International Journal of Electronics and Electrical Engineering

Volume 3 | Issue 3 Article 2

January 2015

CONTROL OF SYNCHRONOUS GENERATOR BASED WIND ENERGY CONVERSION SYSTEMS

A.V. SASI REKHA
Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India, abburi.sasirekha@gmail.com

G. KAVYA
Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India, kavya.gunda13@gmail.com

J. SINDHU
Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India, sindhujagarla@gmail.com

J. VANI
Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India, vanijampala89@gmail.com

DR. S. SHIVA PRASAD
Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India, sshivaprasadeee@gmail.com

Recommended Citation
REKHA, A.V. SASI; KAVYA, G.; SINDHU, J.; VANI, J.; and PRASAD, DR. S. SHIVA (2015) "CONTROL OF SYNCHRONOUS GENERATOR BASED WIND ENERGY CONVERSION SYSTEMS," *International Journal of Electronics and Electical Engineering*: Vol. 3 : Iss. 3 , Article 2.
DOI: 10.47893/IJEEE.2015.1146
Available at: https://www.interscience.in/ijeee/vol3/iss3/2

CONTROL OF SYNCHRONOUS GENERATOR BASED WIND ENERGY CONVERSION SYSTEMS

A.V.SASI REKHA[1], G.KAVYA[2], J.SINDHU[3], J.VANI[4], DR. S.SHIVA PRASAD[5]

[1,2,3,4]Department of Electrical and Electronics Engineering, J B Institute of engineering and Technology, (Autonomous), Hyderabad, India

[5]Professor & HOD i/c, Department of Electrical and Electronics Engineering (Autonomous), J B Institute of engineering and Technology, Hyderabad, India

E-mail: abburi.sasirekha@gmail.com, Kavya.gunda13@gmail.com, sindhujagarla@gmail.com@gmail.com, Vanijampala89@gmail.com, sshivaprasadeee@gmail.com

Abstract- The natural resources which can be renewed are Renewable energy resources. Due to the increased load demand in recent years demand for renewable energy resources have been increasing and attracting us. If this can be met using the renewable energy resources then it can be harmless to the environment. We opt Wind energy because of its enormous advantages, wind energy has emerged as the most reliable source of electric power, and is economically viable with the conventional sources. Wind energy is one of the most available forms of renewable energy. Loads can be classified based on their distance from the main grid. These can be remote villages, islands, ships, forests, deserts etc. For such loads there should be precise electrification system called as standalone generator system which provides constant nominal voltage and frequency. The Wind Energy Conversion system unit features a wind-turbine-driven Synchronous Generator, a diode bridge rectifier, a boost dc/dc converter, a battery bank, and a PWM dc/ac inverter. In this paper, distribution Generation is based on WECS using Synchronous Generator anticipated with a battery and Rectifier. The topology for the same has been demonstrated using MATLAB Simulink based simulations.

Keywords*-Battery bank, DC/DC Convertor, Synchronous Generator and Wind Energy Conversion System*

I. INTRODUCTION

Distributed generation (DG) system [5] has emerged due to the de-regulation in the electric markets. These units comprise both renewable and non-renewable sources. As there is an increase in the awareness for environmental preservation and the drive to reduce greenhouse gas emissions, there has been a significant shift towards renewable energy sources [4], leading most people to associate the acronym DG with such. Among those, wind energy, being clean, reliable and commercially competitive, has been one of the most popular choices. There are many wind energy conversions systems (WECS) in use and many new systems are being planned. According to the Global Wind Energy Council (GWEC), the total capacity of wind power operating in the world reached 194.4 GW in 2010, an increase of 22.5 % from 159.2 GW in 2009. In Canada alone, the installed capacity is 4009 MW in 2010, an increase of 17% from 2009. In coming years With many government incentives across most of its provinces, it is expected that wind power installation will experience steady growth.

As Wind power cannot be predicted like the other resources it has a different conversion system. The main reasons for the contrast nature of the conversion system are
(1)the construction of WECS, which most commonly use power electronics-based converters, resulting in the application of different topologies,
(2) the unpredictable nature of wind power, which is alternating and undecided, and
(3) the change from a passive distribution network into an active one with multiple energy sources and bidirectional power flow.

