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Advanced Optimal PSO, Fuzzy and PI Controller with PMSM and WTGS at 5Hz Side of Generation and 50Hz Side of Grid

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ABSTRACT

To use different control systems, like classical PI controller, Expert System Fuzzy Logic Controller and optimization PSO controller. It used to control for PMSM which worked in the integration system to Wind Energy. Wind energy content of wind turbine, PMSM, rectifier, DC bus, inverter, filter, load and grid. In the first step, to run the PMSM with different speeds to get a different frequency to select the frequency on the side of a generation with the rated speed. Second step, solve the mathematical equation to use different values of wind speed with selected (15,20 m/s and less than with more than 15&20m/s). Third step, calculation the power generation with wind speed (15 m/5 & 20 m/s). Fourth step, using these component system rectifier, DC bus, inverter, filter, load & grid with WTGS & PMSM. Final step, uses different control systems, like classical PI controller, Expert System Fuzzy Logic controller and optimization PSO controller with PMSM to analyze all results after using the simulation model of proposed variable speed based on WECS. The wind turbine is coupled with PMSM. A closed loop control system with a PI control, fuzzy, PSO in the speed loop with current controllers. The simulation circuits for PMSM, inverter, speed and current controllers include all realistic components of the drive system. These results also confirmed that the transient torque and current never exceed the maximum permissible value.

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1. INTRODUCTION

The most emerging renewable energy source, wind energy, by means of power electronics is changing from being a minor energy source to be acting as an important power source in the energy system. That wind power is also getting an added value in the power system operation. The power electronics are changing the basic characteristic of the wind turbine from being an energy source to be an active power source [1].The permanent magnet synchronous machine (PMSM), it has significant advantages, attracting the interest of researchers and industry for use in many applications, that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets [2]. The PMSM, with high level energy permanent magnet materials particularly provide fast dynamics, efficient operation and good compatibility with the applications but only if they are controlled properly. The controller is using to overcome the nonlinearity problem of PMSM and also to achieve faster response [3]. Many industrial applications require new control techniques, the techniques used, applied in all regulation loops, speed regulation of permanent magnet synchronous machine (PMSM) [4]. The development of power electronics and electric technology boost PMSM for extensive applications in many control systems. And PMSM, which are widely used for systems and control devices minute owns several advantages over other machines on Milan. Advantages PMSM include large torque coefficient, and high efficiency, high energy density, and a torque multiplier is small, Low-inertia, low noise, and high-performance in a wide variety [5]. A way controller (PI) in addition to controllers with integral relative formulated and implemented, using speed control magnet synchronous machine system and a permanent pilot phase. While the new strategy promotes traditional PI control performance to a large extent, and proves to be a model-free approach completely, it also keeps the structure and features of a simple PI controller [6].The use consoles mode instead of Fuzzy-PI control to improve the performance of PMSM. To control the speed of PMSM by using fuzzy logic (FL) approach leads to a speed control to improve the dynamic behavior of the PMSM system and immune disorders to download and parameter variations [7,8]. In the WTGS systems and gains from the traditional can't usually be set in proportion-integral (PI) controller speed large enough because of mechanical resonance. As a result, performance degradation and speed control. Fuzzy logic controller (FLC) for use in WTGS systems in order to improve the performance of the speed control. The proposed FLC has been compared with traditional PI control with respect to the speed of response and dynamic load torque. Simulation and experimental results have proved that FLC was proposed is superior to the traditional PI. This FLC can be a satisfactory solution for the high-performance machine lifts systems [9-11]. A modern way to control the speed of PMSM using particle swarm optimization (PSO) to improve the algorithm parameters observer PI-. Simulate the system under different operating year conditions is prepared and the experimental setup. Use PSO algorithm and optimization make a powerful engine, with faster response and higher resolution dynamic and sensitive to load variation [12, 13].

2. MODEL FOR A PMSM DRIVE

(Figure 1 block diagram of a PMSM & Figure2 block diagram of a PMSM Drive)

The complete nonlinear model of a PMSM without damper winding is as follows:

$$vq = Riq + pLqiq + \omega s(Ldid + \lambda_{af}) \quad (1)$$

$$vd = Rid + p\lambda d - \omega s\ Lq\ iq \quad (2)$$

vd and vq are the d,q axis voltages, id and iq are the d,q axis stator currents, Ld and Lq are the d,q axis inductances, R and ω_s are the stator resistance and inverter frequency respectively. λ_{af} is the flux linkage due to the rotor magnets linking the stator.

The electric torque:

$$Te = 3P(\lambda_{af}\, iq + (Ld - Lq)idiq)/2 \quad (3)$$

The motor dynamics:

$$T_e = T_L + B\omega_r + Jp\omega_r \quad (4)$$

P is the number of pole pairs, TL is the load torque, B is the damping coefficient, ω_r is the rotor speed and J the moment of inertia. The inverter frequency is related to the rotor speed as follows:

$$\omega_s = p\omega_r \quad (5)$$

The machine model is nonlinear as it contains product terms such as speed with id and iq. Note that ω_r, id and iq are state variables. During vector control, id is normally forced to be zero

$$T_e = 3P\lambda_{af} i_q /2 = K_t i_q \quad (6)$$

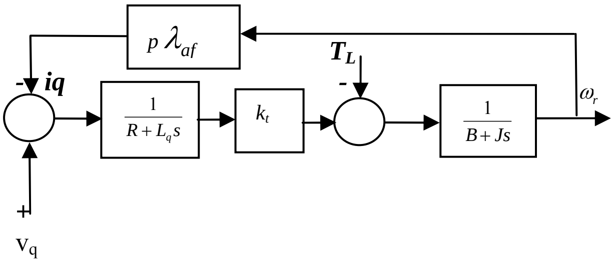


Figure 1. Block diagram of a PMSM

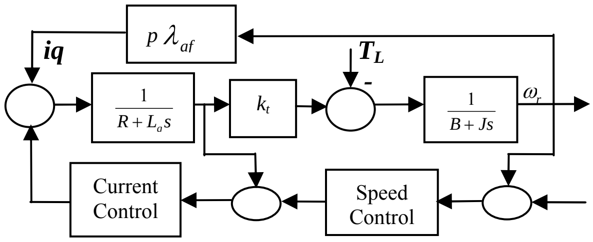


Figure 2. Block diagram of a PMSM Drive

3. SPEED CONTROL OF PMSM

(Figure 3. Block Diagram of Speed Control of PMSM). The PMSM is using control to suppress harmonic noise to a level. Then, noise to a level below and vibration to make the rotation even quieter.

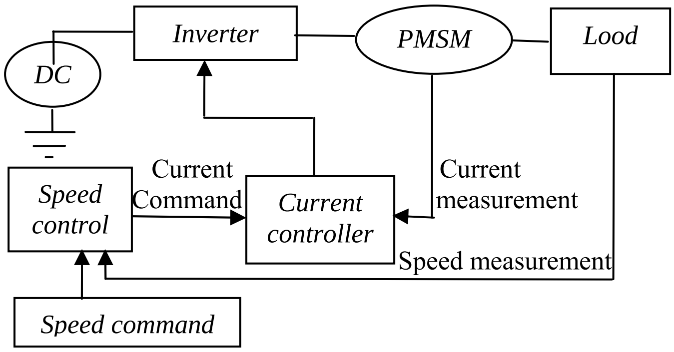


Figure 3. Block Diagram of Speed Control of PMSM

IGBT SPWM inverters make the rotation smoother with precisely adjusting speed control with frequency and voltage regulation. It has the latest low-noise power units to make the rotation even quieter. WGS has directed high-speed used (100 or150 rpm) PMSM. Energy reform in the WGS geared.

3.1. PI Controller Modeling

In the PI speed controller the machine speed is compared with the reference speed and the speed error is the nth sampling interval as

$$\omega e[n] = \omega r^*[n] - \omega r[n] \quad (7)$$

The output of the speed controller gives the reference torque. Hence the output of the speed controller at the nth sampling interval is

$$T[n] = T[n-1] + Kp(\omega e[n] - \omega e[n-1]) + Ki.\omega e[n] \quad (8)$$

For constant air gap flux operation reference quadrature axis current is given as

$$iq^* = T[n]/Kt \quad (9)$$

The limiter is used to limit the maximum value of output of speed controller. The maximum machine rated current and device current of the converter dictate the limit.

