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Control of PMSG Wind Turbine Based on PI/ANN Controllers under Unbalanced Grid Voltage and Nonlinear Load Conditions

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Abstract

Renewable Energy Sources (RES) are nowadays growing rapidly at the distribution level and it employs power electronic converters to ensure reliable operation to the customers. Among the RES, wind energy is now firmly established technology for electricity generation. This paper proposes a conventional PI controller and Artificial Neural Network (ANN) controller to GSC of PMSG, which can obtain zero error in current controller. The grid side converter plays a dual role of interfacing the wind energy to grid as well as to supply reactive power as demanded by the non-linear load connected at the PCC. In this, the system is verified under two considerations: i.e. grid connected PMSG based wind system under fault analysis and comparison study of Proportional integral (PI) controller and ANN Controller to the PMSG grid-side converter Presents of Non-Linear load. Furthermore, the proposed system implemented in Matlab/Simulink and the effectiveness of the proposed Grid based PMSG wind system under grid fault conditions are studied.

Keywords: PMSG, Wind Turbine, PI, ANN, Grid side converter (GSC), Grid-system.

1. INTRODUCTION

The continuously increasing energy demands, along with the necessity of higher reliability requirements, are driving the modern power systems towards distributed generation (DG) as an alternative source. Wind turbines, Fuel cells (FC), Photovoltaic (PV), Batteries, etc. are nowadays the most common available DGs for generation of power mostly in peak times or in rural area. To deliver high quality and reliable power, the microgrid should appear as a single controllable unit that responds to changes in the system. Microgrids should preferably tie to the utility grid so that any surplus energy generated within them can be channeled to the grid. Similarly, any shortfall can be replenished from the grid.

Nowadays, wind power generators represent a prominent facility for generating renewable and clean bulk power to utility grids. Basically, there are many good reasons for using more wind energy on power grids. For instance, wind generation is supported by not only being clean and renewable but also having minimal running cost requirements.

The amount of the energy extracted from the wind depends not only on the incident wind speed, but also on the control system applied on the wind energy conversion system (WECS). Typically, maximum wind power extraction is accomplished by using fully controlled variable speed wind turbine generators. The rotational speed of wind turbine hub is adjusted according to the incident wind speed to track the maximum wind power trajectory. The power generating unit connected to the grid, the wind turbine generator should have the capability to control the active and reactive powers injected to grid. Variable speed wind turbine (VSWT) topologies include many different generator, converter configurations, based on cost, efficiency, annual energy capturing, and control complexity of the overall system.

To run a WECS may use several Permanent Magnets synchronous generators (PMSGs) connected directly to the power grid through an offshore step-up transformer. This paper is organized as below. The configuration and the employed models for the studied integrated grid and WECS are introduced first [1]. Then, the design procedure and design results for the PI damping controller of the proposed GSC using pole-placement technique are depicted. Both steady-state operation points under various wind speeds and marine-current speeds and the comparative dynamic responses of the studied system with the designed PI damping controller under different operating conditions can be elaborately done here. Generally, Artificial Neural Networks relatively crude electronic models based on the neural structure of the brain. The brain basically learns from experience. It is natural proof that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modeling also promises a less technical way to develop machine solutions.

2. MODELLING OF PROPOSED SYSTEM

It can be said, that in order to fully realize the potential that wind energy holds, it must be integrated into the transmission grid. This is especially difficult since the grid should be an extremely stable supply of power, and as discussed earlier, the wind is hardly an ideal supply source. As the wind speeds change, the turbine blades will spin respectively faster or slower, causing the output electrical voltage and frequency to also fluctuate. This can cause different types of power quality issues. Therefore, for wind to become widely used and accepted as a decent resource, these complications must be addressed.

To begin with, reactive power must be controlled, not only for input into the grid, but also for output from the grid. Since inductive generators require the supply grid to excite the rotor, it can draw a lot of reactive power from it, which can then make it become unstable. Also, a low power factor will increase current in the line, the output of reactive power, and create losses within the system.

