MODELING AND POWER CONTROL OF DFIG-BASED WIND TURBINES UNDER UNBALANCED GRID VOLTAGE CONDITION

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Abstract: This paper emphasizes on control of a doubly fed induction generator (DFIG) grid-connected wind turbine system to track the highest absorbable power in different wind speeds. This study proposes an improved control strategy for Rotor Side Controllers (RSC) and Grid Side Controllers (GSC) in a Doubly Fed Induction Generator (DFIG) connected to grid using Genetic Algorithm (GA) technic. In this new proposed method, design of DFIG control based on analysis of characteristic functions and DFIG system reaction has been used to estimate wind speed and GA has been employed to obtain favorable features. The main objective of this plan is to control optimal power extracted from wind considering power of characteristic curve speed of DFIG wind turbine. In this paper, GA has been employed in both control methods of RSC and GSC to achieve an optimal output power. Also, MATLAB/SIMULINK software is employed for simulation.

Keywords: wind turbine, power control Doubly Fed Induction Generator (DFIG), Genetic Algorithm (GA)

1. Introduction

Wind turbines are applied in two types of fixed-speed and variable-speed. Fixed-speed turbines have 1% Rotor speed change and are directly connected to grid. In fixed-speed turbines, speed is stabilized to grid frequency and wind speed influences on voltage; it means that speed oscillations are effective in turbine function and output voltage. Rotor speed controlling is possible in variable-speed turbines in which, generators are controlled by power electronic equipment. In this method, power oscillations are controlled by wind changes within rotor speed change.

Variable-speed wind turbines are increasingly becoming substituents of fixed-speed turbines due to their higher power quality and on the other hand, DFIGs are more employed due to their injection ability and reactive power control and no need of capacitors. Presence of active and reactive power controllers to control output power of DFIG-based wind turbines would lead to interference of these controllers with other system modes such as torsional modes of turbine-generators, controller modes of power system, etc.

If unbalanced grid voltage is not considered in DFIG control system, there will be a disruption in grid or harm to wind turbine parts and grid stability. In this case, DFIG-based wind turbines with no control system might be harmed or disconnected from grid due to unbalanced voltage. Vertical Control (VC) is one of technics used to control Rotor Side Controller (RSC) and Grid Side Controller (GSC) that may control active and reactive power.

In this research, a new design method for DFIG control is discussed based on the analysis of characteristic functions and DFIG reaction system. To achieve favorable features, NSGA-LL algorithm was employed. Finally, a model, which indicates reactive power control under unbalanced voltage in DFIG, will be simulated in MATLAB/SIMULINK environment and obtained results will be examined.

2. Research Background

With raising oil prices in 1973, industrial developed countries more paid attention to energy issue and this became the start point of long-term programs in field of energy use optimization and frugality (Zandzadeh and Vahedi, 2014; Choo et al., 2010). Among renewable energy sources, wind energy is more attractive. Wind plant is more used because of its low cost and environmental pollution. One of the most important issues is that the turbine generator should be such controlled to track and generate maximum power in moment. Wind turbine systems equipped with DFIG have numerous advantages (Zamanifar et al., 2014; Kim yet al., 2016; Jiabing and Yikang, 2009). Among induction turbines, doubly fed induction generators have better function than other induction generators. Some of the mentioned advantages include active ad reactive control, grid voltage control, frequency control in grid-disconnected mode, and lack of need to capacitor banks to provide induction generator with required reactive power. DFIG power is controlled through rotor side power electronic controller (Jiabing and Yikang, 2011; SHeate and Gerges, 2013; Hu et al., 2013; Santos-Martin and Rodriguez- Amended, 2010).

In reference (Kim, 2016), voltage control of a DFIG-Based wind power for a grid fault is studied using adaptive hierarchal method and voltage adjustment is done with proportional-integral controllers and filter design. Reference (Firouzi et al., 2016) studied power control and short circuit limitations of wind farms using unified inter-phase power controller. Mathematical and equivalency aspect of circuits was done using equivalent circuit of power system. Also, three-phase short circuit was examined.

Reference (Choo et al., 2010) studied DFIG-based wind system under unbalanced grid voltage. This system was modeled using Synchronous then active and reactive powers were controlled through analysis of functions. In this system, output power of stator was has been compensated by RSC (Rotor Side Convertor).