Where,

ωe[n] is speed error at nth instant, ωr*[n] is the reference speed at nth instant

ωr[n] is the actual machine speed at nth instant, ωe[n-1] is the speed error at (n-1)th instant

T[n] is the reference torque at nth instant, T[n-1] is the reference torque at (n-1)th instant

Kp is proportional gain of the speed controller

Ki is integral gain of the speed controller is reference quadrature axis current
Kt is torque constant

3.2. Fuzzy Logic Controller

The Basic configuration of a Fuzzy Logic Controller (FLC) consists of the following components:
1) Fuzzification Interface
2) Knowledge Base (KB)
3) Decision Making Logic
4) Defuzzification Interface

A fuzzy controller is a special fuzzy system that can be used as a controller component in a closed loop system. The integration of a fuzzy system into a closed loop is shown. Special emphasis is put onto the transfer behavior of fuzzy controllers, which are analyzed using different configurations of standard membership functions. For a PM machine drive system with a full speed range, the system will consist of a machine, an inverter, controller (constant torque and flux weakening operation, generation of reference currents and PI controller)

3.3. Particle Swarm Optimization

It is a technique used to explore the search space for a given problem to find the settings or parameters required to optimize a particular objective. PSO has two main concepts: the first is through the observation of human decision making, it was proposed that humans use both their own best experience and others' best experience to form a basis of making a decision, to develop the concepts of individual learning and cultural transmission. The second is to propose a simple theory to explain group behavior in nature, and to popularize the theory to create systems to simulate things. The biggest characteristic of PSO is in its simple structure, fast convergence, and its ability to prevent falling into a local optimum solution. At the same time, PSO is a random algorithm with a parallel structure. A uniform distribution is used to randomly create a particle swarm. Each particle represents a feasible solution to the problem, the particle swarm refers to the individual's best experience, and the group's best experience, and logically chooses the method it will move itself. After continuous iterations, the particle swarm will gravitate towards the optimum solution.

4. WIND TURBINE GENERATION SYSTEM (WTGS) & MATHEMATICAL MODELING

4.1. Wind Turbine Generation System (WTGS)

Wind Turbine Generation System (WTGS) is used to convert kinetic energy into electrical energy. As wind case varies, the electrical energy produced from the generator needs to be converted for convenience. An inverter, rectifier, transformer and filter are needed within the Wind Turbine Generation System (WTGS), in order for utility-grade AC power to be transmitted over long distances (Figure 4). A transformer is usually installed at the undermost of the tower to provide voltage diversion from the low voltage by the wind turbine, to medium/high voltage for transit.

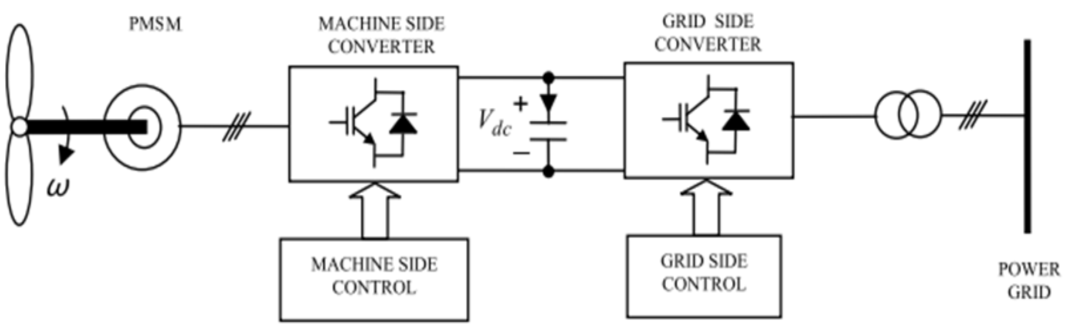


Figure 4. PMSM Wind Energy Conversion System

Most modern Wind Turbine Generation System (WTGS) have intelligent feature to observe and control the system to diverse wind conditions. Like, atmospheric sensors detect wind speed and direction. Other sensors observe the status and strength of the turbine parts to bypass run-to-failure. Wind turbines need to resist extreme weather conditions, such as storms and lightning. In these types of conditions, it is important to ensure that the turbine monitoring system is designed to provide high voltage.

4.2. Mathematical Modeling of Wind Turbines
1st E:Kinetic Energy
m: Total mass
Vw: The velocity of the air particles (Wind Speed)

$$E = \frac{1}{2} m V_{\omega}^{2} \tag{10}$$

2nd The air particles are moving at a speed(Vw)of the particles for a period of time, t, can be rewritten as follows:

$$m = \rho \mathrm{A} V_{\omega} t = \rho \pi r^{2} V_{\omega} t \tag{11}$$

ρ : the air density
A: the swept area of the wind turbine rotor
r: the radius of the wind turbine rotor
3rd the kinetic energy of the air particles can be expressed as follows:

$$E = \frac{1}{2} \rho \pi r^{2} V_{\omega}^{3} t \tag{13}$$

4th the actual wind power at any instant of time can be represented as:

$$P_{wind} = \frac{E}{t} = \frac{1}{2} \rho \pi r^{2} V_{\omega}^{3} \tag{14}$$

where, P_{wind} , is the potentially available power in the wind.
5th The relationship between the power that is captured by the wind turbine and the potential maximum power in the wind can be expressed as follows:

$$C_p = \frac{P_{Turbine}}{P_{wind}} \tag{15}$$

where, $P_{Turbine}$ is the mechanical power captured by the wind turbine, and C_p is the power coefficient of the wind turbine which can be expressed as follows:

$$C_p = c_1 (c_2 \frac{1}{\alpha} - c_3 \beta - c_4 \beta^{X} - c_5) e^{-c_6 \frac{1}{\alpha}} \tag{16}$$

$$\frac{1}{\alpha} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1 + \beta^{3}} \tag{17}$$

$$\frac{1}{\alpha} = \omega_m r / V_{\omega} \tag{18}$$

where, β, is the blade angle and λ is the tip speed ratio of the wind turbine, while, ωm, is the angular speed of the wind turbine generator. The values of the coefficients (c1~c6) depend on the type of the wind turbine.

$$P_{Turbine} = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V_\omega^{\ 3} \tag{19}$$

5. SIMULATION RESULTS

By using Simulation model PMSM & Simulation of WTGS Drive system by using PMSM:

5.1. Simulation model Permanent Magnet Synchronous Machine (PMSM).

Model of the system (Figure 5) is verified through computer simulations using the software package MATLAB/Simulink. Summarizes the performance of the WTGS, both in computer simulation and experimental implementation. The analyzed WGS considers electrical drive (PMSM Drive System).

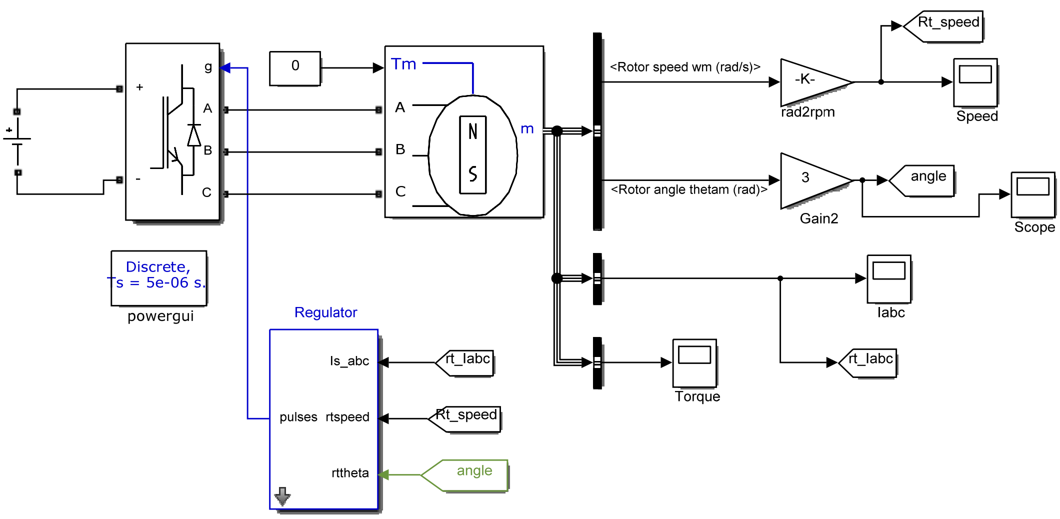


Figure 5. Simulation Model of PMSM

Drive converter is currently regulated SPWM voltage source inverter (CRSPWM VSI) direct current power supply. The controller is used for the task to provide position reference tracking and zero error in steady state. Constant load is usual for WTGS. Thus, controller with proportional and integral action (PI) is used, Block diagram of PI Controller is shown in Figure 6.

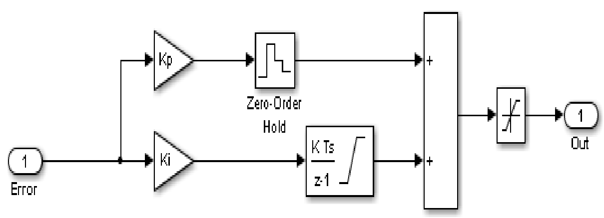


Figure 6. Block diagram of PI Controller

Simulation of the entire system with the designed controller is made in the Matlab/Simulink and given results show that design controller meets the requirements completely smooth and precise position and speed.