Due to these factors with wind power, it interacts differently with the power system network. The challenging part of this is the dependency of the injected power on the wind speed. Therefore ,fluctuations in wind velocity can affect branch power flows, bus voltages, reactive power injections, system balancing, frequency control, power system dynamics and stability. In addition, it can also affect the power quality by introducing harmonics and flicker, due to the Switching actions of the power electronics converters and can also affect protection systems due to the increase in fault levels.

As above mentioned, different grid codes have been developed for wind power integration so as to fulfill technical requirements such as frequency and voltage control, active and reactive power management and fast response during transient and dynamic situations. Different topologies for the conversion system have been developed keeping in view the technical and economical reasons. Variable-speed WECS are the preferred option due to superior power extraction, controllable output power, quick response under transient and dynamic situations, reduced mechanical stress and acoustical noise .Variable-speed WECS can be applied to Doubly-Fed Induction Generators (DFIGs or

Type-3 generators) or synchronous generators and full-scale converters (also referred to as Type-4 generators). While DFIGs have gained popularity in recent years, Type-4 generators have been gradually capturing the market.

So it is necessary to reunite each topology for the WECS to get better benefits. The interaction of wind turbines with electrical power systems is becoming more significant. With the rapid increase in the number of WECS in power system, the effects of wind power on the grid [3] need to be fully understood and properly investigated.

As the size of WECS is becoming larger and the penetration of wind power in power system is increasing, the inherent problems of fixed-speed WECS become more and more pronounced, especially in areas with relatively weak supply grid [1]. To overcome these problems and to comply with the grid-code connection requirements, the trend in modern WECS technology is to apply variable-speed concepts. With the developments in power electronics converters, which are used to connect wind turbines to the grid, variable speed wind energy systems are becoming common. The main advantages of variable-speed WECS are increased power capture, improved system efficiency, improved power quality with less flicker, reduced mechanical stress, reduced fatigue, and reduced acoustic noise. Additionally, the presence of power converters in wind turbines also provides high potential control capabilities for both large modern wind turbines and wind farms to fulfil the high technical demands imposed by the grid operators. The main features of variable-speed WECS are controllable active and reactive power (frequency and voltage control) [2], quick response under transient and dynamic power system situations, influence on network stability and improved power quality. Their disadvantages include losses in power electronic elements and increased cost.

Variable-speed WECS are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds. It is possible to continuously adapt (increase or decrease) the Rotational speed of WECS according to the wind speed. As the wind turbine operates at variable rotational speed, the electrical frequency of the generator varies and must therefore be decoupled from the frequency of the grid. This is achieved by using a power electronic converter system, between induction or synchronous generator and the grid. The power converter decouples the network electrical frequency from the rotor mechanical frequency enabling variable speed operation of the wind turbine. Variable-speed operation can be achieved by using any suitable combination of generator (synchronous or asynchronous) and power electronics interface, as it will be explained in the following subsections.

There are three main configurations of variable-speed converters. They are the limited variable-speed, the variable-speed with partial-scale frequency converter, and the variable-speed with full-scale frequency converter. These configurations can use any of the power-control mechanisms, namely stall, pitch or active stall control. As mentioned earlier, the pitch control mechanism is the most widely used.

Limited Variable-Speed (The Type-2WECS)

This concept uses a wound rotor induction generator (WRIG), which is directly connected to the grid. A capacitor bank is used for reactive power compensation and a soft- starter is employed for smoother grid connection. A unique feature of this concept is that it has a variable rotor resistance, which can be changed to control the slip. This way power output in the system is controlled, typical speed range being 0-10% above synchronous speed.