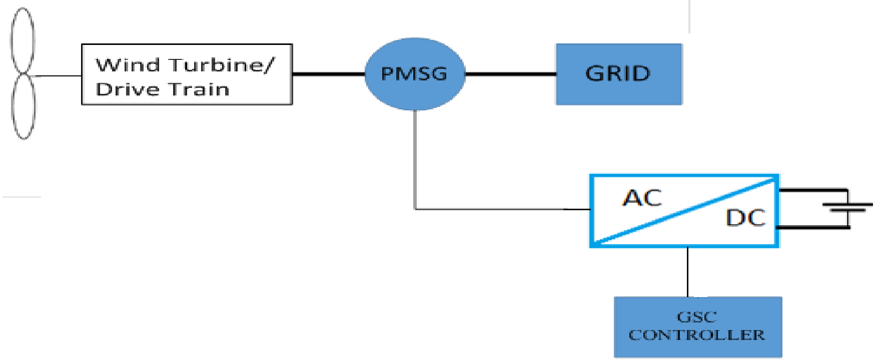


Figure 1: Wind energy System

Power factor correction is one way of controlling the reactive power, which can be done through a control system on the grid-side converter. In this paper a PMSG based WECS hybrid system with different controllers is considered, feeding power to a local load and the grid as shown in Figure 1.

Harmonics are responsible for increasing distortion in the network, which reduces the quality of power delivered to customers. Filters are commonly used to remove most harmonic distortions for a clean connection to the grid. Another issue with connecting wind turbines to the supply grid has to do with grid faults. When there is a fault in the electrical system, it is typical for wind energy conversion systems to disconnect from the grid, which is a non-ideal situation. As technology advances, it has become possible to provide turbines with fault ride-through capability. This will disallow the WECS to disconnect from the grid, and instead provide reactive power to it until it can fully recover.

Wind Turbine

A wind turbine is a device that converts the wind's kinetic energy into electrical power. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. The wind generator system using Permanent Magnet Synchronous Generator is shown in fig.2. The kinetic energy produced by the wind turbine is the most desirable type of energy which is converted into electrical power which can be stored in batteries or linked to a utility power grid [5].

The maximum theoretical power output of a wind machine is thus 0.59 times the kinetic energy of the air passing through the effective disk area of the machine. If the effective area of the disk is ‘A’ and the wind velocity v, the maximum theoretical power output P is:

$$P = 0.5\rho A v^3 * C_p(\lambda, \beta)$$

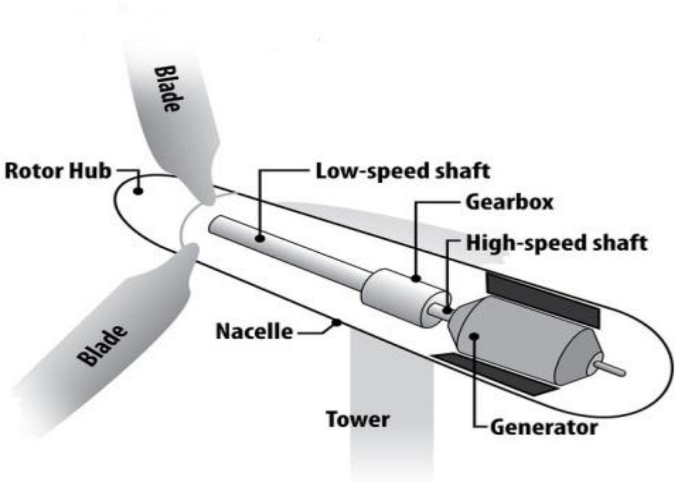


Figure 2: Basic diagram of wind turbine

Permanent Magnet Synchronous Machine

Recently, the commercial trend of wind power generation is in using variable speed wind turbine driving a Permanent Magnet Synchronous Generator (PMSG).

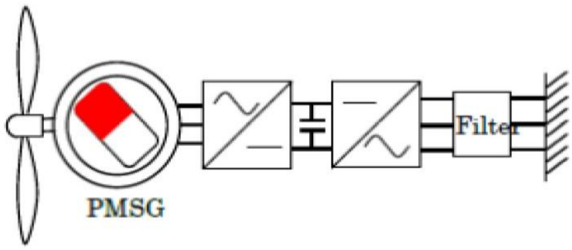


Figure 3: Modeling of PMSG based Wind system

PMSG converts the mechanical power from aerodynamic system to AC electrical power, which is then converted to dc power through IGBT pulse width modulation (PWM) converter connected with dc link at its dc port. The power is transferred to the grid through another IGBT pulse width modulation (PWM) inverter. PMSG is considered in many research articles, a good option to be used in WECS due to its self-excitation property, which allows operation at high power factor and efficiency. The salient pole of PMSG operates at low speed and thus the gearbox can be removed. This is a big advantage of PMSG based WECS as the gearbox is a sensitive device in wind power systems. The mathematical model of a PMSG is similar to that of a wound rotor synchronous machine and is expressed in the rotor reference frame (dq frame).