To verify the feasibility of control, PMSM drive simulation model with control is created and studied using MATLAB. Simulation parameters: stator resistance Rs = 0.01Ω, inductance Ld = Lq = 0.01835H, flux Ψ = 0.4 V.s, pair of poles p = 3, inertia J = 0.029kg.m2. Simulation conditions: reference speed n = 100,150 rad / s, start with TL = 0N.m. Simulation results are presented in Figure 7-9 speed is shown in Figure 7, Torque is shown in Figure 8, and current is shown in Figure 9. It is obvious that correct responses to speed, current, and torque in a control system. Using PI control and Fuzzy control has a good application for PMSM drive. At the same time, with speed have faster response. Ripple of torque is obviously reduced. So the system performance is improved.

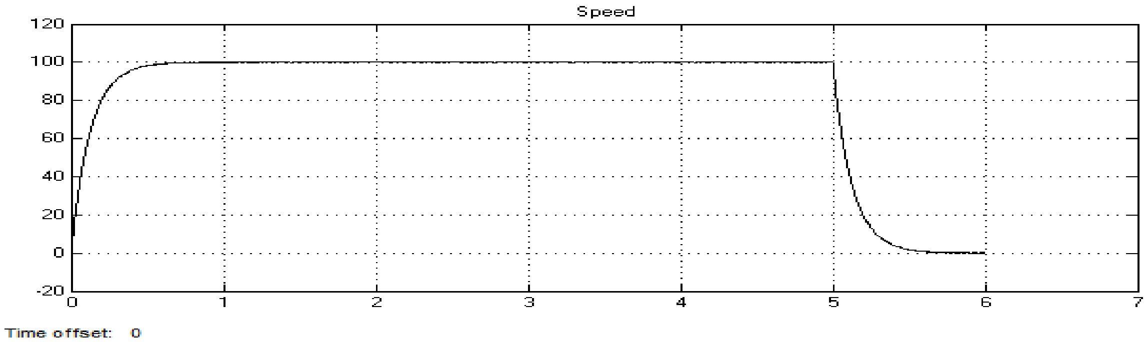


Figure 7. Simulation result response of Speed

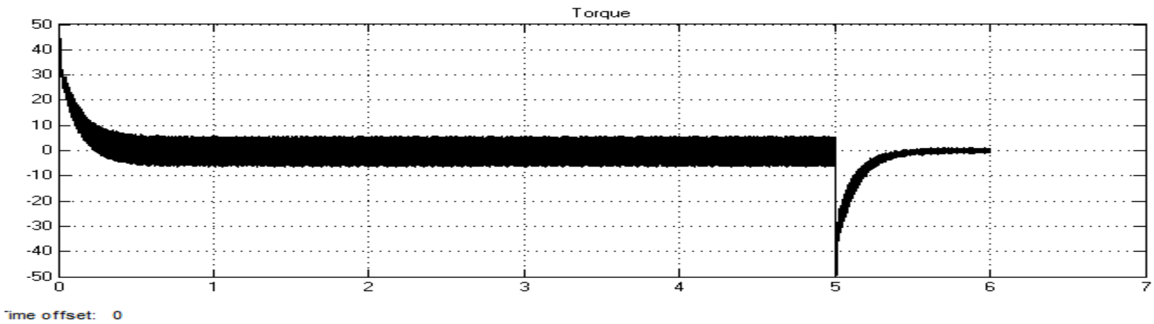


Figure 8. Simulation result response of Torque

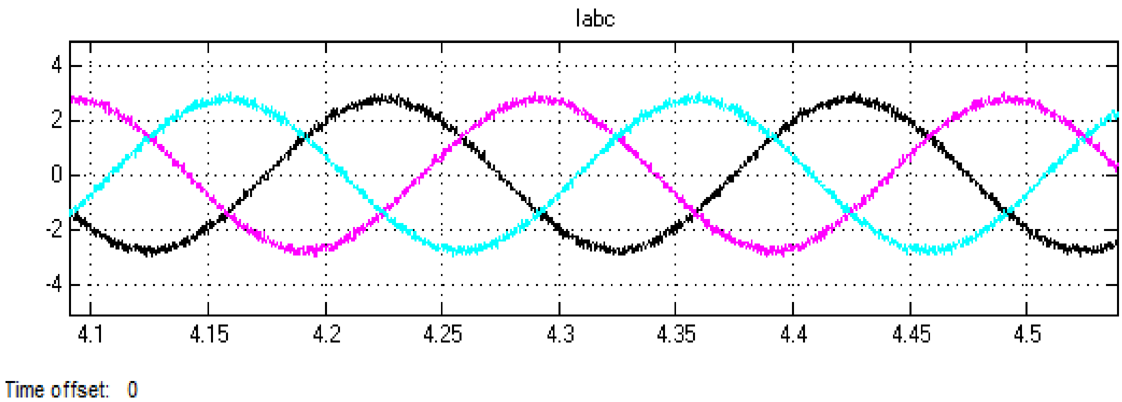


Figure 9. Simulation result response of Current

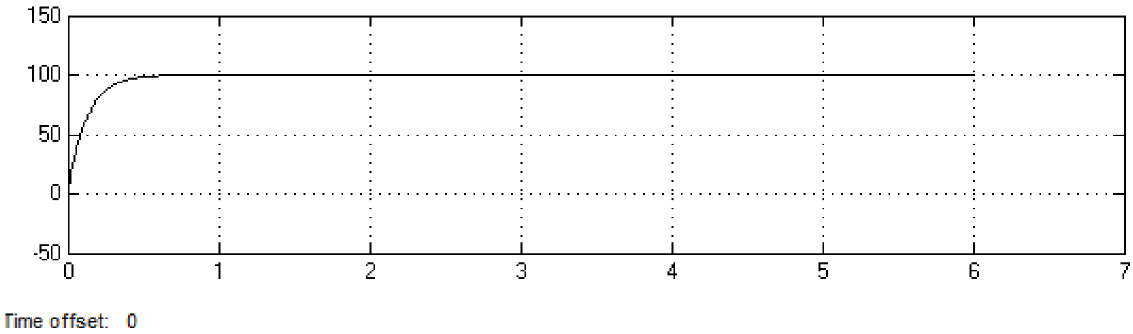
5.2. Simulation of WTGS with PMSM.

To Analysis simulation results, There are some cases to do it as a following analysis WTGS By Using PMSM (Speed, Torque, Current) and (Tm(pu),Wind Speed, Vdc, Grid Voltage and Grad Current).

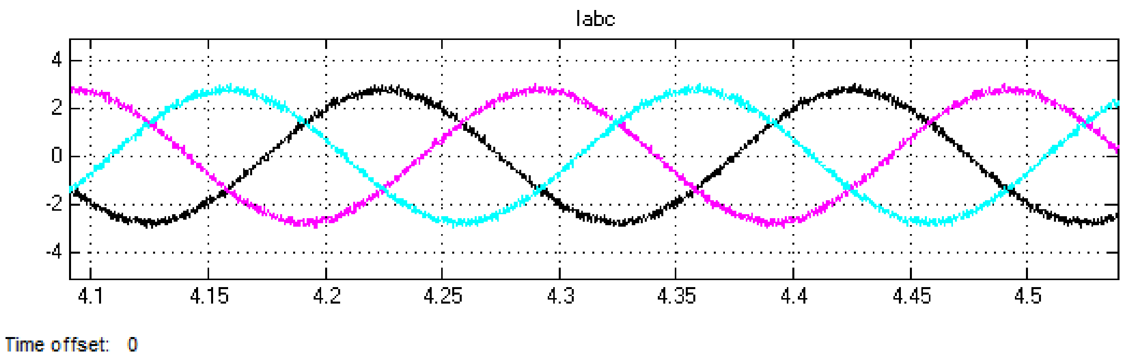
First step, to run the PMSM with different speeds to get a different frequency to select the frequency on the side generation with the rated speed. The simulation result in the table (1), it was clearly to get 5Hz side of generation by using rotation speed 100 rad/sec which using the simulation system of this work. Simulation Model of PMSM is illustrated in figure (5) which using this step.