Variable-Speed With Partial Scale Frequency Converter (The DFIG or Type-3 WECS)

This configuration, known as Doubly-Fed Induction Generator (DFIG), corresponds to the limited variable speed WECS with WRIG and a partial scale frequency converter (usually rated at approximately 30% of nominal generator power) on the rotor circuit. It uses a WRIG with slip rings to take current into or out of the rotor winding and variable speed operation is obtained by injecting a controllable voltage into the rotor at slip frequency. The rotor winding is fed through a variable frequency power converter, typically based on two AC/DC IGBT-based voltage source converters (VSCs) linked by a DC bus. A DFIG system delivers power to the grid through the stator whereas the rotor can either inject or absorb power, depending on the rotational speed of the generator. If the generator operates above synchronous speed, power will be delivered from the rotor through the converter to the network, and if the generator operates below synchronous speed, the rotor will absorb power from the network through the converters. The partial-scale frequency converter compensates for reactive power and provides a smoother grid connection. It has a relatively wide range [5] of dynamic speed control, typically 30% around the synchronous speed. Its main drawbacks are the use of slip rings and high short-circuit currents in the case of grid faults (as compared to the Type-4 WG- presented in the next subsection). Thus in this system, it is possible to control both active and reactive power, providing high grid performance. In addition, the power electronics converter enables the wind turbine to act as a more dynamic power source to the grid [3].

Variable-Speed With Full-Scale Frequency Converter (The Type-4 WECS)

This configuration corresponds to the full variable speed wind turbine [6], with the generator connected to the grid through a full-scale frequency converter [7-9]. The frequency converter compensates for reactive power compensation and provides a smoother grid connection. The generator is decoupled from the grid by a DC link. The power converter enables the system to control active and reactive power very fast. The generator can be electrically excited (WRIG or WRSG) or by a permanent magnet (PMSG). The gearbox may not be required in some configurations using a direct driven multiple generator [6]. The synchronous generators and full-scale converters configuration is also referred to as Type-4 generators.

While DFIGs have gained popularity in recent years, Type-4 generators have been gradually capturing the market. As compared to the DFIGs, Type-4 WECSs have a wider range for the controlled speed, are more efficient, less complicated, and easier to construct from an electrical engineering perspective. In addition, the Type-4 WECS can be made direct- driven system without using a gear box, resulting in reduced noise, installation and maintenance costs. SG can also be connected to diode rectifier or VSC. A major cost benefit is in using a diode bridge rectifier. The synchronous generators can be electrically excited or excited by permanent magnets. The Permanent Magnet Synchronous Generators (PMSG) do not require external excitation current, meaning less losses, improved efficiency and more compact size. Further detailing of this topology is presented in the next section.

II. PERMANENT MAGNET GENERATOR

Magnetization can be normally done electrically or by using permanent magnets. The same can be used to magnetize the generator. The types of synchronous generators have often been used in the wind turbine industry are: (1) the wound rotor synchronous generator (WRSG) and (2) the permanent magnet synchronous generator (PMSG). The synchronous generator with a suitable number of poles can be used for direct-drive applications without any gearbox. PMSGs do not require external excitation current, meaning fewer losses, improved efficiency and more compact size.

The major difference between PMG and the induction motor is that, the magnetization is provided by a Permanent Magnet Pole System on the rotor, instead of taking excitation current from the armature winding terminals, as it is the case with the Induction Generator.

This means that the mode of operation is synchronous and not asynchronous. That is to say, in the PMG, the output frequency bears a fixed relationship to the shaft speed, whereas in the mains connected IG, the frequency is closely related to the network frequency, being related by the slip. These differences will be discussed at length. However, it must be recognized at the outset that the differences have a significant effect on the operating characteristics and performance of the two generator types.

Permanent magnet machines [5] can be put into several categories, those with surface mounted magnets, those with buried magnets, those with damper windings, etc. All these machines are unique and have special features to offer.PM motors are broadly classified by the direction of the field flux. The first field flux classification is radial field motor meaning that the flux is along the radius of the motor. The second is axial field motor meaning that the flux is perpendicular to the radius of the motor.

