variations between the two values will be provided to be a Proportional Integral (PI) controller which will generate (ref I) the required value of q-axis rotor current. Similarly, a Proportional Integral controller is used in the reactive power side to generate (ref I) the required d-axis rotor current.

B. Grid side converter control For DFIG

The converter $C_{grid}$ is used to regulate the voltage of the DC bus capacitor. In addition, this model allows using $C_{grid}$ converter to generate or absorb reactive power.The compensation and decoupling procedures of a typical grid side converter control can be seen in system model. The (DC actual E) that is actual DC link voltage is compared with (DC ref E) that is reference value. The variations between the two values will go to the two Proportional Integral controllers by which are utilized to generate the required value of d-axis stator voltage. Also the difference between the actual reactive power that is actual Q and reference value that is ref. Q will go to another two Proportional Integral (PI) controllers to generate the value of q axis stator voltage which will be required

### 3.4 Pitch Angle Control System

The pitch angle is kept constant at zero degree until the speed reaches of the tracking characteristic. Beyond point control the pitch angle is proportional to the speed deviation from point of specific speed.

## 4. SIMULATION MODEL

Simulation Model for using DFIG wind turbine System using Simulink MATLAB

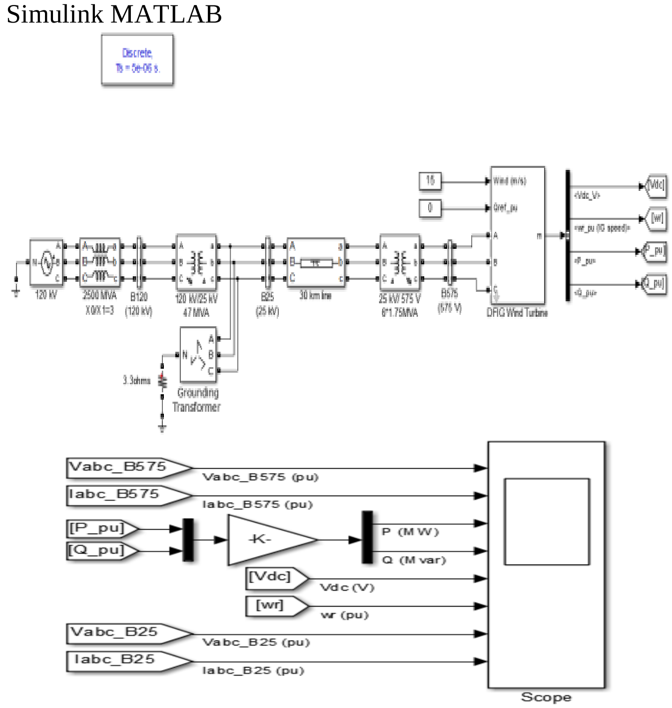


Fig.4 Simulation Model of DPC of DFIG under Distorted Grid Condition.

In the following simulation model (Fig. 5) a wind mill of a capacity of generating 9 MW is connected to an electrical grid. The wind mill is connected to a transformer which step ups the generating power for a 25 kv distribution. Through a 30 km transmission line this distribution network is connected to a 120 KV Grid system. In between the distribution system another step up distribution transformer is used to step up the voltage level to 120 KV with this star delta connected transformer a grounding transformer is used for providing path for zero sequence current are to be provided. Wind turbine used here will be using a wound rotor induction generator and IGBT-based converters. The stator of DFIG is directly connected to grid while the rotor is connected through AC/DC/AC Converters.

## 5. RESULT ANALYSIS

Depending on the range of frequencies to be represented, model VSC based energy conversion systems connected on power grids.

The detailed model includes detailed representation of power electronic IGBT converters. In order to the achieve & acceptable accuracy with the 1620 Hz and 2700 Hz switching frequencies used, the model must be discretized at a relatively small time step (5 microseconds). This model is well suited by the observing for distorted harmonics and control system to the dynamic performance over the relatively short periods of times (typically hundreds of milliseconds to one second) of the power.