Table 1. PMSM with different speeds to get different frequency

Rated Speed(rad/sec)	Time(sec)	Frequency(Hz)
50	0.42	2.38
100	0.2	5
200	0.1	10
1000	0.02	50
1500	0.01666	60

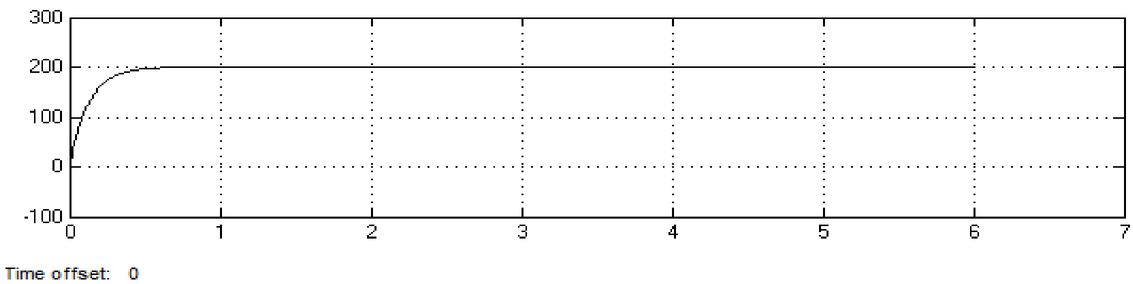


a) Speed

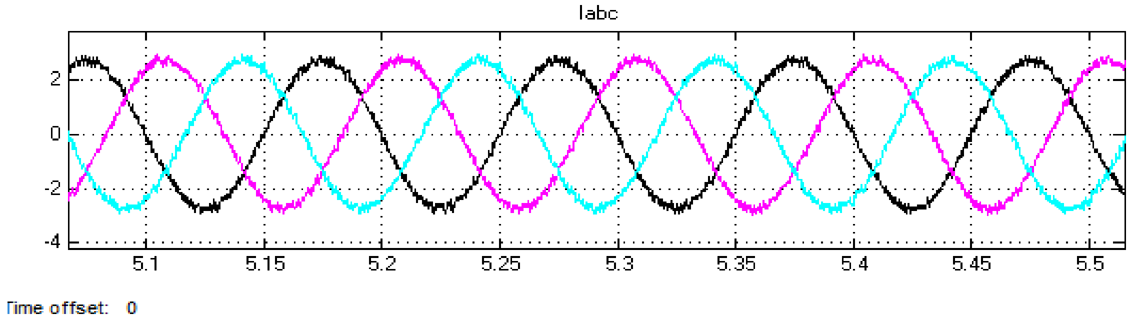


b) Current

Figure 10. Simulation Model of PMSM at Speed=100,5Hz, a) Speed & b) Current



a) Speed



b) Current

Figure 11. Simulation Model of PMSM at Speed=200,10Hz, a) Speed & b) Current

Second step, solve the mathematical equation to use different values of wind speed with selected (15, 20 m/s and less than with more than 15&20m/s).

In this paper, we used two types of variable and constant speed. Constant speed has (15m/s, 20m/s, 15&20m/s), one hour the speed was (15m/s) so one time by using (20m/s) the third time four hours be used (15&20m/s). For one day, we used variable speed with more than (15&20m/s) so less than (15&20m/s).

Used a special type to get variable speed with more than (15&20m/s) so less than (15&20m/s).
We need a mathematical equation by designed to these values.
First, selected some values like (15, 20, 20.42, 20.38, 19.68, 15.42, 15.38, 14.98&14.68).
Second, Amplitude &Frequency:
Amplitude, X0 = 15m/s, X1 = 20m/s, S1 = 0.4m/s, S2 = 0.2m/s, S3 = 0.02 & S4 = 0.002

$$Y1=X0+S1+S2+S3+S4 \quad (20)$$

$$Y2=X1+S1+S2+S3+S4 \quad (21)$$

Frequency, X0 for 12 hours, X1 for 12 hours, S1 at 0.175 hours, S2 at 0.5 hours, S3 at 0.08 hours & S4 at 0.25 hours. Simulation model (wind speed) of this step is shown in figure (12) and the simulation results is shown in figures (13).

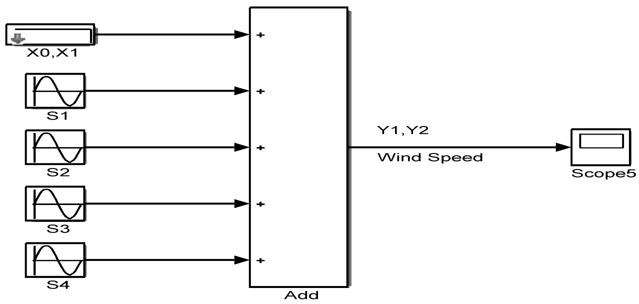


Figure 12. Simulation model of wind speed

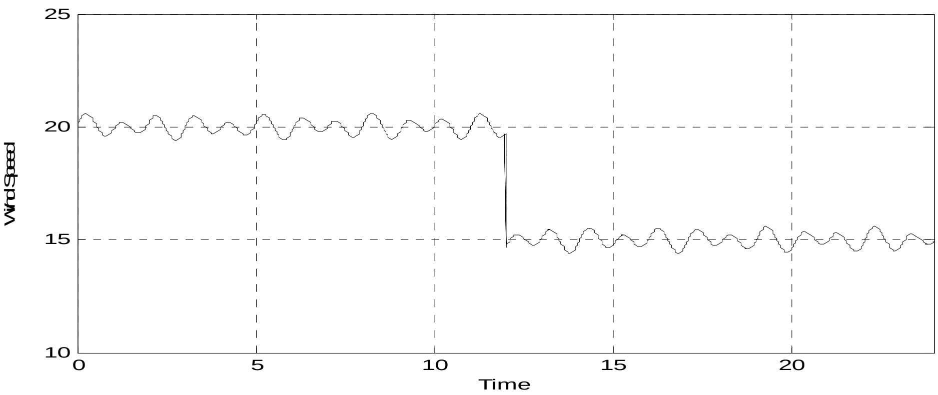


Figure 13. Variable wind speed (15m/s at 12Hours &20m/s at 12Hours)

Third step, Calculation the power generation with wind speed (15 m/5 & 20 m/s).
In this step, by using equation of power generation with have date of wind energy turbine.
By using Parameters and operating conditions

PMSM, 2.0 MW, 690 V, 9.75 Hz,	Rated Mechanical Power 2.0 MW
Rated Apparent Power 2.2419 MVA,	Rated Power Factor 0.8921
Rated Rotor Speed 22.5 r/min,	Number of Pole Pairs 26
Rated Mechanical Torque 848826 Nm,	Rated Rotor Flux Linkage 5.8264 (rms)
Stator Winding Resistance 0.821$m\Omega$,	d axis Synchronous Inductance 1.5731mH
q axis Synchronous Inductance 1.5731mH,	Wind Turbine Rotor Radius 34 m
Wind Turbine Optimal Tip Speed Ratio 6.16,	IGBT Modulation Frequency 1.5 kHz

1st when the wind speed is 15m/s

Speed
$$\omega_e = (\frac{p}{2})\frac{\lambda V_\omega}{r} = \frac{26*6.16*15}{34} = 70.6$$

$$P_{Turbine} = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V_\omega{}^3$$

$$P_{Turbine} = 0.5*1.225*3.14*(34)^2*0.4*(15)^3$$

Power
$$P_{Turbine} = 3001423.95 = 3.00142395*10^6 = 3.00142395\ MW$$

Torque
$$Torque = \frac{Power}{\omega_m} = \frac{Power}{Speed/26} = \frac{3001423.95}{70.6/26} = 1115770$$

Current
$$i_{qs} = \frac{Torque}{(\frac{3}{2})(\frac{p}{2})\lambda_r} = \frac{1115770}{1.5*26*8.2398} = 3472.11$$

2nd when the wind speed is 20m/s

Speed
$$\omega_e = (\frac{p}{2})\frac{\lambda V_\omega}{r} = \frac{26*6.16*20}{34} = 94.211$$

$$P_{Turbine} = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V_\omega{}^3$$

$$P_{Turbine} = 0.5*1.225*3.14*(34)^2*0.4*(20)^3$$

Power
$$P_{Turbine} = 7114486.4 = 7.1144864*10^6 = 7.1144864\ MW$$

Torque
$$Torque = \frac{Power}{\omega_m} = \frac{Power}{Speed/26} = \frac{7114486.4}{94.211/26} = 2831636.3$$

$$i_{qs} = \frac{Torque}{(\frac{3}{2})(\frac{p}{2})\lambda_r} = \frac{2831636.3}{1.5*26*8.2398} = 8811.62$$

Current

Fourth step, using these component system Rectifier, DC bus, Inverter, Filter, Load & Grid with WTG & PMSM. Simulation model (wind speed) of this step as shown in figures (14&15) and the simulation results as shown in figures (16-22).