In reference (Pulgar, 2011) capability of passing fault in DFIG system with high order sliding mode is studied. Control of capability of passing through low voltage in adaptive conditions with DFIG system with design of a controller for this nonlinear system has been done using Genetic Algorithm (NSGA-II).

In reference (Choo et al., 2008), effective factors in disruption and fault in grid such as change in wind speed, which has an important role in rotor flow swings, have been studied providing a genetic algorithm for better performance in DFIG system.

Analysis of mathematical model of DFIG under unbalanced grid voltage has been studied. Flow control of RSC and GSC under unbalanced voltage is examined and finally, simulation of wind power generation system is done in 15MV (Slootweg, 2003; Akhamtov, 2002).

In reference (Hess and Muljadi, 2000), Direct Power Control (DPC) has been studied. Active and reactive power swings with GSC is examined to achieve constant active and reactive power.

In references (Benbouzid et al., 2014; SHeate and Salma, 2013), a proposed model is designed to control RSC and GSC for a wind system to remove swings of these convertors. The result of this design is achieving constant output active power in an unbalanced system.

In reference (Zhang et al., 2011), the effect of wind power on constant frequency of power systems is examined. Also, inertia control, rotor side and angular control are analyzed in different wind speeds (low, moderate, high).

In reference (Harnefors, 2007), analysis of constant frequency modulation in DFIG is studied using three different methods. First method: reducing bandwidth of rotor flow controller, second method: BACK-IMS of high bandwidth control loops and rotor direct flow regulation adapted by flux derivate, third method: biaxial damping system in which, rotor flow is adapted by changes in system parameters such as stator flux and α angle.

In reference (Gardenas et al., 2013), different options including control and operation of brushless DFIG system, direct operations for system control in two balanced and unbalanced grid-connected, sensor-less control, DFIG frequency improvement and voltage drop of equipment were studied.

In reference (SHuhui et al., 2012), DC Vector Control method is presented for DFIG wind system to control direct-current DFIG system, control reactive power, and improve grid voltage under variable-speed wind conditions.

Reference (Tsili and Papathanassiou, 2009) has expressed a review of grid technical codes and connections for system operators.

In reference (Hailling et al., 2012), integrated modeling and Enhanced Control of DFIG under Unbalanced and Distorted Grid Voltage Conditions is presented with extensive mathematical operations, negative sequences and low-order harmonics of grid voltage as well as enhanced control of this system under unbalanced grid voltage conditions.

In reference (Behera et al., 2016), pitch control is used for Wind Energy Conversion System (WECS) in high wind speeds to keep constant output (speed and frequency). The proposed model in this study is designed based on a discrete model of grid-connected WECS including Line to Grand (LG) error. In this study, Proportional-Integral (PI) controllers with K_p and K_i interests in angle control loop was used. Proportional and Integral interests of K_p and K_i are adjusted in optimization process of Particle Swarm (PSO) and Pattern Search (PS). Comparison of two different target functions with their weight coefficients is provided in this paper.

Yancai Xiao et al., 2016, presented a paper to examine accuracy and speed of reaction of permanent magnet direct drive (PMDD) wind turbines. In their research, they proposed a fuzzy PI controller with a new control method for wind turbine convertors. The objective of this control strategy is to achieve a general optimization for quantization factors (K_e, K_{ec}) and scale factors (K_{up}, K_{ui}) in a fuzzy PI controller with improved PSO method. Advantages of improved PSO and fuzzy controller strength can be used in optimization process control.

In reference (Syahputra and Soesanti, 2016), DFIG control scheme of wind power using ANFIS Method is proposed. This design proposed to control a part of wind speed in power grid system. In this paper, wind turbine is derived by a DFIG, which have AC power supply in distribution grid.

In reference (Jamal et al., 2016), a paper is presented for performance evaluation of wind turbine with doubly fed induction generator (DFIG). In this research, directed control stator flux has been used for performance of variable-speed DFIG. Controlling generator excitation current, stator EMF domain is regulated by grid voltage domain.

In general, wind turbines are divided to four categories. Two types of A and B are induction generator-based that Type A provides fixed-speed operation and type B provides variable-speed operation with limited domain (Choo et al., 2008). Swinging the transmitted power to the grid due to changes in wind speed is a major defect of turbines type A and B; C and D types of wind turbines, which are DFIG-based and Permanent Magnet Synchronous Generators-based (PMSG), respectively, provide variable-speed operation in a more extensive interval. The main advantage of latter (types C and D) is reducing swings of output power and extraction of maximum power from wind. Configuration of type C is the most common option in wind farm projects.