### 5.1 System Parameters

Table I: System parameters

| **Parameter** | | **Rating** |
|---|---|---|
| Rated Power | | 9MW |
| Stator Voltage | | 575V |
| Stator Resistance | ( $R_s$ ) | 0.023Ω |
| Rotor Resistance | ($R_r$ ) | 0.016Ω |
| Stator Inductance | ( $L_s$ ) | 0.18H |
| Rotor Inductance | ( $L_r$ ) | 0.16H |
| Mutual Inductance | ($L_m$) | 2.9H |
| Pairs of Poles | | 3 |
| Wind Speed At Nominal Speed And At $C_p$ Max | $C_p$ | 15 m/s |
| Dc Link Voltage | | 1150V |
| Dc Bus Capacitor | | 10000 µF |
| Inertia Constant | | 0.685 |

A 9 MW wind farm consisting of six 1.5 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder. Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC using IGBT-based PWM converter. The stator winding is directly connected to the 50 Hz frequency grid while the rotor is fed to the variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind

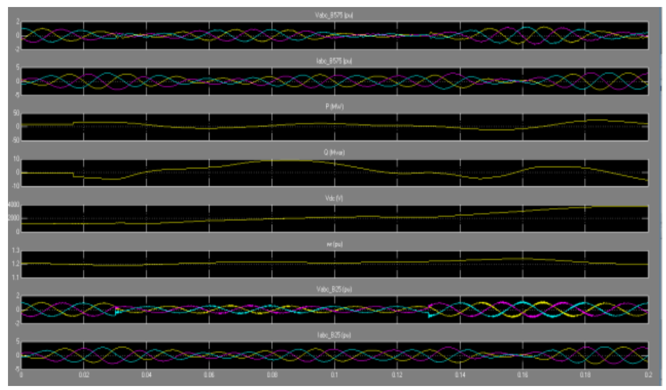

Fig. 5 Waveform for three phase output Distribution Voltage and current Active Power & Reactive Power, DC Voltage, Rotor speed, Grid Voltage & Current of wind farm.

In this system the wind speed is maintained constant at 15 m/s. The control system uses a torque controller of the system in order to maintain the speed at 1.2 pu. The reactive power produced by the wind turbine is regulated at to 0 Mvar.

Right-click on the "DFIG Wind Turbine" block and select "Look Under Mask" to see how the model is built up. The sample time used to discretize in the model (Ts= 50 microseconds) is specified in the Initialization function of the Model Properties.

For the open “DFIG Wind Turbine" block menu to see the data of the generator, converter, turbine, drive train and control system of the system. In this Display menu select "Turbine data for 1 wind turbine", check "Display wind turbine power characteristics" and then click apply for the system. The turbine Cp curves are displayed in Figure 6 The turbine power, the tip speed ratio lambda and the Cp values are displayed in Figure 7 as function of wind speed. For a wind speed of 15 m/s, the turbine output power is 1 pu of its rated power, the pitch angle is 8.7 deg and the generator speed is 1.2 pu.

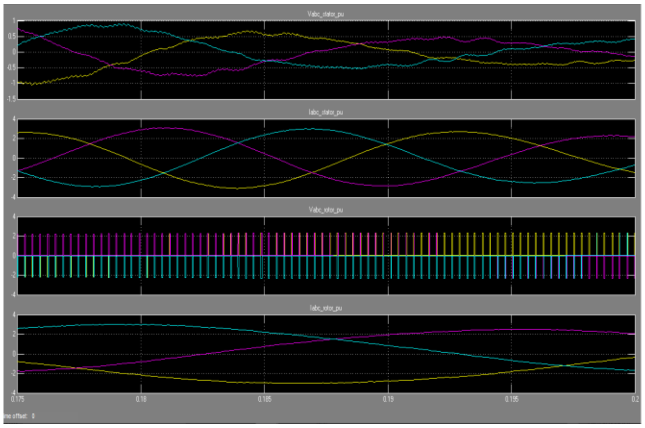

Fig 6 Waveform for three phase output Stator Voltage and current output Rotor Voltage & Current of wind farm