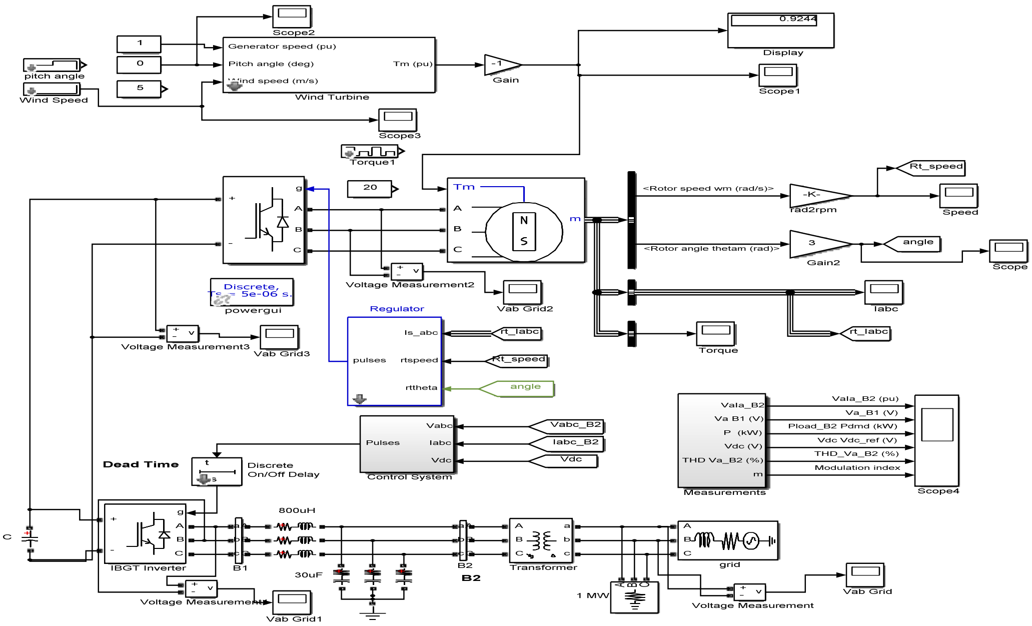


Figure 14. WTG & PMSM. Simulation model with wind speed (15m/s at 2Hours &20m/s at 2Hours)

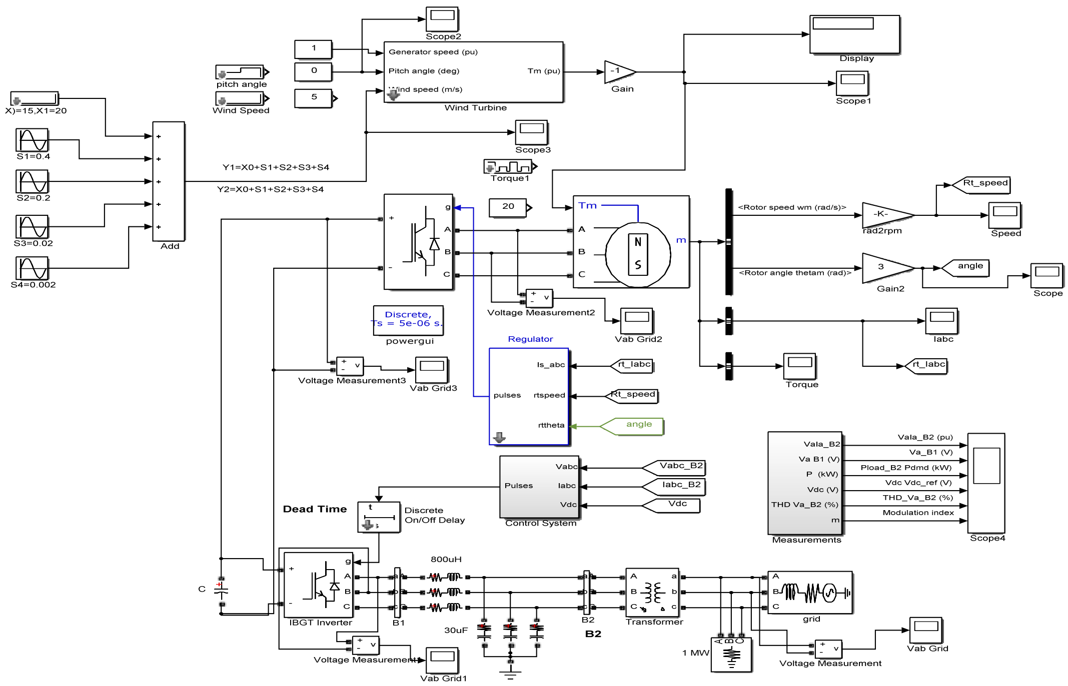


Figure 15. WTG & PMSM. Simulation model with wind speed (15m/s at 12Hours &20m/s at 12Hours)

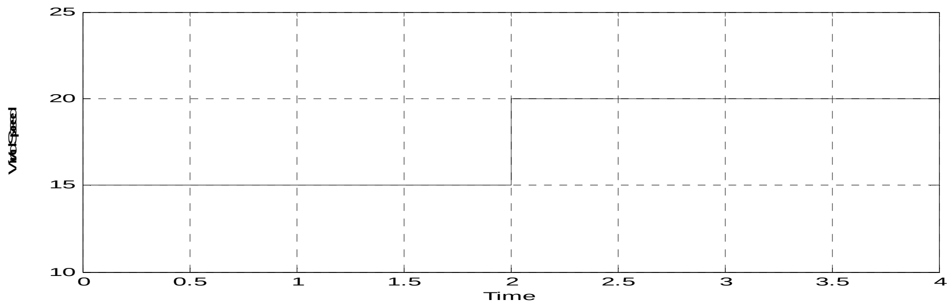


Figure 16. Wind speed (15m/s at 2Hours &20m/s at 2Hours)

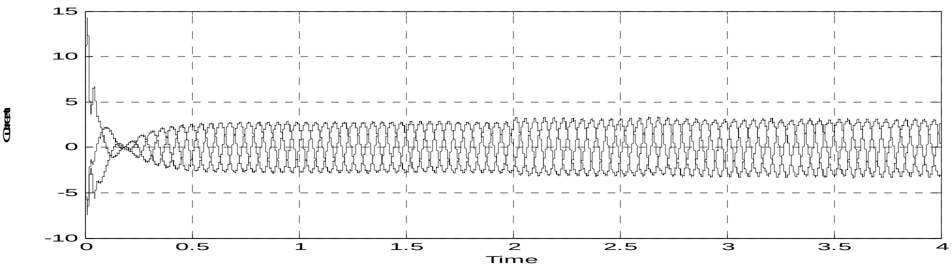


Figure 17. Current (Iabc) (15m/s at 2Hours &20m/s at 2Hours)

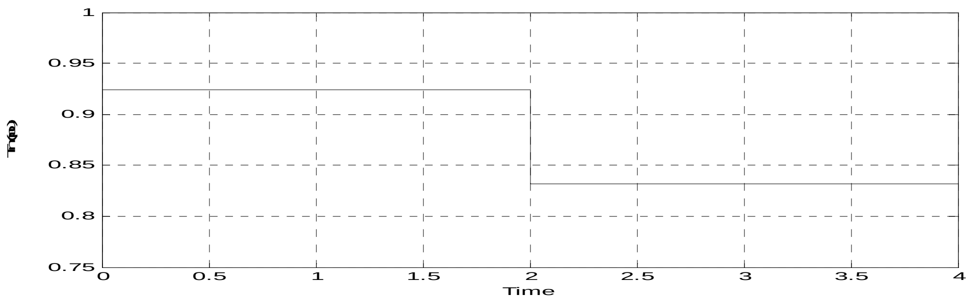


Figure 18. Tm (pu) with wind speed (15m/s at 2Hours &20m/s at 2Hours)

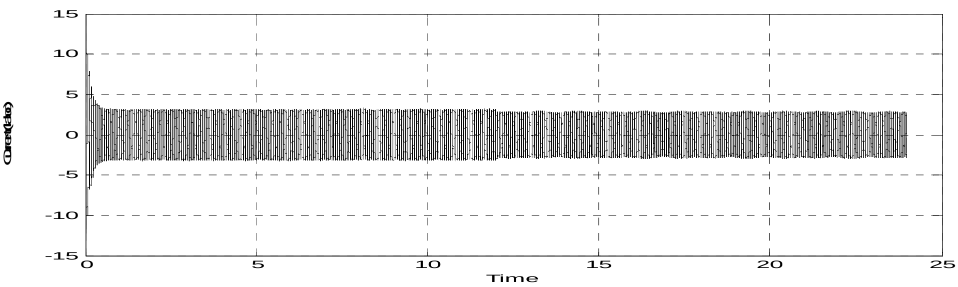


Figure 19. Current (Iabc) with wind speed (15m/s at 12Hours &20m/s at 12Hours)