Mechanical power of wind turbine extracted from wind is calculated by following formula:

$$P_t = \frac{1}{2}\rho A v_\omega^3 C_\rho \quad (1)$$

Where, P_t is extracted power from wind turbine, ρ is air density, A is the area swept by the rotor, v_ω is wind speed, and C_p is power coefficient of wind turbines. Power coefficient of C_p is a function of pitch angle of rotor blade (β), design type of blades and ratio of blade speed to wind speed (λ) and is calculated as follows:

$$C_p(\lambda, \beta) = 0.5176(\frac{116}{\lambda_i} - 0.4\beta - 5)e^{21/\lambda_i} + 0.0068\lambda$$
$$\lambda_i = (\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1})^{-1} ; \ \lambda = \frac{\omega_{tur}R}{V_\omega} \quad (2)$$

Where, ω_{tur} is angular speed of blade and R is blade length.

Wind turbine consists of blades, central shaft, low-speed axis, gearbox, high-speed axis and generator. Increase in generation power level of wind turbines up to 8MW and having some unique features such as high inertia of turbine opposed low inertia of generator as well as low stiffness coefficient of axis have led to modulation of wind generator-turbine collection in two mass three mass groups. Modes related to these masses are called torsional modes and oscillations related to them are called torsional oscillations. Interference of other power system components with turbine-generator shaft would drive torsional modes and increase torsional oscillations imposed to shaft; therefore, interference between system modes and torsional modes should be accurately examined. In figure 1, three-mass model is illustrated. In fact, mechanical part of wind turbine is modeled with three masses; hence, six stat variables are considered for it, which are as follows:

$$\omega_{gen}, \omega_{hub}, \omega_{blade}, \theta_{gen}, \theta_{hub}, \theta_{blade} \quad (3)$$

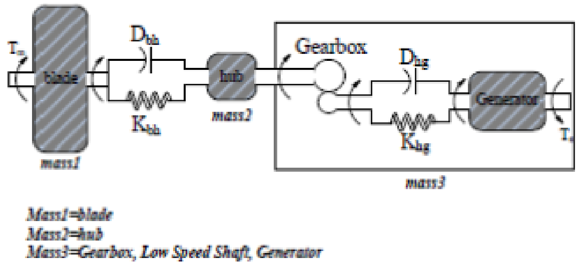

Figure 1. Components of three-mass model for wind generator-turbine system (Slootweg, 2003)

Equation 4 indicates electrical-mechanical balance relations of all three masses after transmitting to generator.

$$
\begin{aligned}
\frac{d\omega_{blade}}{dt} &= \frac{1}{2H_{blade}}\begin{bmatrix} T_m - K'_{bh}K^2_{gear}(\theta_{blade}-\theta_{hub}) \\ -D'_{bh}K^2_{gear}(\omega_{blade}-\omega_{hub}) \end{bmatrix} \\
\frac{d\theta_{blade}}{dt} &= \omega_{blade} \\
\frac{d\omega_{hub}}{dt} &= \frac{1}{2H_{hub}}\begin{bmatrix} -K'_{bh}K^2_{gear}(\theta_{hub}-\theta_{blade}) \\ -K_{hg}K_{gear}(K_{gear}\theta_{hub}-\theta_{gen}) \\ -D_{hg}K_{gear}(K_{gear}\omega_{hub}-\omega_{gen}) \\ -D'_{bh}K^2_{gear}(\omega_{hub}-\omega_{blade}) \end{bmatrix} \\
\frac{d\theta_{hub}}{dt} &= \omega_{hub} \\
\frac{d\omega_{gen}}{dt} &= \frac{1}{2H_{gen}}\begin{bmatrix} -T_e - K_{hg}(\theta_{gen}-K_{gear}\theta_{hub}) \\ -D_{hg}(\omega_{gen}-K_{gear}\omega_{hub}) \end{bmatrix} \\
\frac{d\theta_{gen}}{dt} &= \omega_{gen}
\end{aligned}
\tag{4}
$$

In these equations, ω_{blade}, ω_{hub}, and ω_{gen} are related to blades, central hub, and generator rotor, respectively and H_{blade}, H_{hub}, and H_{gen} are inertia of blades, hub, and generator, respectively. θ_{blade}, θ_{hub} and θ_{gen} are angular displacements related blades, hub, and generator. D_{bh} is damping coefficient between blades and hub, D_{hg} is damping coefficient between central hub and generator rotor. K_{hb} is stiffness coefficient between blades and hub, K_{hg} is stiffness coefficient between hub and generator. K_{gear} is the conversion ratio of gearbox, T_e is electrical torque, and T_m is aerodynamic torque supplied by wind.