The advantages of PM machines over electrically excited machines can be summarized as follows according to literatures:

- Higher efficiency and energy yield,
- No additional power supply for the magnet field excitation,
- Improvement in the thermal characteristics of the PM machine due to the absence of the field losses,
- Higher reliability due to the absence of mechanical components such as slip rings, lighter and therefore higher power to weight Ratio.

However, PM machines have some disadvantages, which can be summarized as follows:

- High cost of PM material,
- Difficulties to handle in manufacture,
- Demagnetization of PM at high temperature.

In recent years the use of PMs is more attractive than before because the performance of PMs is improving and the cost of PM is decreasing. The trends make PM machines with a full-scale power converter more attractive for direct-drive wind turbines. Considering these factors these systems are more suitable for the off shore wind powers On the other hand, variable speed concepts with a full-scale power converter and a single- or multiple-stage gearbox drive train may be interesting solutions not only in respect to the annual energy yield per cost but also in respect to the total weight. For example, the market interest of PMSG system with a multiple-stage gearbox or a single-stage gearbox is increasing.

III. TOPOLOGIES FOR ISOLATED OPERATION OF VARIABLE SPEED WIND DRIVEN PMSG

The complete model of the three-phase Type-4 WECS incorporates six sub-models: (1) a Wind Turbine, (2) a Permanent Magnet Synchronous Generator, (3) a three-phase diode-bridge rectifier, (4) a Boost Converter, (5) a Voltage Source Inverter, and (6) the control mode action.

The steady-state analysis of power systems uses only the models at fundamental frequencies. These models represent AC fundamental frequency and DC average values of voltages and currents .The balance of power including the converter losses are also considered in the approach to develop models and equivalent circuit. The conduction losses in the converters depend on the on-state voltage, on-state resistance and current through it .With the constant DC voltage, the converter losses can be represented by a constant value. This is done by the drop across an equivalent series resistor which also includes the resistance of inductors .Hence the equivalent circuit can be designed keeping in view the above requirements with a voltage source in series with impedance can be used for inclusion in the power flow. At variable speed, the DC link voltage is maintained constant by exchanging power with battery as shown in Fig. 1

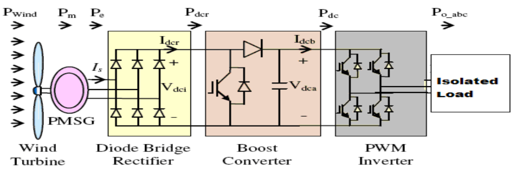

Fig.1 PMSG with PWM rectifier with battery for storing the extra wind energy

IV. MATLAB SIMULATION OF THE PROPOSED TOPOLOGY

The mat lab Simulink tool box Simpower has been used for getting the required results [8]. The working principle of this generator is as follows. The wind turbine axis is directly coupled to the generator rotor. Since the wind power fluctuates with the wind velocity, the PMSG output voltage and frequency vary continuously. The varying AC voltage is rectified into DC by the diode bridge rectifier. The rectified DC voltage is boosted by the DC/DC boost converter by controlling its duty ratio to obtain a regulated voltage across the capacitor. This DC voltage is inverted to obtain the desired AC voltage and frequency by using the PWM VSI.

V. MODELING OF PROPOSED SYSTEM

A. Modeling of System

This section includes modeling of supply system (PMSG), load, controller etc. The relevant mathematical analysis is illustrated as follows.

B. Modeling of Supply system

The supply system consists of three-phase (PMSG) system, diesel engine and governor blocks. The model of permanent magnet synchronous generator (PMSG) is realized considering fixed excitation of an alternator. The mathematical representation of all these are given below.