$$v_{sd} = I_{sd} R_f + L_f \frac{dI_{sd}}{dt} - w_s L_f I_{sq} + v_g$$

$$v_{sq} = I_{sq} R_f + L_f \frac{dI_{sq}}{dt} - w_s L_f I_{sd}$$

$$P_s = \frac{3}{2}(v_{ds} i_{ds} + v_{qs} i_{qs}) = \frac{3}{2}[\omega_s L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) + r_s (i_{ds}^2 + i_{qs}^2)]$$

The d-q model has been developed on rotor reference frame shown in Figure 4. At any time t, the rotor d-axis makes and angle with the fixed stator phase axis and rotating stator mmf makes an angle ± with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

As shown in Fig. 1, in variable speed wind turbines, PMSG is connected to the utility grid via a converter. The first converter, known as the grid side converter and is connected to the grid at the PCC via ac filter. The dc terminals of the converter are collected together with shunt dc capacitor. The power scheme of the converter simply contains a voltage source inverter. However, from control prospective, different control schemes based on the control functions can be applied on the inverter switches. Control schemes of the converter will be described in details below.

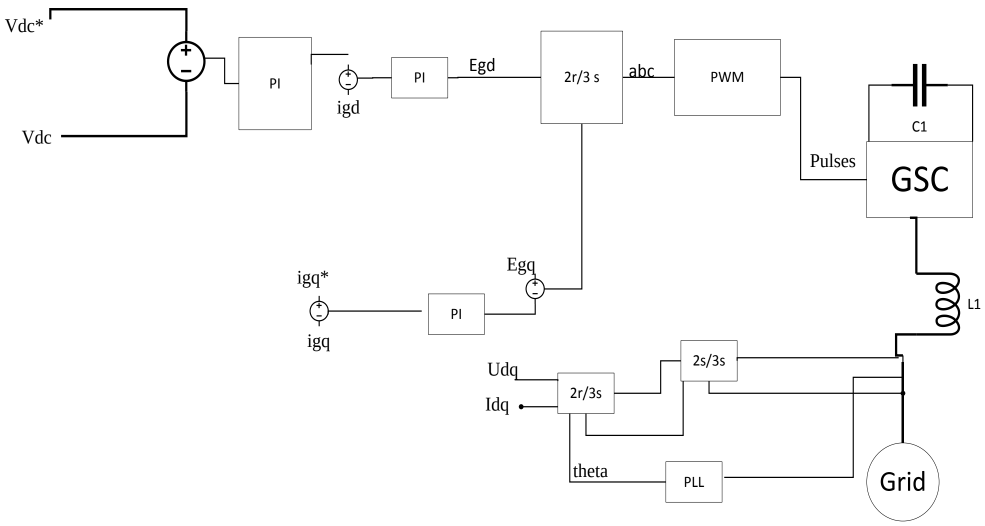


Figure 4: PMSG Control Diagram

In this control strategy, the currents are represented in the dq synchronous rotating reference frame and controlled with standard PI controllers. This control transforms the grid voltages and currents from the abc to their equivalents in the dq reference frame. Worth mentioning that the abc variables are transformed to dc components (dq components), and thus offers much easier and more feasible controllability. The control structures developed in this work, use PI controllers since they have proper performance for controlling dc variables. It could be seen from Fig. 4 that the outer loops control the dc voltage by taking the dc voltage reference of 220 V, and the error signal produce Igd reference to inner current control loop that control active power. The second channel controls the reactive power by producing Igq reference to inner current control loop.

PI Controller:

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system.

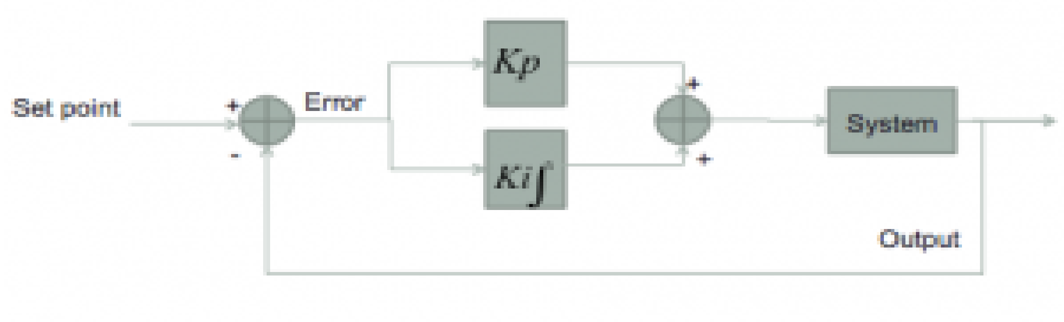


Figure 5: Configuration of PI controller

Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

Artificial Neural Networks:

The neuro controller is one of the important controllers in adaptive techniques. This section provides the information regarding the designing of neuro controller. This neural controller has 2 inputs that are Δe (x) and Δde (y) and it has 1 output that is f ∈ {x, y}. Each input consists of 5 membership functions. Figure 6 shows the configuration of ANN controller.

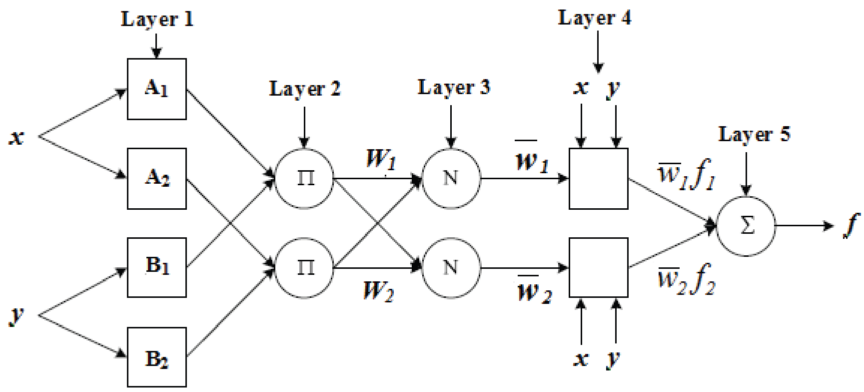


Figure 6: ANN architecture

Neural networks typically consist of multiple layers or a cube design, and the signal path traverses from front to back. Back propagation is where the forward stimulation is used to reset weights on the "front" neural units and this is sometimes done in combination with training where the correct result is known.

Algorithm for Neural Structure:

1. Assume the inputs and outputs in the normalized form with respect to their maximum values and these are in the range of 0-1.
2. Assure the No.of input stages given network.
3. Indicate the No.of hidden layers for the network.
4. Design the new feed forward network based on the system parameters ‘transig’ and ‘poslin’.
5. Assume the learning rate be 0.02 for the given network.
6. Identify the number of iterations for the system.
7. Enter the goal.
8. Train the network based on the given input and outputs.
9. For the given network Generate simulation with a command ‘genism’

The goal of the neural network is to solve problems in the same way that the human brain would, although several neural networks are much more abstract. Modern neural network projects typically work with a few thousand to a few million neural units and millions of connections, which are still several orders of magnitude less complex than the human brain and closer to the computing power of a worm.

3. SIMULATION RESULTS

To examine the performance of the implemented control scheme, two case studies considering different wind speed variations have been conducted.

Case 1: Grid interfaced PMSG based wind system under fault analysis

The proposed system consisting of PMSG based variable speed WECS is simulated using MATLAB/SIMULINK. The results of simulation are shown in fig 7. It is seen from the figure that the speed of generator varies as the speed of the wind varies, which is indicated by a variation in magnitude of PMSG phase voltage and phase current. It is also seen that the feeder current of the system and direct-quadrature axis currents, active and reactive powers at grid are show in figure.