The other technic used in this paper is GA. GA is a member of calculative models adopted from evolution trend. These algorithms code potential solutions of an issue in frame of simple chromosomes and then operate combined operators on these structures. Genetic Algorithms are usually recognized as a method for functions optimization, of course these algorithms are more widely used (Syahputra and Soesanti, 2016; Shir and B¨ack, 2005; Limouzade, 2013). Genetic Algorithm is different with search methods, which use random selection for their search methods, because this algorithm does not behave randomly in search space although uses chance and accident to define decision-making methods (Michalewicz, 1994). Genetic Algorithm follows probability rules not definite rules (Jamal et al., 2016).

3. New Theory

First, an initial population is chosen randomly without considering any specific criterion. Fitness amount is determined for all zero generation chromosomes (individuals) considering processing function that can be simple or complex. Then, a subset is chosen from initial population is chosen using different defined mechanisms for selection operator and then mutation and crossover operations is implemented on the elected individuals if it is required based on the problem.

Now, these individuals, who are affected by GA mechanism, should be compared to individuals of initial population (zero generation) based on fitness value. (Certainly, it is expected that individuals of initial generation have more competency in accordance with once implementation of GA on them; however, it is not mandatory). However, there would be some individuals with highest fitness value and such individuals are the initial population for the next step of GA.

Every replication in algorithm step would create a new generation that tends to be evolved due to modifications received. It is worthy noted that although Genetic Algorithms have no sound mathematical base, have shown their effectiveness as an accurate executive model that can be simply implemented.

General scheme of an algorithm is as follows:

Start: Generate random population of n chromosomes (suitable solutions for the problem)

Evaluation: Evaluate fitness f(x) of each chromosome x in the population

New population: Create a new population by repeating following steps until the new population is complete

Selection: Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)

Crossover: With a crossover probability cross over the parents to form a new offspring (children)

Mutation: With a mutation probability, mutate new offspring at each locus (position in chromosome)

Accepting: Place new offspring in a new population

Replace: Use new generated population for a further run of algorithm

Based on experience, the number of population would be better between 10 and 160. Initial population size is usually related to coded set. For instance, if chromosomes are 32-bit in a problem, the selected initial population should be surely more than the state, in which chromosomes are 16-bit.

Usually, jumping probability expected to between 80 and 95%, mutation probability 0.5-1% and population size 20-30 members. Then, a real value (that indicates chromosomes' value) is given to selected chromosomes in accordance with a fitness function and GA steps continue.

We now consider equivalent circuit of DFIG illustrated in synchronous reference system in figure 2, in order to match this method with present problem (Xu and Agelidis, 2002).

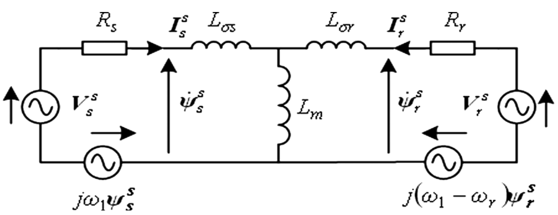

Figure 2. Equivalent circuit of DFIG in synchronous reference system

Stator and rotor voltage vectors in synchronous reference system are expressed as follows:

$$V_s^s = R_s I_s^s + j\omega_1 \psi_s^s + \dot{\psi}_s^s \tag{5}$$

$$V_r^s = R_r I_r^s + j(\omega_1 - \omega_r)\psi_r^s + \dot{\psi}_r^s \tag{6}$$

Where, ψ_s^s is stator flux, ψ_r^s is rotor flux, I_s^s is stator circuit and I_r^s is rotor circuit in synchronous reference system.