C. Modeling of Permanent Magnet Synchronous Machine

The permanent magnet synchronous machine block operates in generating or motoring modes. The operating mode is dictated by the sign of the mechanical power (positive for generating, negative for motoring). The electrical part of the machine is represented by a sixth-order state-space model. The model takes into account the dynamics of the stator and damper windings. The equivalent frame (d-q frame). The following equations are used to express the model of the PMSG as:

$V_d = R_s i_d + p\Phi_d - w_r \Phi_q$ ……… (1)

$V_q = R_s i_q + p\Phi_q + w_r \Phi_d$………… (2)

$V'_{fd} = R'_{fd} i'_{fd} + p\Phi'_{fd}$……………. (3)

$V'_{kd} = R'_{kd} i'_{kd} + p\Phi'_{k}$…………… (4)

$V'_{kq1} = R'_{kq1} i'_{kq1} + p\Phi'_{kq1}$……. (5)

$V'_{kq2} = R'_{kq2} i'_{kq2} + p\Phi'_{kq2}$……. (6)

Where the subscripts used are defined as: d, q: d and q axis quantity, r, s: Rotor and stator quantity, l, m: Leakage and magnetizing inductance, f, k: Field and damper winding quantity. R_s represents stator resistance, Damper d-axis resistance Rkd’, Damper q-axis resistance $R_{kq}1$’ and the q-axis resistance $R_{kq}2$’ .All these values are referred to the stator. All rotor parameters and electrical quantities are viewed from the stator and are identified by primed variables. D. Excitation System The excitation system block is a Simulink system implementing an IEEE Type I synchronous machine voltage regulator combined to an exciter. The basic elements that form the excitation system block are the voltage regulator and the exciter.

E. Wind Turbine Modeling

This block implements a wind energy conversion system. The inputs are actual and desired speed and the output of the block is mechanical power (P_ω).

The amount of power harnessed from the wind of velocity is as follows.

$P=1/2\rho ACv^3$ ………..(7)

Where

P_ω= wind power in watts

ρ = air density in kg/m^3

A= swept area in m^2
C_p=power coefficient of wind turbine
v= wind speed in m/s

VI. SIMULATION RESULTS

Simulation results are obtained as shown in the fig 2, 3, 4, 5, 6, 8, 9. These show the Variation of load voltages, load power, load currents, battery current, battery power, generated power & d c voltage with PI and PID controllers. The rating of the PMSG is given in the Appendix.

VII. CONCLUSION

A model of a Permanent Magnet Synchronos Generator with a full converter has been implemented in SIMULINK. The model has been used in a simulation using a varying input and the results have been presented.

This paper discussed control of synchronous generator based wind energy conversion systems (WECS) with PWM (Pulse Width Mode) rectifier and a battery for storing the extra wind energy. According to the proposed topology, Battery energy storage system provides power balance between the generated power and the load. The power mismatch is absorbed by the BESS. Even we use here the PID controller which shows better transient response which reduces peak overshoot and the settling time compared to PI controller.

APPENDIX

Number of phases	: 3-Phase,
Voltage rating	: 300 V,
Supply frequency	: 50 Hz
Proportional gain (K_p)	:400
Integral gain (K_i)	:300
Derivative gain (K_d)	:40

Nickel-Metal-Hydride BATTERY:

Nominal Voltage	: 200 V
Rated Capacity	: 6.5 Ah
Fully Charged Voltage	: 235 V
Internal Resistance	: 0.30769 Ω

REFERENCES

[1] Bhim Singh and Gaurav Kumar Kasal, "Solid-State Voltage and Frequency Controller for a stand alone wind power generating system,"IEEE Trans. Power Electronics, vol. 23, no.3, pp.1170–1177, 2008.

[2] Bhim Singh and Gaurav Kumar Kasal, "Voltage and Frequency Controller for a 3-Phase 4-WireAutonomous Wind Energy Conversion System" accepted for publication in IEEE Trans. on Energy Conversion.

[3] S. Heier "Grid Integration of Wind Energy Conversion Systems", 1998 :Wiley

[4] M. G. Simoes and F. A. Farret "Renewable Energy Systems", 2004 :CRC

[5] L. L. Lai and T. F. Chan "Distributed Generation-Induction and Permanent Magnet Generators", 2007 :Wiley

[6] M. P. Kazmierkowski , R. Krishnan and F. Blaabjerg "Control in Power Electronics"- Selected Problems, 2002 :Academic

[7] Zouaghi, "Variable Speed Drive modeling of Wind Turbine Permanent Magnet Synchronous Generator," ICREP'04 International Conference on Renewable Energy and Power Quality, Barcelona, Spain, 2004.

