International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231-2307, Volume-2 Issue-2, May 2012

Simulation and Analysis of Wind Energy and Photo Voltaic Hybrid System

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Abstract- This paper models a hybrid system consisting of a wind turbine and a photovoltaic array as main energy sources and this is simulated using MATLAB. To connect the PV system to the grid the only adaptation required is to adjust the DC bus voltage to the conventional/isolated grids characteristics. Both energy sources are parallely linked to a common PWM voltage source inverter through individual AC/DC and DC/DC converters. A AC/DC converter transforms the 3 phase variable frequency wind turbine AC power, into variable DC power. A DC/DC converter controls variable power from the solar array DC. Though all sources have their individual controllers they have a common configuration. A VLSI based fuzzy logic controller ensures constant voltage needed for the load through the convertor's PWM signals. The wind turbine and photovoltaic array voltage are controlled through error signal which is fed to the controller to generate pulses for the dc-dc converter. Simulation results reveal that the hybrid system provides a constant power to the load.

Index Terms: Photovoltaic array, Wind turbine, VLSI, Fuzzy logic controller.

I. INTRODUCTION

Power quality improvement using different renewable energy sources requires extensive study as it is an emerging field. The increasing number of renewable energy sources and distributed generators requires new strategies for their operations in order to maintain or improve the power-supply stability and quality [1]. Combining multiple renewable resources via a common dc bus of a power converter has been prevalent because of convenience in integrated monitoring and control and consistency in the structure of controllers as compared with a common ac type. There are some previous works on similar hybrid systems [2]. Dynamic performance of a stand-alone wind and solar system with battery storage was analyzed [3]. A few grid-connected systems consider the grid as just a back-up means to use when there is insufficient supply from renewable sources [4]. They are originally designed to meet local load demands with a loss of power-supply probability of a specific period. Such hybrid systems, focusing on providing sustainable power to their loads, do not care much about the quality or flexibility of power delivered to the grid. From the perspective of utility, however, a hybrid system with less fluctuating power injection or with the capability of flexibly regulating its power is more desirable. In addition, users will prefer a system that can provide multiple options for power transfer since it will be favorable in system operation and management. Control strategies of such a hybrid system should be quite different from those of conventional systems.

Traditionally, ASICs have been used to achieve significant speedup in communication, signal processing, and scientific computing. In many applications, algorithms are subject to change making reconfigurability desirable [5,6]. Currently Field Programmable Gate Arrays (FPGAs) are providing alternative for designers to provide the flexibility of hardware implementation [7,8]. To realize optimized applications in reconfigurable hardware, the high-level description has to be translated into a representation at the binary level.

An FPGA is a set of digital logic gates with high density. It can be reprogrammed and designed to meet the user's requirements of size, speed and price [9]. The fast execution speed and unconstrained input/output (I/O) interfaces give flexibility to the designers and are able to meet the specific motor-control requirements. Compared with C, C++ and assembly languages used by DSPs and microcontrollers, the very high speed integrated circuit hardware description language (VHDL) used to program FPGAs is independent of devices and manufacturers, so it is compatible with different platforms and can be synthesized into any FPGA without major changes. In this way, the VHDL-supported direct hardware implementation gives the same flexibility and easy programming as software solutions. In addition, FPGAs support high-speed and concurrent algorithms and it is possible to implement full integration of all control tasks in a single device. A complete vector control for a permanent magnet ac servomotor using only one FPGA has been reported [10]. One disadvantage of FPGAs is that they need many resources for complex mathematical operations since they are not arithmetic-oriented like DSPs. To save or optimize the required logic resources (silicon area), control algorithms are usually simplified to keep arithmetic operations to a minimum, which may lead to degradation of performance. Current FPGA implementations are rapidly approaching the limit of not being able to satisfy cost and performance demands.

Solar photovoltaic panels or small wind turbines depend on climatic conditions to operate/produce electrical energy. So when they operate alone they are poor as power sources.

Manuscript received on April 14, 2012.