According to the figure above (2), stator and rotor vectors are as follows:

$$\psi_s^s = L_s I_s^s + L_m I_r^s \tag{7}$$

$$\psi_r^s = L_r I_r^s + L_m I_s^s \tag{8}$$

If these equations are combined, will obtain:

$$I_s^s = \frac{\psi_s^s}{\sigma L_s} - \frac{L_m \psi_r^s}{\sigma L_s L_r} \tag{9}$$

Stator flux domain is calculated as follows:

$$|\psi_s| = \left|\int (V_s - R_s I_s)dt\right| \approx \left|\int V_s dt\right| \tag{10}$$

With presumption of constant grid voltage and regardless of stator copper losses, stator flux domain will be constant in above equation. Therefore, input active and reactive power from grid is as follows:

$$P_s = -k_\sigma \omega_1 |\psi_s||\psi_r|\sin\theta \tag{11}$$

$$Q_s = k_\sigma \omega_1 |\psi_s|(|\psi_r|\cos\theta - \frac{L_r}{L_m}|\psi_s|)$$

In which, θ is angle of rotor and stator flux vectors in following figure 3 and k_σ is defined as follows:

$$k_\sigma = \frac{1.5 L_m}{\sigma L_s L_r} \tag{12}$$

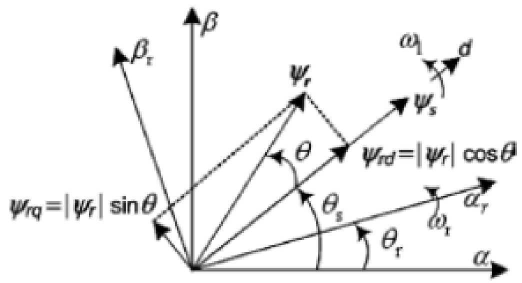

Figure 3. Spatial relation between stator flux, rotor flux and rotor voltage

As can be seen in figure 3, stator flux is on the axis d of synchronous reference system; therefore, $|\psi_s| = \psi_{sd}$. The equations provided for active and reactive power can be revised as follows:

$$P_s = -k_\sigma \omega_1 \psi_{sd} \psi_{rq}$$

$$Q_s = -k_\sigma \omega_1 \frac{L_r}{L_m} \psi_{sd}^2 + k_\sigma \omega_1 \psi_{sd} \psi_{rd} \tag{13}$$

This equation indicates that active power with ψ_{rq} regulation and reactive power with ψ_{rd} are independently controlled.

Principles of DC (direct-control) predictive power consist of following aspects:

1) Vector space modulation is used to generate suitable voltage vectors during constant sampling period.
2) To calculate required rotor voltage directly during a constant sampling period, the following power model can be used:

$$P_s = -k_\sigma \omega_1 \psi_{sd} \psi_{rq} \tag{14}$$

$$Q_s = -k_\sigma \omega_1 \frac{L_r}{L_m} \psi_{sd}^2 + k_\sigma \omega_1 \psi_{sd} \psi_{rd} \tag{15}$$

Therefore, a fast dynamic response power control and a constant switching frequency will be obtained.

Active and reactive power errors at the beginning of sampling period are calculated as follows:

$$\delta P_s(k) = P_s^*(k) - P_s(k)$$

$$\delta Q_s(k) = Q_s^*(k) - Q_s(k) \tag{16}$$

At the end of sampling period, active and reactive power errors should be zero, which means:

$$\delta P_s(k+1) = P_s^*(k+1) - P_s(k+1) = 0$$

$$\delta Q_s(k+1) = Q_s^*(k+1) - Q_s(k+1) = 0 \tag{17}$$

Therefore, power changes during sampling period are as follows:

$$\Delta P_s(k) = P_s(k+1) - P_s(k) = P_s^*(k+1) - P_s^*(k) + \delta P_s(k)$$

$$\Delta Q_s(k) = Q_s(k+1) - Q_s(k) = Q_s^*(k+1) - Q_s^*(k) + \delta Q_s(k) \tag{18}$$

On the other hand, we have:

$$P_s^*(k+1) = P_s^*(k)$$

$$Q_s^*(k+1) = Q_s^*(k) \tag{19}$$

Therefore, power changes during K sampling period are as follows:

$$\Delta P_s(k) = \delta P_s(k)$$

$$\Delta Q_s(k) = \delta Q_s(k) \tag{20}$$

Therefore, the objective of DC predictive power is to generate required high power changes using correct rotor voltage. Since stator flux is constant, active and reactive power changes during a short sampling period is projected as follows:

$$\Delta P_s = -k_\sigma \omega_1 \psi_{sd}(k) \Delta\psi_{rq}(k)$$
$$\Delta Q_s = k_\sigma \omega_1 \psi_{sd}(k) \Delta\psi_{rd}(k) \tag{21}$$