[8] C.Ong "Dynamic Simulation of Electric Machines Using MATLAB/Simulink" Editorial "Prentice Hall", 1998.

[9] D.C.Aliprantis,S.A.Papathanassiou,M.P Papadopoulos, A.G.Kaladas, "Modeling and control of a variable-speed wind turbine equipped with permanent magnet synchronous generator," Proc. Of ICEM, Vol.3, pp.558-562,2000.

[10] Mukhtiar Singh, A. Chandra," Power Maximization and Voltage Sag/Swell Ride-Through Capability of PMSG based Variable Speed Wind Energy Conversion System" in proc. of 34th Annual conf. of IEEE Indus.

SIMULATION RESULTS

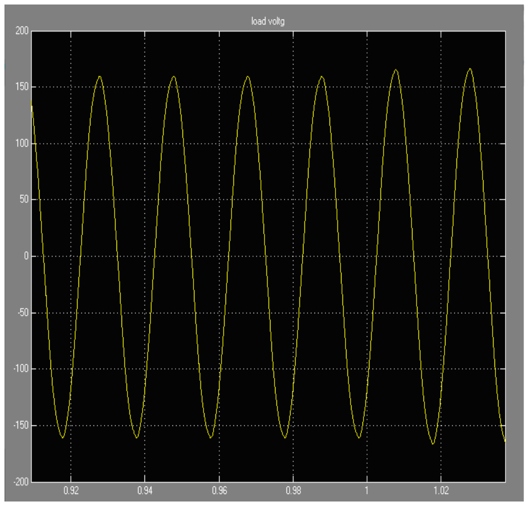

Fig.2 Variation of load voltage with variation of load

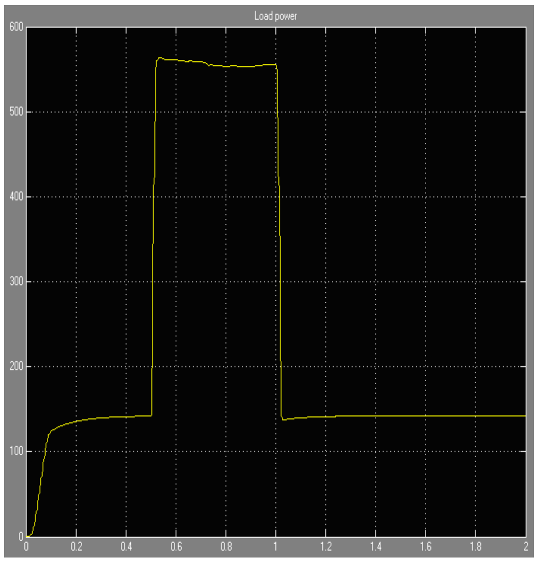