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Systems that merge two sources - wind and sun - are better for electricity production. Called “hybrid systems” they supply stand-alone systems (isolated electric systems unconnected to a power grid) or grid-connected systems (systems connected to the power grid). But hybrid systems have periods when neither source produces energy. Stand-alone systems need energy storage to produce energy in such periods overcoming such situations. A hybrid system is a combination of a small wind turbine and photovoltaic solar panels whose outputs are optimized through power controllers. The extracted energy charges a battery bank or supplies an inverter with energy. The inverter is linked to consumer loads and when present, to the electrical power grid. This paper models a hybrid system consisting of a 6MW wind farm and a 100 KW Solar photovoltaic system and they are simulated using MATLAB. Bansal (2005) has presented an exhaustive survey of the literature over the past 25 years discussing the process of self-excitation and voltage buildup, modeling, steady-state, and transient analysis, reactive power control methods, and parallel operation of Self Excited Induction Generator (SEIG) [11]. Tariq Masood (2006) has presented the straightforward technique for simulation and analysis of STATCOM using MATLAB. The paper presents the current statistics of FACTS in transmission and distribution system, the significance of STATCOM and analysis of STATCOM as well as SVC in power systems. The STATCOM is simulated using MATLAB and the results show how the power quality can be improved by means of STATCOM and SVC.

In this work a VLSI based fuzzy logic controller is incorporated into the hybrid system to ensure continuous power to the grid. The system’s dynamic and static behavior is simulated and analyzed. Various faults including line to ground, line to line, double line to ground and symmetrical faults are introduced in the wind farm and simulation results analyzed. The results reveal that even under faulty wind farm conditions the hybrid system provided continuous power to the grid.

II. SIMULATION SETUP

The block diagram of the wind farm used in the experimental setup is shown in Figure 1.