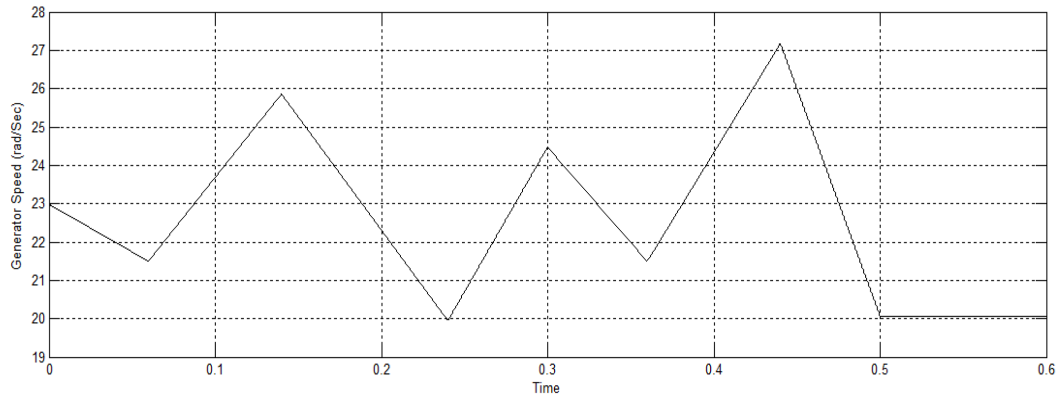


Figure 7: Simulation Result for generator speed

Case 1(a): Single Phase to Ground Fault

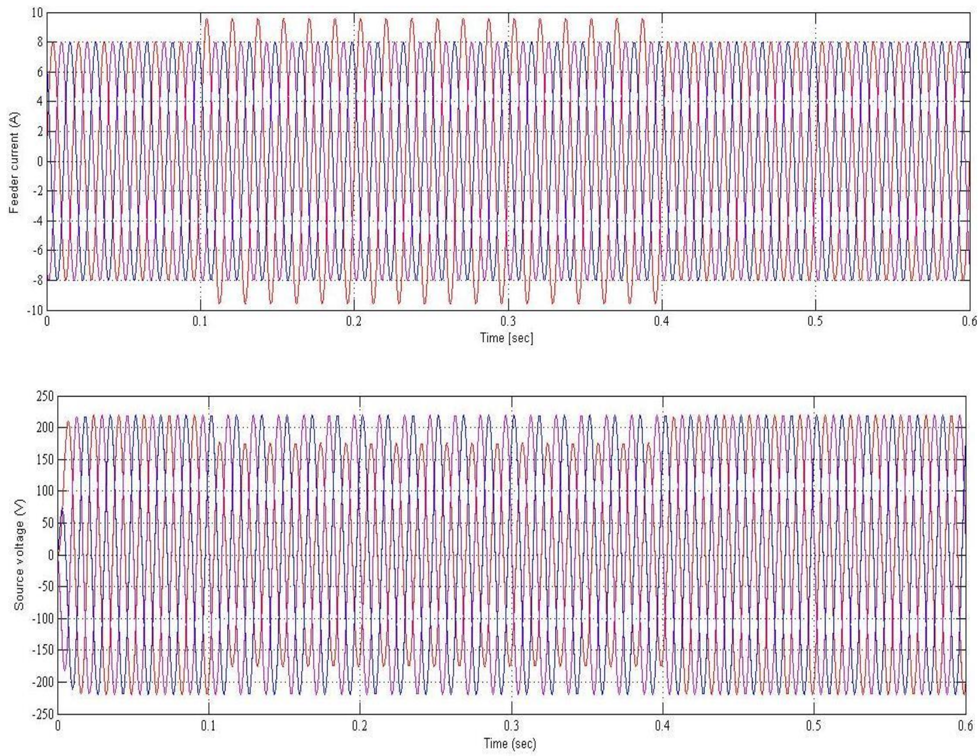


Figure 8: Simulation Result for Feeder Current and source voltage under L-G fault