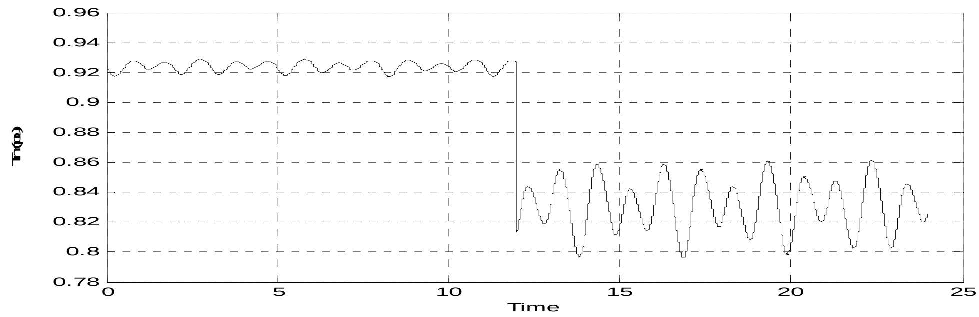


Figure 20. Tm (pu) with wind speed (15m/s at 12Hours &20m/s at 12Hours)

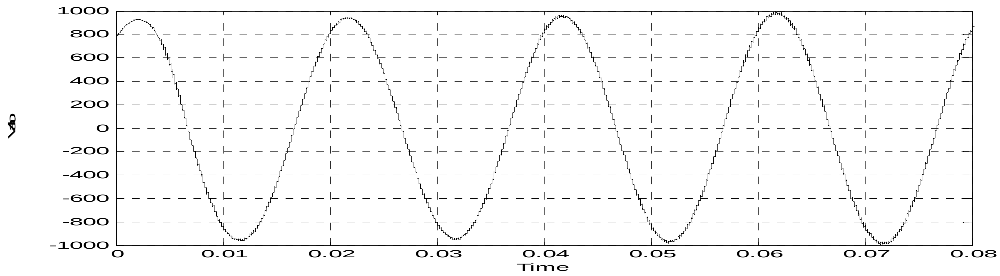


Figure 21. Simulation response of Voltage o/p filter (Vab)

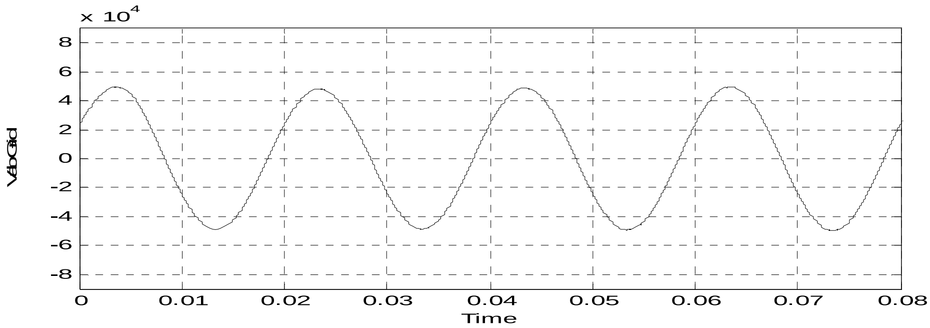


Figure 22. Simulation response of Voltage Grid (Vab)

Final step, use different control systems, Like Classical PI Controller, Expert System Fuzzy Logic Controller and Optimization PSO Controller With PMSM to analysis all result.Simulation models (Classical PI Controller, Expert System Fuzzy Logic Controller and Optimization PSO Controller With PMSM) of this step as shown in figures (23-25) &The transfer function of the PMSM can be obtained from its state model by using the following formula:

$$T(S) = C\,[SI-A]\,B + D \quad (22)$$

And the transfer function of the PMSM considered is [14]:

$$T.F = \frac{s^2 + 14.34s + 5.88}{s^3 + 14.76s^2 + 11.95s + 2.49} \quad (23)$$

The the simulation model for transfer function of the PMSM as shown in figures (26-28) and simulation results as shown in figures (29-34).