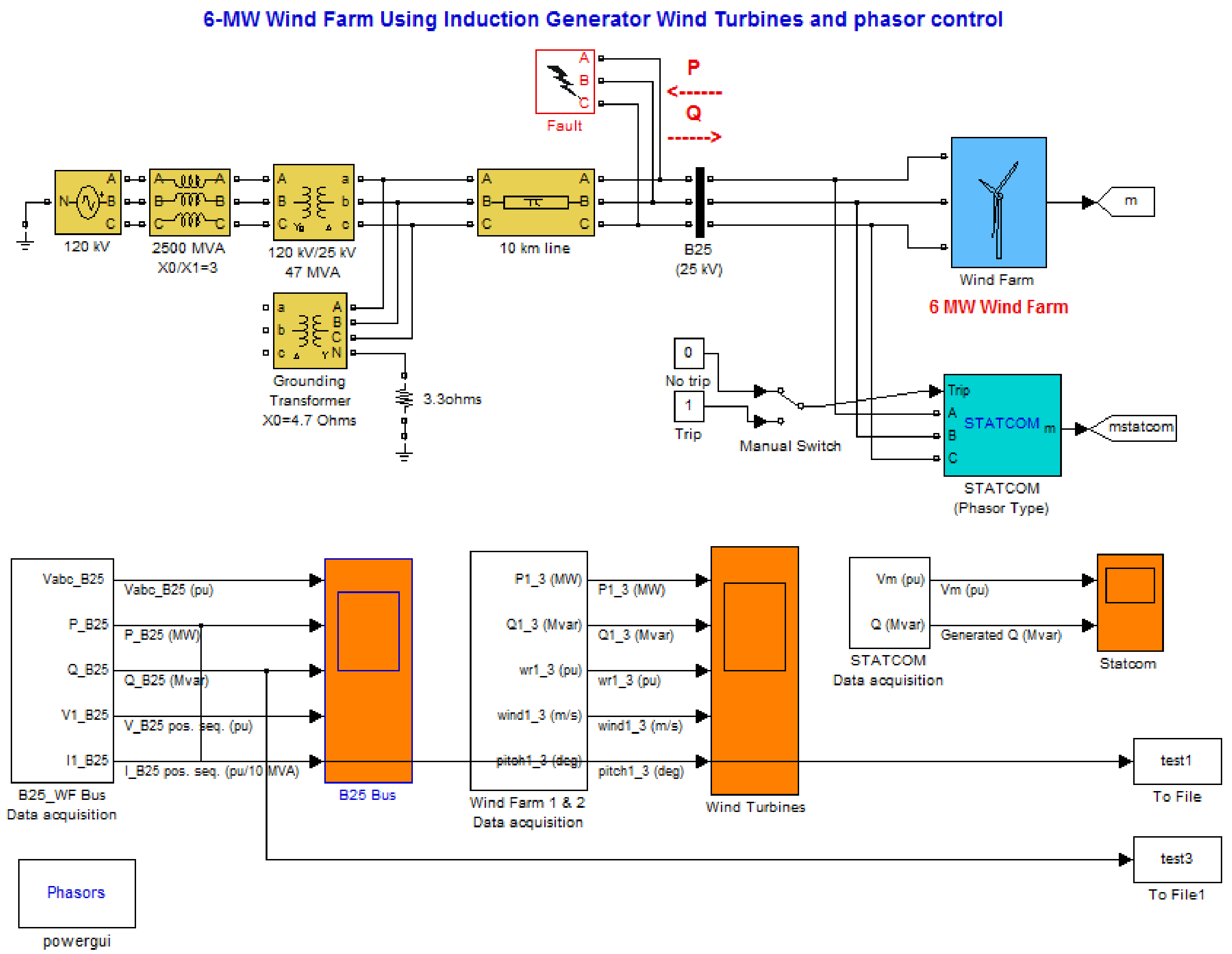

Fig.1. Model of the 6MW wind farm

The wind farm consists of two wind turbine units. Each unit consists of two wind generators of 1.5 MW rating. The two wind turbines are connected in parallel to supply power to the grid. The voltage generated by each wind turbine unit is stepped up to 25KV using a step up transformer. The power from the step up transformer is transmitted to the grid through a 1km transmission line. The proposed photovoltaic system used to integrate with the wind energy system to form the hybrid system is shown in Figure 2. The PVA model created using Simulink incorporates the required filters and load. The filter connected to the load maintains a stable voltage and is made up of a R-L and parallel C components. The PVA system has a total of 8 PV cells connected in series. Temperature and irradiance are represented using variable blocks and can be adjusted for different scenarios.

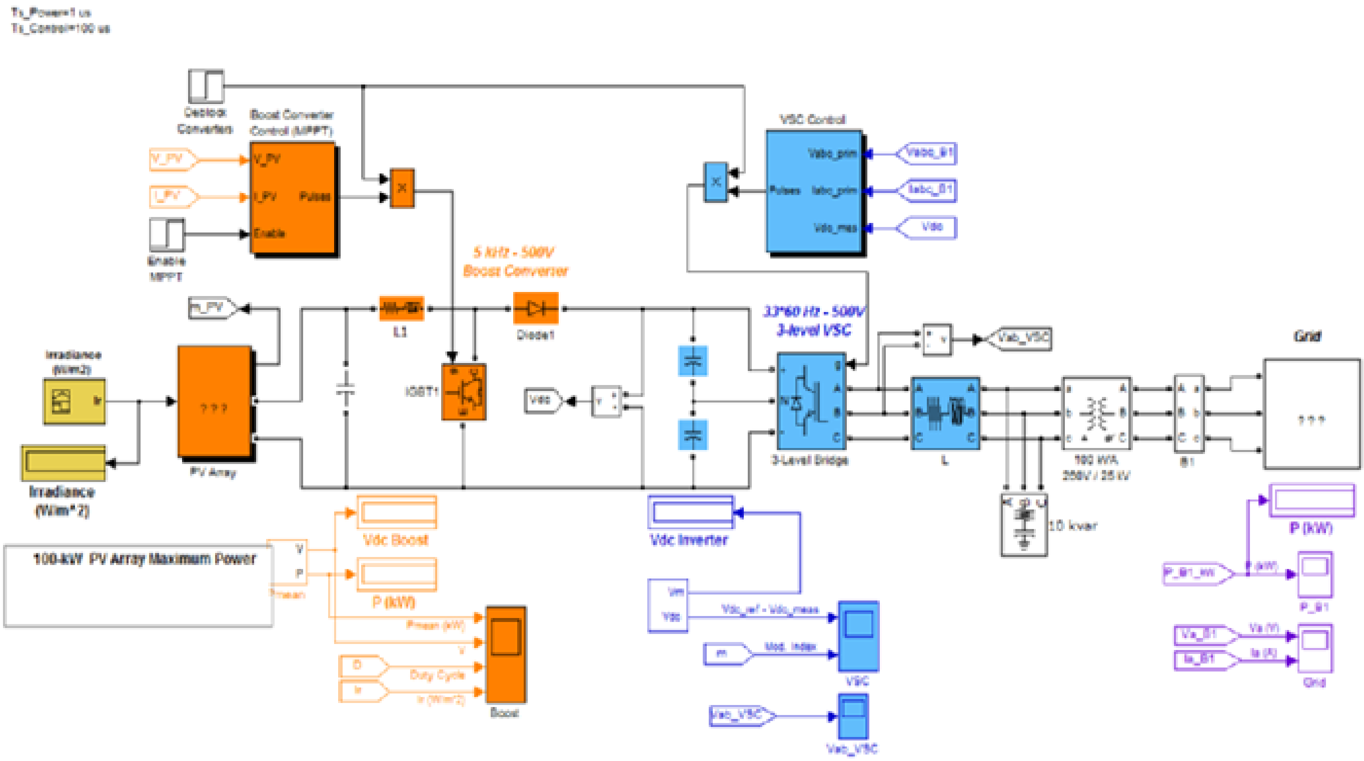

Fig.2. Model of the Solar photovoltaic system

The wind farm and the solar PV system described are integrated and connected to a common grid system to form a hybrid renewable energy system to ensure continuous power flow to the grid.