Fig.3 Variation of load power with load

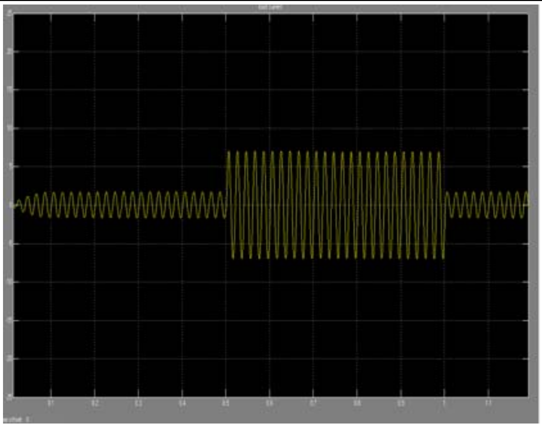

Fig.4 Variation of load current with variation of load

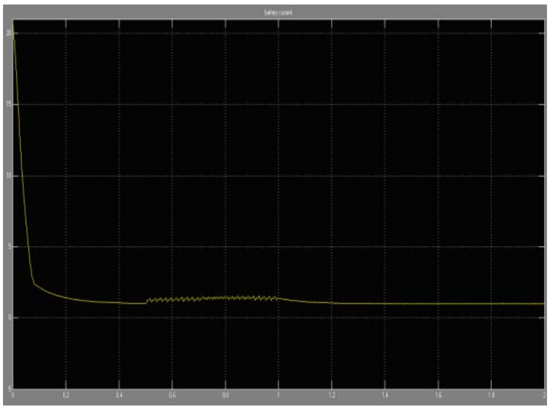

Fig.5 Variation of battery current with load

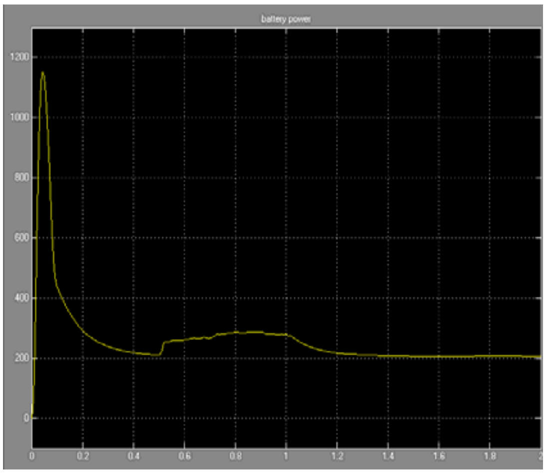

Fig.6 Variation of battery power with sudden perturbations on load

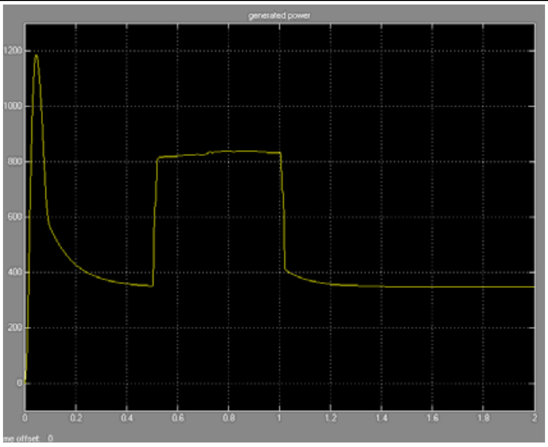

Fig.7 Variation of generated power with sudden perturbations on load side

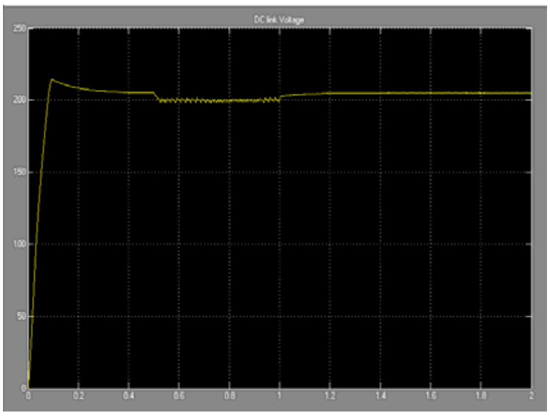

Fig.8 Variation of DC link voltage with PI controller

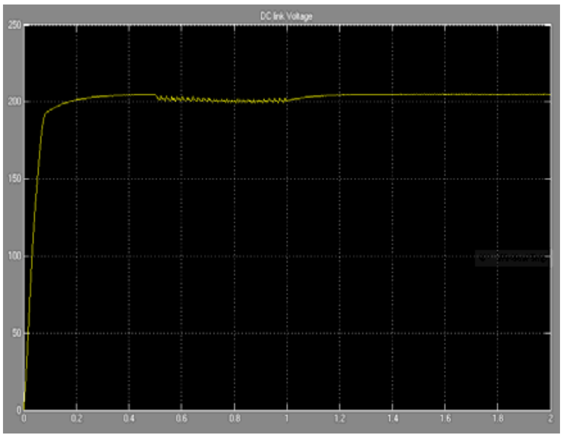

Fig.9 Improvement of DC link voltage with PID controller

◈◈◈