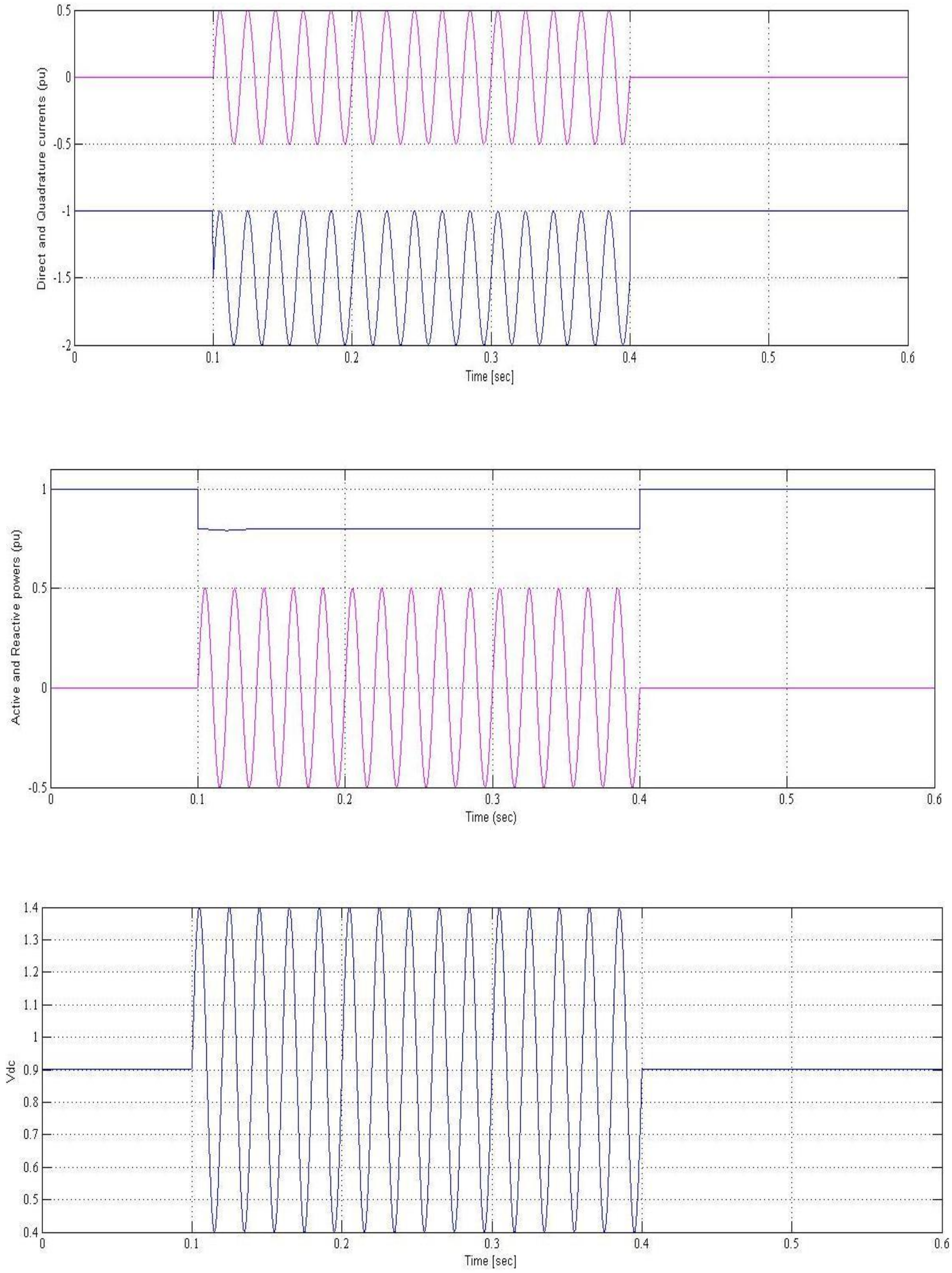


Figure 9: Simulation results for direct and quadrature currents, active and reactive powers and DC link voltage under phase to ground fault