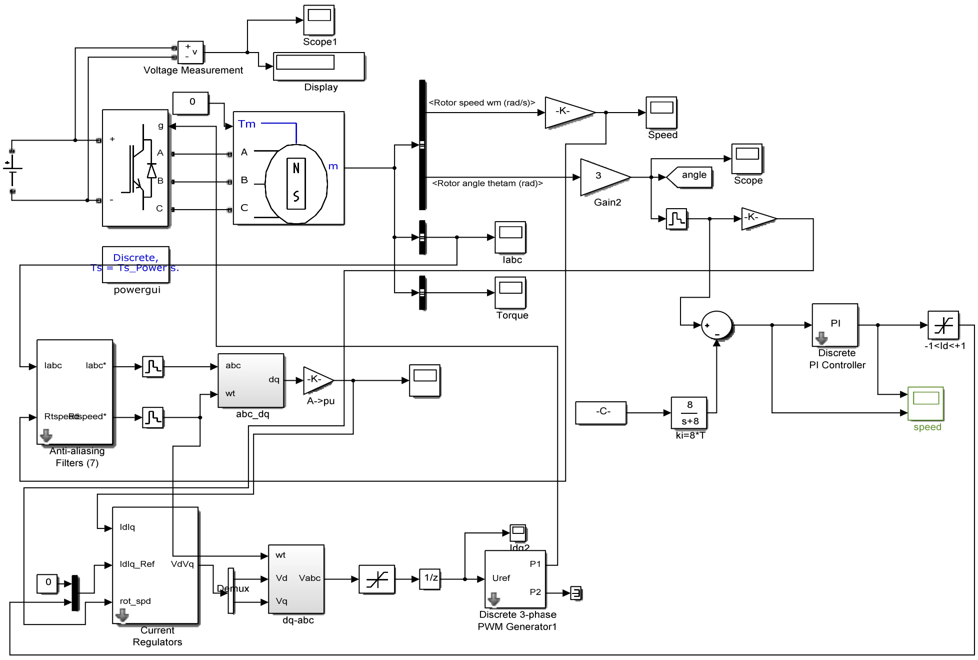


Figure 23. Simulation model with PI Controller

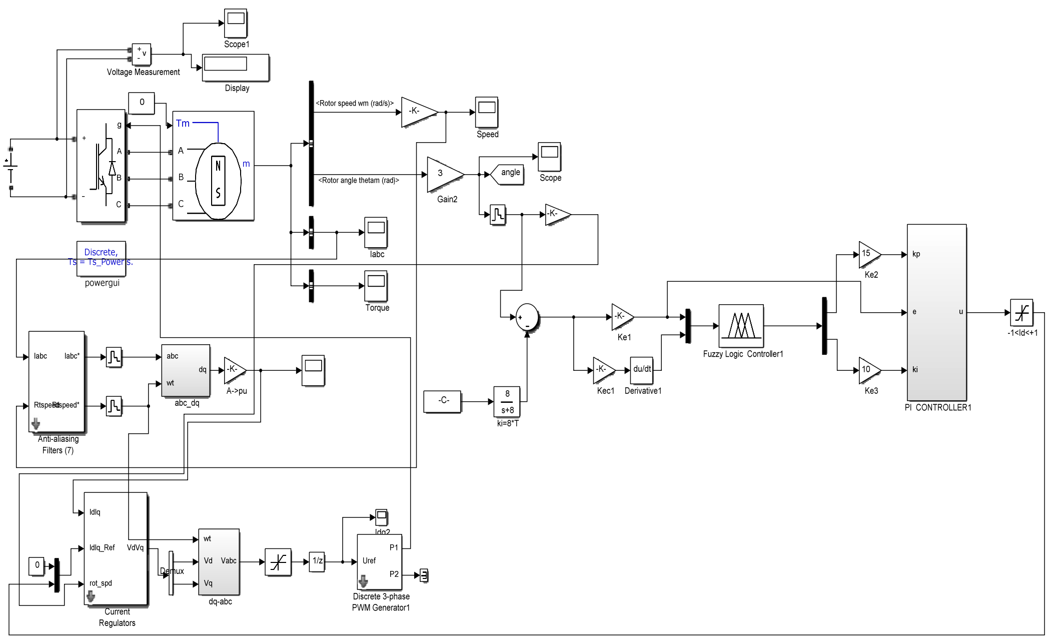


Figure 24. Simulation model with Fuzzy_PI Controller

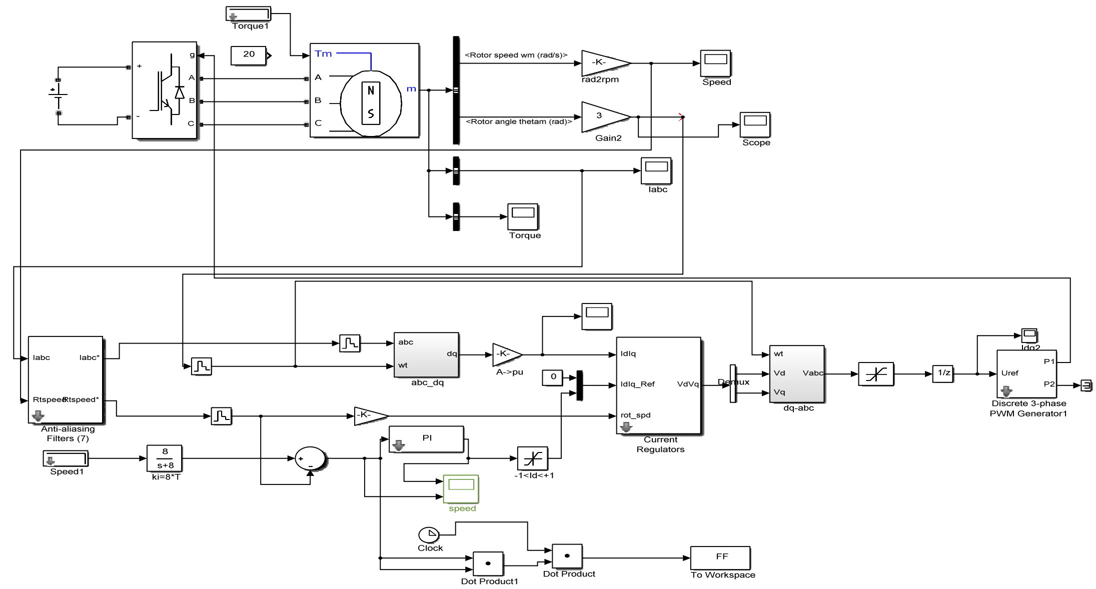


Figure 25. Simulation model with PSO_PI Controller

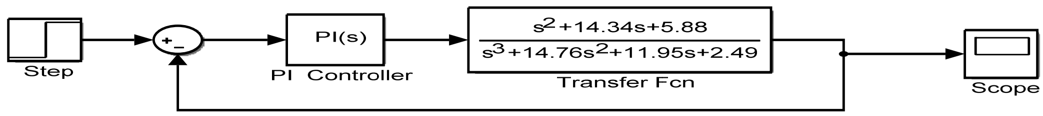


Figure 26. Simulation model for transfer function of the PMSM with PI control

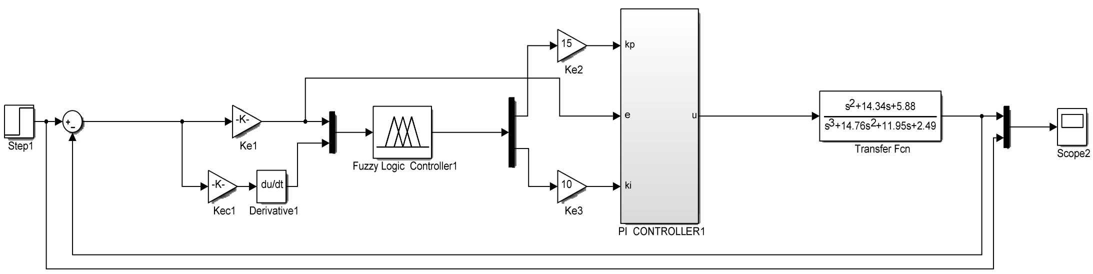


Figure 27. Simulation model for transfer function of the PMSM with Fuzzy_PI control

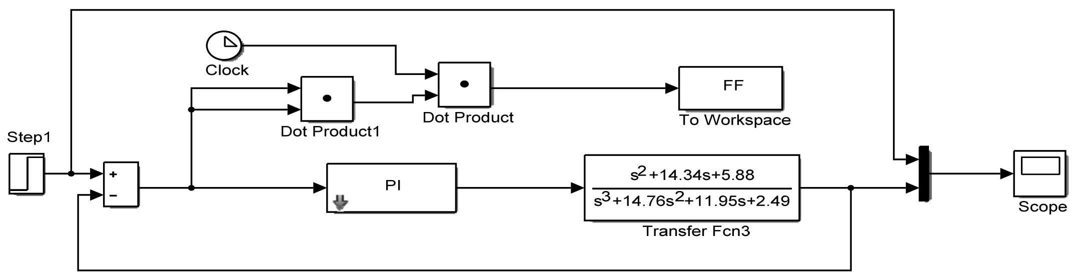
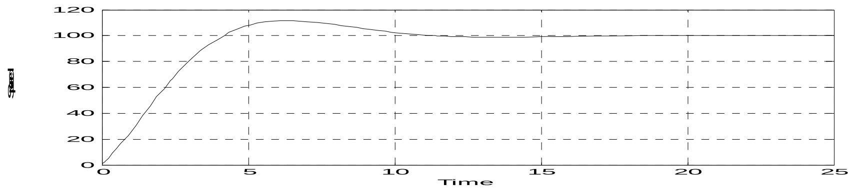
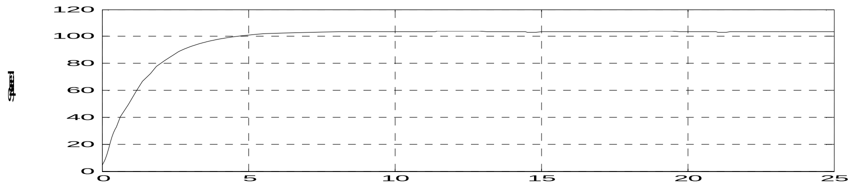


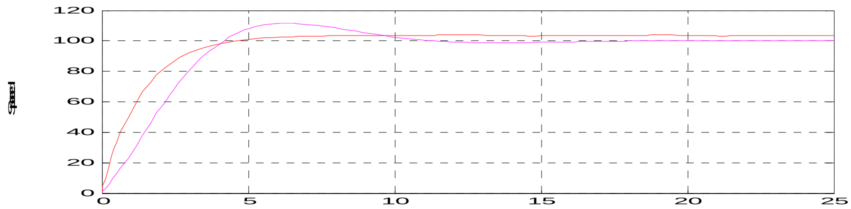
Figure 28. Simulation model for transfer function of the PMSM with PSO_PI control



a) PI Control

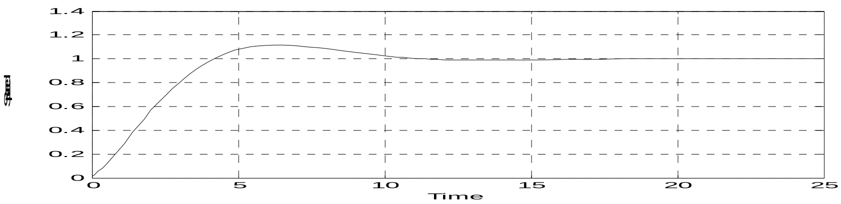


b) Fuzzy_PI Control

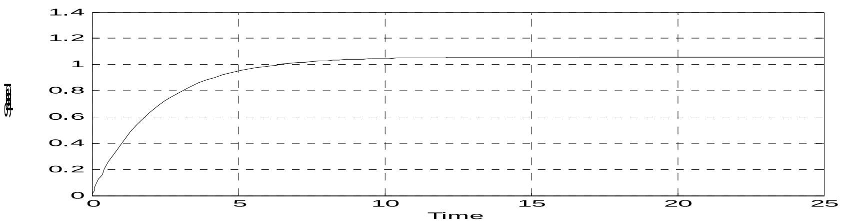


c) PI Control & Fuzzy_PI Control

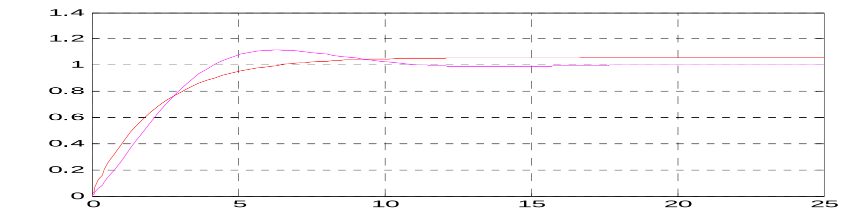
Figure 29. Simulation Response of a) PI Control, b) Fuzzy_PI Control, c) PI Control & Fuzzy_PI Control