Rotor flux changes also are calculated as follows:

$$\Delta\psi_r^s = \int_{Ts} (V_r^s - R_r I_r^s - j\omega_s \psi_r^s) dt \tag{22}$$

Rotor flux changes are obtained as follows:

$$\Delta\psi_{rd}(k) = \psi_{rd}(k+1) - \psi_{rd}(k) = [V_{rd}(k) - R_r I_{rd}(k) + \omega_s \psi_{rq}(k)]T_s$$
$$\Delta\psi_{rq}(k) = \psi_{rq}(k+1) - \psi_{rq}(k) = [V_{rq}(k) - R_r I_{rq}(k) - \omega_s \psi_{rd}(k)]T_s \tag{23}$$

Rotor voltage is obtained from mentioned equations:

$$V_{rd}(k) = R_r I_{rd}(k) - \omega_s \psi_{rq}(k) + \frac{1}{T_s} \frac{\Delta Q_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)}$$
$$V_{rq}(k) = R_r I_{rq}(k) + \omega_s \psi_{rd}(k) - \frac{1}{T_s} \frac{\Delta P_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)}$$
$$V_r^s(k) = V_{rd}(k) + jV_{rq}(k) = R_r I_r^s(k) + j\omega_s \psi_r^s(k) + \frac{1}{T_s} \frac{\Delta Q_s(k) - j\Delta P_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)} \tag{24}$$

Regardless of rotor resistance, theses equations can be simplified as follows:

$$V_{rd}(k) = -\omega_s \psi_{rq}(k) + \frac{1}{T_s} \frac{\Delta Q_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)}$$
$$V_{rq}(k) = \omega_s \psi_{rd}(k) - \frac{1}{T_s} \frac{\Delta P_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)}$$
$$V_r^s(k) = j\omega_s \psi_r^s(k) + \frac{1}{T_s} \frac{\Delta Q_s(k) - j\Delta P_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)} \tag{25}$$

Also, we have:

$$\psi_{rq} = -\frac{P_s}{k_\sigma \omega_1 \psi_{sd}} \tag{26}$$

$$\psi_{rd} = \frac{Q_s + k_\sigma \omega_1 \frac{L_r}{L_m} \psi_{sd}^2}{k_\sigma \omega_1 \psi_{sd}} \tag{27}$$

Substituting equations above, will obtain:

$$V_{rd}(k) = \omega_s \frac{P_s(k)}{k_\sigma \omega_1 \psi_{sd}} + \frac{1}{T_s} \frac{\Delta Q_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)} \tag{28}$$

$$V_{rq}(k) = \omega_s \frac{Q_s(k) + k_\sigma \omega_1 \frac{L_r}{L_m} \psi_{sd}^2}{k_\sigma \omega_1 \psi_{sd}} - \frac{1}{T_s} \frac{\Delta P_s(k)}{k_\sigma \omega_1 \psi_{sd}(k)} \tag{29}$$

As can be seen, rotor side convertor (RSC) can be controlled in this method if machine, voltage and stator circuit parameters are given. Now, these two voltages are transferred to rotor reference system and changed to three-phase voltage using reverse Park conversion. This voltage is given to vector modulation to provide required pulses for RSC.

4. Simulation Result

Genetic Algorithm was used in this research and data related to DFIG existed in MATLAB software was used in proposed GA strategy. Wind speed is assumed constant (10m/s) in this model. The applied circuit in MATLAB software is for a 120 kv system. It should be mentioned that real time simulation (RTS) is used to control software loops or accelerate model speed, control, and test. This time was predetermined value usually equal to 5, 10, or 20 ms and used to read input signals such as sensors, calculations, controlling algorithms and to control analog/digital outputs. Genetic Algorithm is applied to obtain and control measured power values to grid and the purpose is to make control parameters equal to reference values or close to them. Generated reference active power is determined based on wind speed and mentioned feature in wind turbine, whereas, reactive power, as a determinant for reactive power conversion performance, is considered for loss compensation. This paper has studied a wind system with DFIG connected to grid through a back-to-back convertor. Generator side convertor regulates generator speed and grid side convertor controls reactive power. The purpose of controller and proposed algorithm is to control input active power to generator and to control bus reactive power of generator terminal side under different states such as load change, error and presence of non-linear load. Control parameters are determined by GA optimization algorithm for a better performance. Results of simulation indicate ability of proposed control strategy. To keep turbine speed in considered value, Direct Torque Control with 1.09 PU was applied. To regulate controllers and optimization with GA, considered target functions were designed. Target function of RSC is as follows:

$$F_1 = \int \left|(i_{dr_{ref}} - i_{dr})\right| + \left|(i_{qr_{ref}} - i_{qr})\right| + \sqrt{v_{dr}^2 + v_{qr}^2} \tag{30}$$