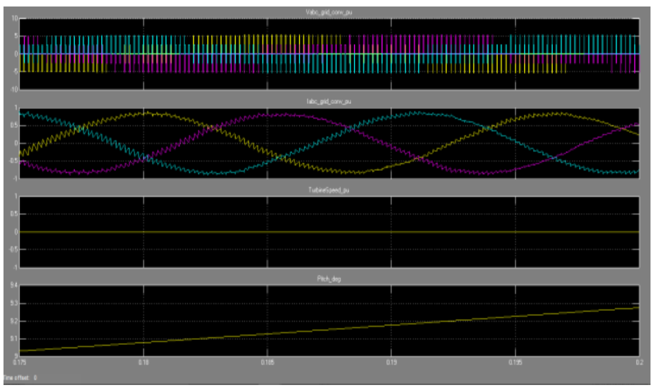

Fig 7 Waveform for three phase output Grid Voltage and Grid current output & Turbine Speed, Pitch Degree of wind farm

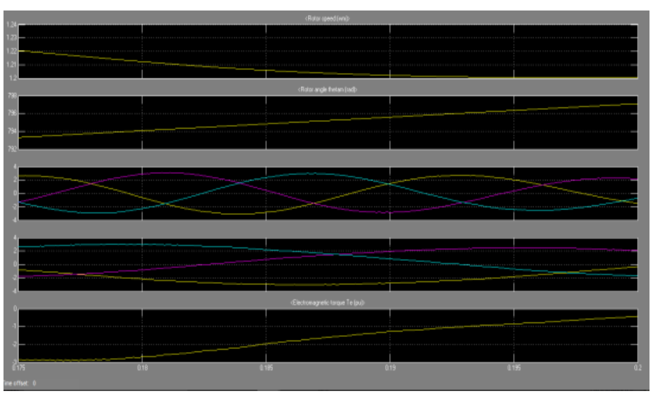

Fig 8 Waveform for output rotor speed, rotor angle

**Table 2:** Harmonic Analysis Data with the Proposed DPC Strategy

| | **Distorted Power Grid** | **Proposed Approach** |
|---|---|---|
| Ps Pulsation | ± 5MW | ± 8-9MW |
| Qs Pulsation | ± 0.68-1.28Mvar | ±0.10MVar |
| Iavg | 20-25% | 4-5% |

The value of the DC voltage in volts and the rotor speed is shown in Figure 5 In this model the wind speed is maintained constant at 15 m/s. The control system uses a torque controller in order to maintain the rotor speed at 1.2 pu. Same is shown in the figure 5 also the nominal value of the DC voltage is 1150 volts. From above waveform the result drawn is that by using DFIG in wind farm the efficiency can be improved and maximum power can be extracted and maintained constant for the whole time period.

The Experimental result shows the in distorted grid condition THD values for different order harmonics is found to be 20-25%, but after applying the proposed control technique it will reduces to THD = 4-5%. This shows the significant reduction in harmonic i.e. distortion at the grid side.

## 6. CONCLUSION AND FUTURE SCOPE

In this paper, we discussed here the operation of DFIG and its controls. First we simulated a wind turbine driven the isolated (not connected to grid) induction generator. But for best efficiency of the DFIG system is used to connect the grid side is a better control. To provide the active and reactive power control of the machine is usually rotor side converter (RSC) & while using the grid-side converter (GSC) keeps the voltage of the DC-link constant of the system.

So finally we simulated grid side and wind turbine side parameters and the corresponding results have been displayed. From the study of the design & simulation model we understand that using doubly fed induction generator under distorted grid voltage using wind energy conversion can be made more reliable and efficient.

The DFIG system is able to provide the considerable contribution to grid voltage support during short circuit periods of the system. Considering the results it can be said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems. The percentage level of harmonic present in the system is analyzed using FFT analysis and the results are compared.

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