Case 1(b): under Three Phase Fault

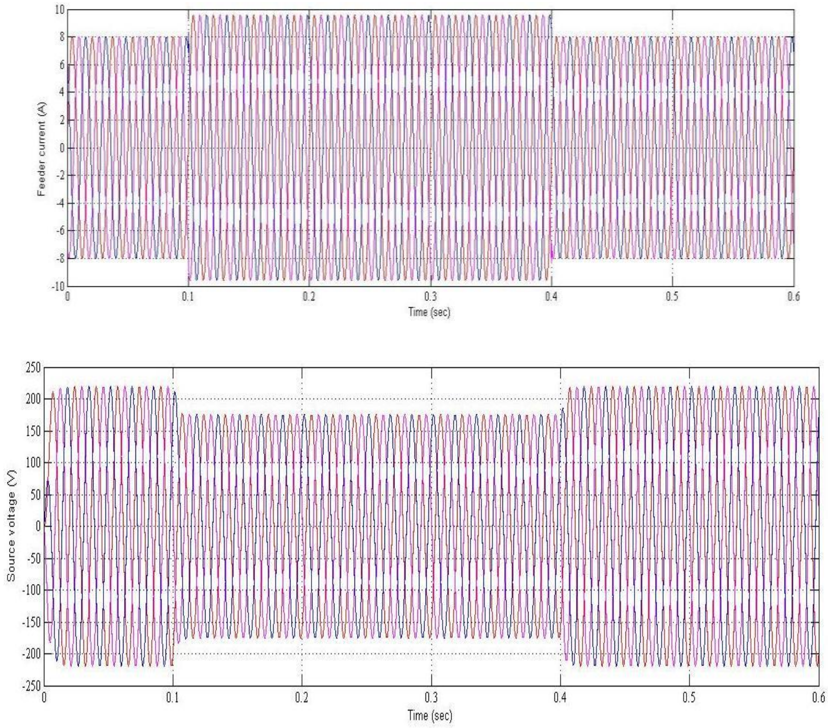
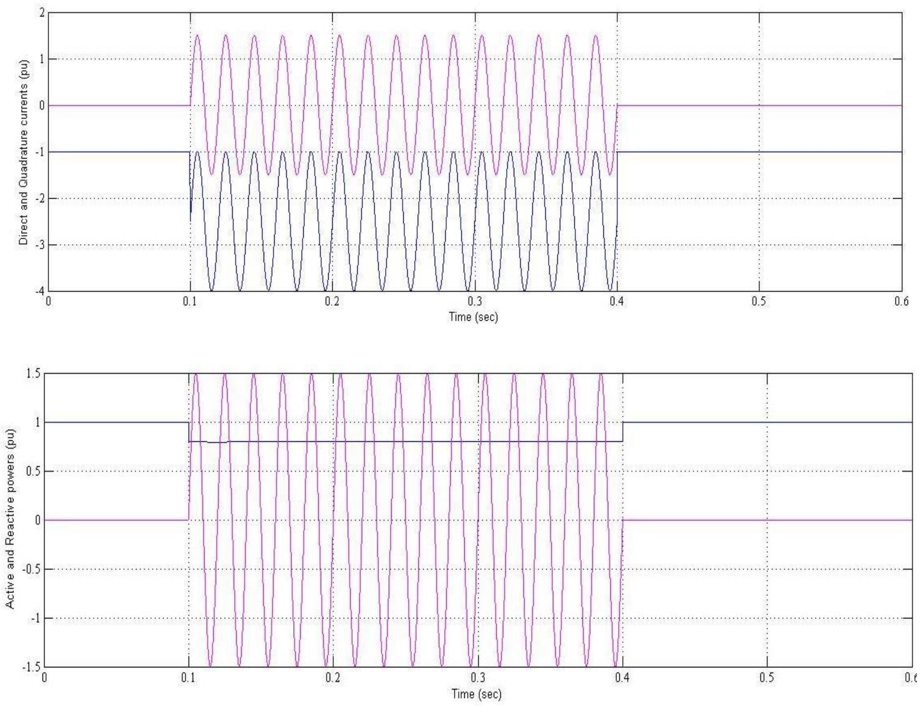


Figure 10: Simulation results for Three Phase feeder current and Grid Volatge Under Three Phase Fault



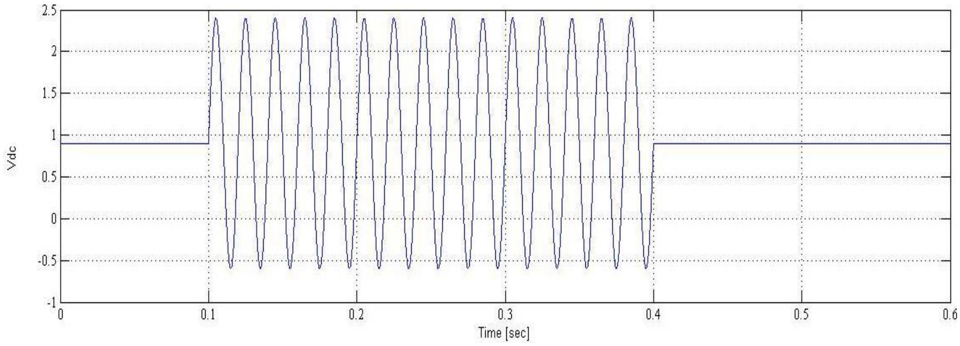


Figure 11: Simulation results for direct and quadrature currents, active and reactive powers and DC link voltage under three phase fault

Caes 2: Non-Linear Load operated by PMSG Wind turbine

In this the system performance is verified by considering Non-linear Load. Generally, due to presence of non-linear load an harmonic content present in this system. In order to protect the system from this harmonics, a Conventional PI and ANN controller is proposed.

Case a: With PI Controller

The waveforms of non-linear load current and its THDs had shown in figure 12, 13 and 14.