Also, to have better control and obtain favorable parameters, target function of GSC was added as follows:

$$F_2 = \int \left|(i_{dg_{ref}} - i_{dg})\right| + \left|(i_{qg_{ref}} - i_{qg})\right| + \sqrt{v_{dg}^2 + v_{qg}^2} \tag{31}$$

Where, i_{qg}, i_{dg}, i_{qr}, i_{dr}, v_{dg}, v_{qg}, v_{dr}, and v_{qr} are circuit and voltage factors for RSC and GSC. The purpose of designing proposed target function is to minimize flow on TSC and GSC in circuits and functions related to grid as well as flow of RSC. In addition to controlling flows (i_{qg}, i_{dg}, i_{qr}, i_{dr},), voltage reduction, which might be realized through related conditions to (v_{dg}, v_{qg}, v_{dr}, v_{qr}), is done to minimize losses in power system. Therefore, the applied GA method is an optimal method to find favorable parameters in both RSC and GSC controllers in order to optimize target functions. DC voltage (external loop) and grid flow (internal loop) can be controlled optimizing control parameters of system. Realization of considered objectives is done as follows:

First: use of GA for both RSC and GSC using target functions F1 and F2.

Second: use of GA for RSC only for optimizing first target function that is related to rotor side convertor (RSC).

Interest coefficients, control parameters, and favorable values obtained using GA are indicated in tables 1 and 2 and the obtained results are illustrated in figures 4-8.

Table 1. Gain control of first option

coefficients	LB	UB	Genetic Algorithm
Kp1	0	0.01	0.0061
Ki1	0.01	0.1	0.01733
Kp2	1	10	2.5709
Ki2	400	600	400.0042
Kp3	0	0.1	0.001
Ki3	1	20	15.082
Kp4	0.05	1	0.05035
Ki4	1	0	1.0175

Table 2. Gain control of second option

coefficients	LB	UB	Genetic Algorithm
Kp3	0	0.1	0.013
Ki3	1	20	1.34
Kp4	0.05	1	0.054
Ki4	1	20	10.589