a) PI Control

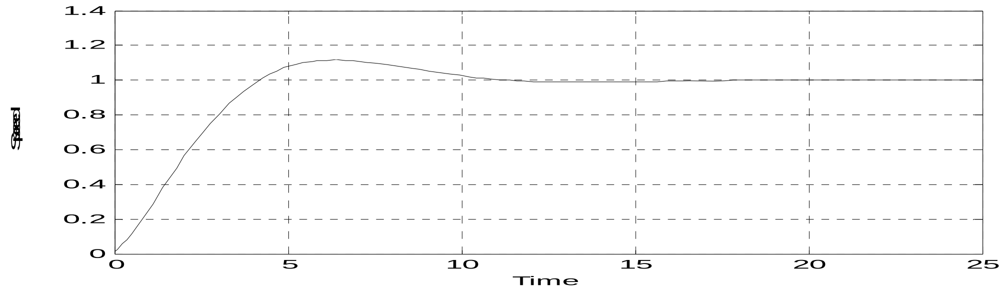


b) Fuzzy_PI Control

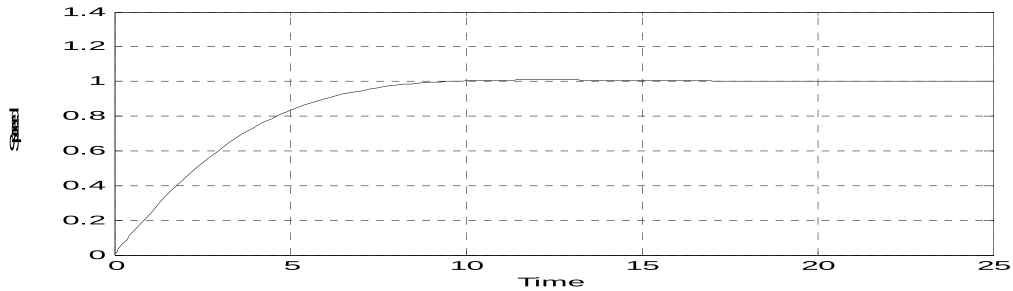


c) PI Control & Fuzzy_PI Control

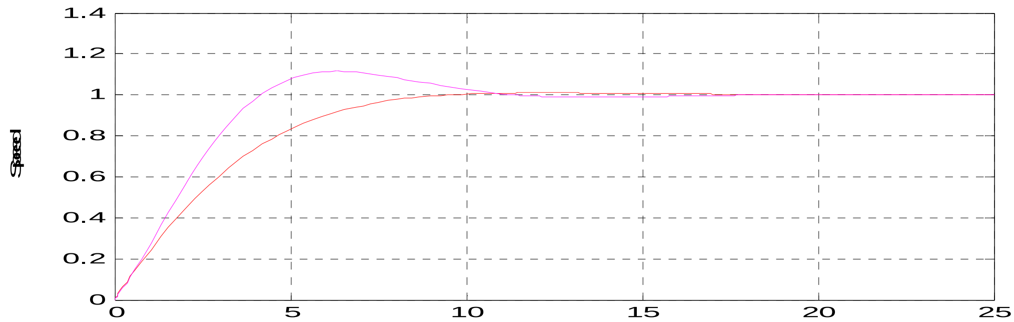
Figure 30. Simulation Response (pu) of a) PI Control, b) Fuzzy_PI Control, c) PI Control & Fuzzy_PI Control



a) PI Control

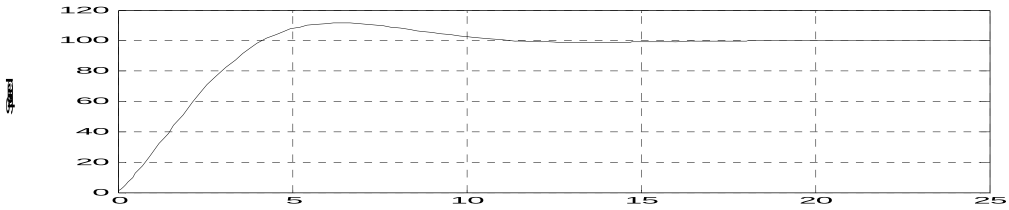


b) PSO _PI Control

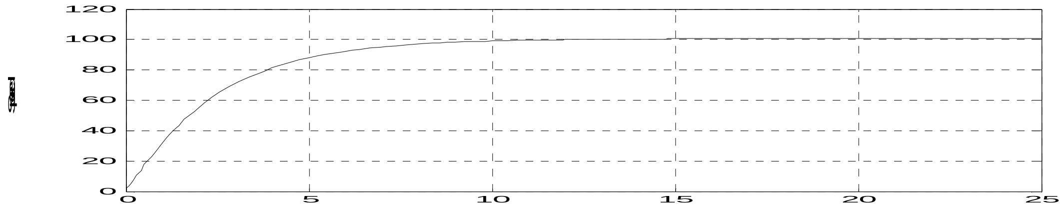


c) PI Control & PSO_PI Control

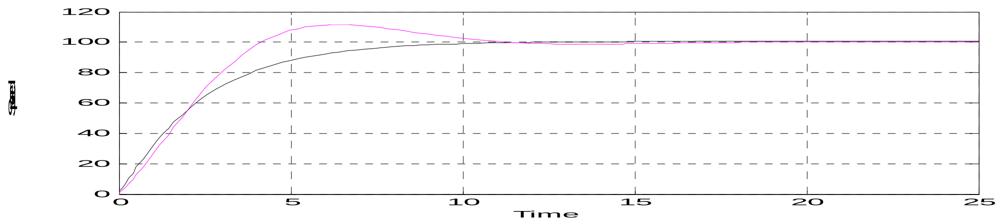
Figure 31. Simulation Response (pu) of a) PI Control, b) PSO _PI Control, c) PI Control & PSO_PI Control



a) PI Control



b) PSO _PI Control



c) PI Control & PSO_PI Control

Figure 32. Simulation Response of a) PI Control, b) PSO _PI Control, c) PI Control & PSO_PI Control

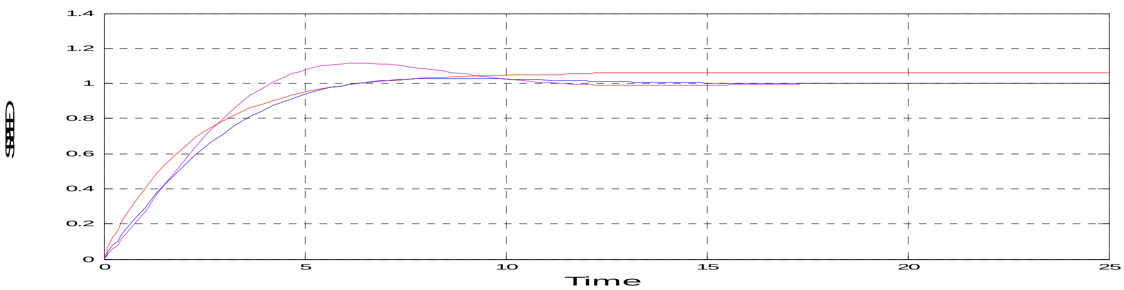


Figure 33. Simulation Response (pu) of PI Control, Fuzzy_PI Control & PSO_PI Control

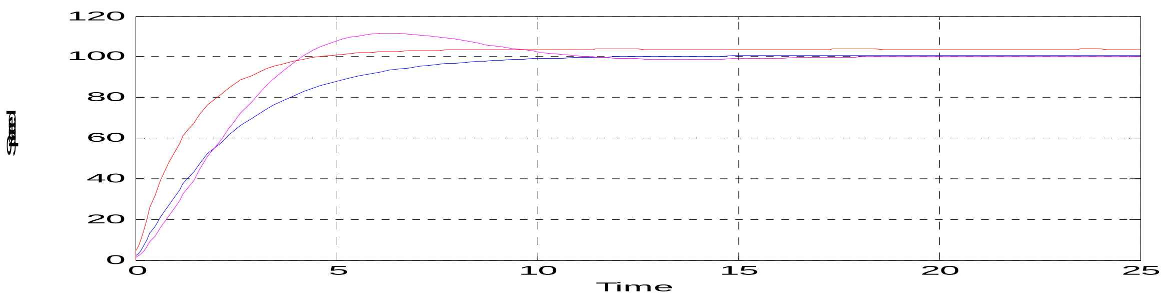


Figure 34. Simulation Response of PI Control, Fuzzy_PI Control & PSO_PI Control

6. CONCLUSION

This paper will cover the simulation, and implementation of a PMSM controlled by a control system WGS system, the implementation of a WTGS by the electric system through the addition of control systems and switching power supplies. Simulation of WGS with PMSM is used for this paper. There are some tasks to achieve a WGS, determining the parameters of PMSM, designing a control system, and verifying the performance of the system through use of computer simulations and experimental testing. Implementation of a WGS with a PMSM is successful and provides an illustrative example to those who wish to apply electric drives to various electrical systems.

Wind energy is seen nowadays as one of the most promising energy sources. Variable speed wind turbine generators, a new topology of wind turbine generation system (WTGS) based on a permanent magnet synchronous machine (PMSM) with full rated converter have become more popular due to the decreasing price of the power electronics. Better behavior under grid, disturbances as the machine is isolated from the grid by the converter and the full power rated converter allows to easily implement new behaviors to provide grid. Control of the grid connection inverter and the generator rectifier and increases the robustness in case of communication failure between the control systems of both sides of the back-to-back converter allowing to place both sides in different locations far from each other.

Also, even though here a PMSM wind turbine with full power converter will be considered, the same procedure can be easily extended to other topology of wind generators connected to the grid through full power converters.

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