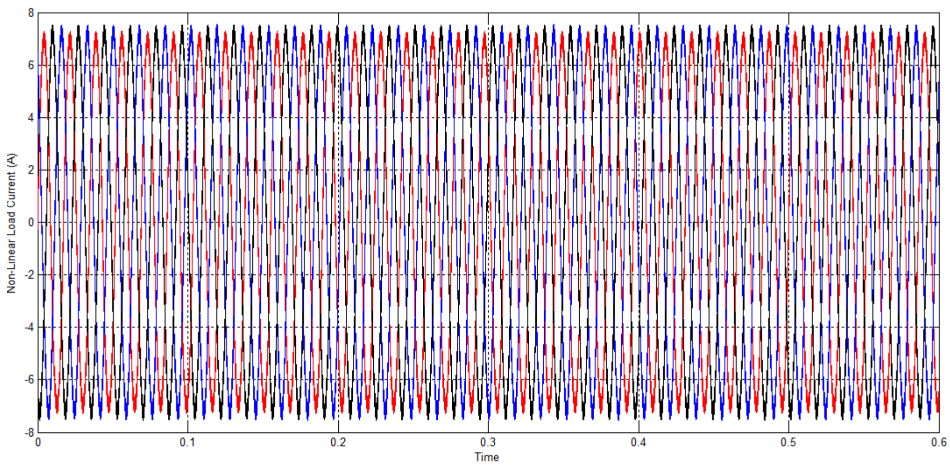


Figure 12: Simulation Result for Non-Linear Load Current

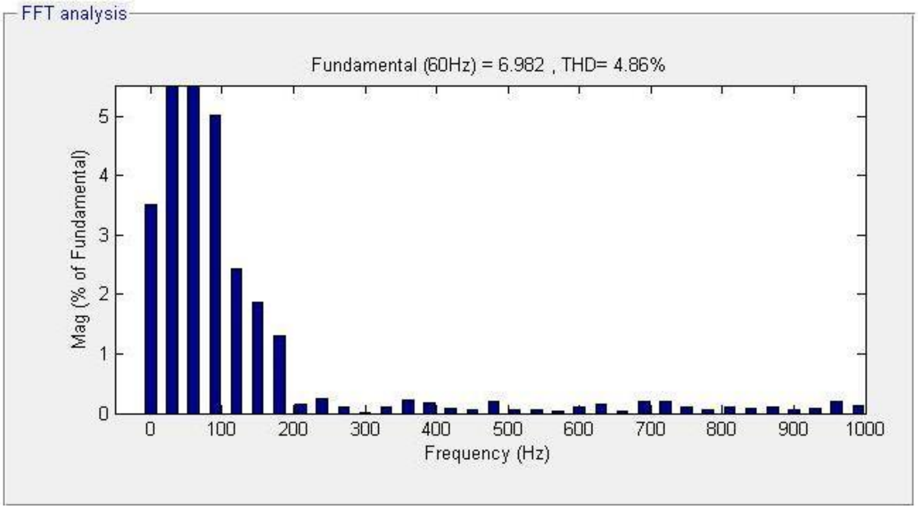


Figure 13: Load Current THD

Case b: With ANN Controller :

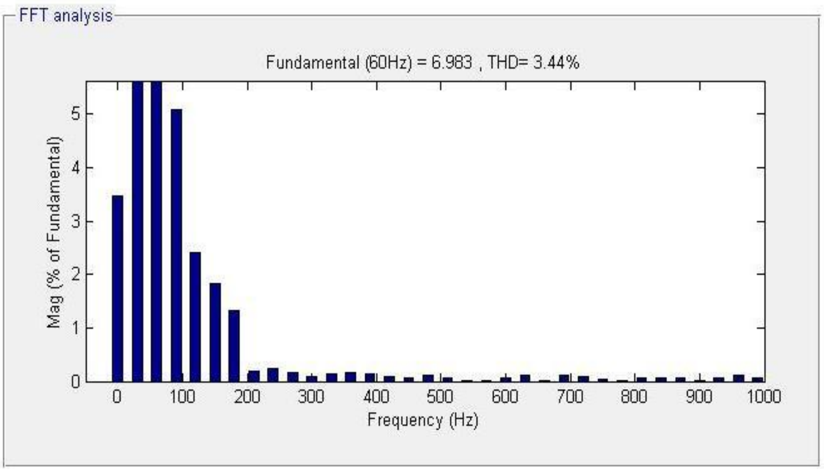


Figure 14: Load Current THD

CONCLUSION

In order to compensate the unbalanced grid voltages, this paper proposed the concept of GSC converter which is controlled by general PI or ANN. For this converter the reference signals is generated by positive sequence voltage signals. From the result, the suggested Ann-based control strategy is easy without any decomposition and complicated research calculation. From the simulation results and harmonic distrotion factor, we conclude that the neuro controller shows the better results as compared to conventional PI controller.

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