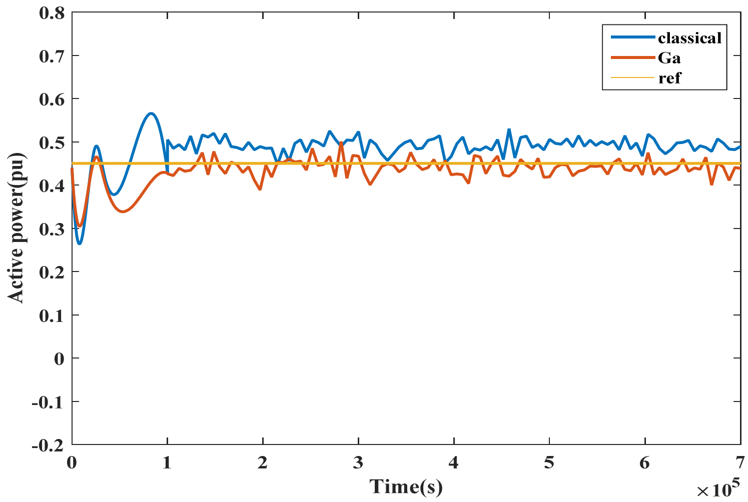

Figure 4. Active Power

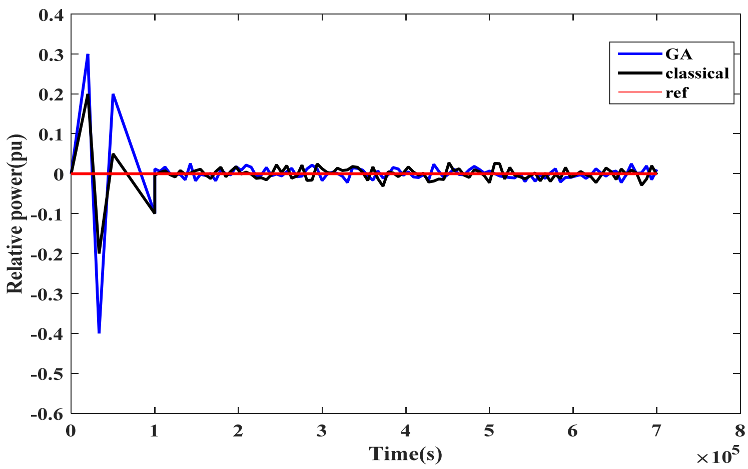

Figure 5. Reactive Power

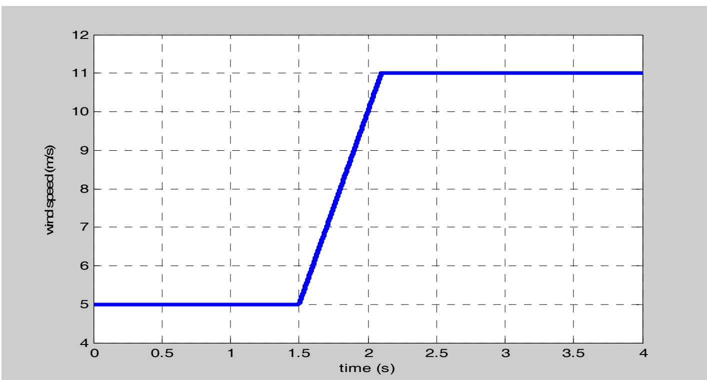

Figure 6. Wind speed changes curve

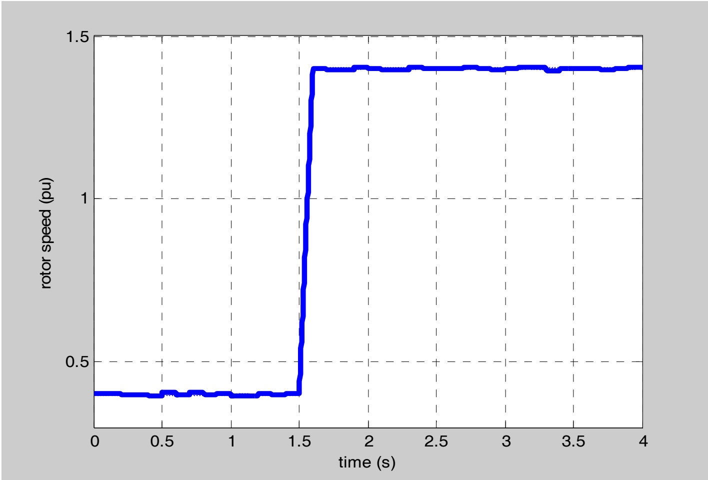

Figure 7. Rotor speed changes

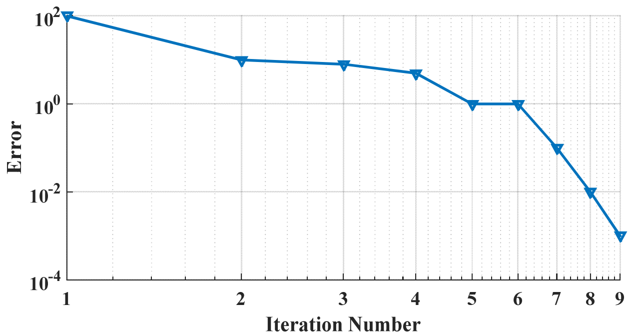

Figure 8. Reduction in errors with iteration

5. Conclusion

As can be seen, convergence to references signal is done well and performance is better in GA. In different time intervals, wind speed changes and non-linearity of loads are applied and these options can be seen as blue color in figure of reference signal. With optimizing parameters, although we have some positive and negative errors in different intervals such as 1-2 seconds and 2-5 seconds, error average is a minor value and optimized signal follows reference signal properly and is capable of removing errors and oscillations.

Error level from reference values will be reduced with iterations and in almost 40st iteration, error value is negligible. Convergence speed is illustrated in figure 8 properly using GA.

In this paper, a new strategy was proposed using GA to control direct active and reactive powers in a DFIG system. This proposed method was used besides a suitable voltage vector selection based on the stator flux position and errors of active and reactive powers to eliminated problems related to rotor flux estimation. Results obtained from simulation indicate that the proposed GA method adjusted with target function would provide the best control parameters in RSC loop and GSC of DFIG to achieve the optimal power from wind speed.

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