The block diagram of the proposed hybrid renewable energy system is shown in Figure 3.

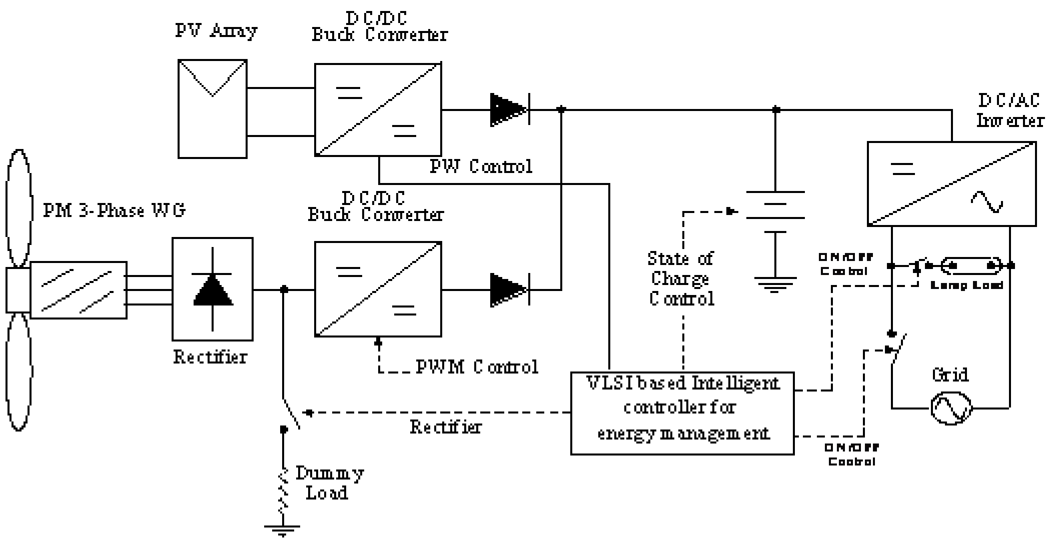

Fig.3. Block diagram of the hybrid system with VLSI based fuzzy logic controller

The proposed hybrid system comprises of a wind turbine and a photovoltaic array as main energy sources. For connecting the PV system to the grid the only adaptation needed is to adjust the DC bus voltage to the characteristics of the conventional or isolated grids. Both energy sources are connected in parallel to a common PWM voltage source inverter through their individual AC/DC and DC/DC converters. A AC/DC converter (rectifier) is used to transform the 3 phase variable frequency wind turbine, AC power, into variable DC power, and a DC/DC converter is used to control variable power DC from the solar array and produce DC power using a PWM voltage source to balance the necessary power required from the inverter onto the DC bus. Even though every source has its individual controller mechanism, they share a similar configuration. The VLSI based fuzzy logic controller controls the constant voltage level required from the load through the PWM controller of each converter. The wind turbine and the photovoltaic array voltage are controlled based on the error signal. The error is fed into the controller, to generate the pulses (switch status) for the dc-dc converter. The results show that the load receives a constant power supply from the two sources.

RESULT AND DISCUSSION

In the simulation, the pitch angle is controlled to limit the generator output power when the wind speed exceeds the nominal speed of 32 kmph. The Induction generator speed is set higher than the synchronous speed to generate power and the speed varies between 1.005 pu at full load and at 1 pu at no load. Capacitor banks are used at each wind turbine low voltage bus to partly compensate reactive power absorbed by the induction generators. In the second setup a statcom of 3 Mvar is used to maintain the rest of the reactive power required to maintain the 25 kV voltage close to 1 pu.

The wind turbine was designed as to yield the nominal mechanical power of 6 MW at 32.4 kmph.wind speed. In the simulation setup a slowly varying wind speed was considered. Faults were introduced for 0.1 second and studied. Simulations were carried on with the statcom and without statcom in the network.

The proposed hybrid system comprises of a wind turbine and a photovoltaic array as main energy sources. VLSI based fuzzy logic controller is designed to ensure continuous power to the grid. Figure 4 shows the fuzzy logic membership function for the proposed controller.

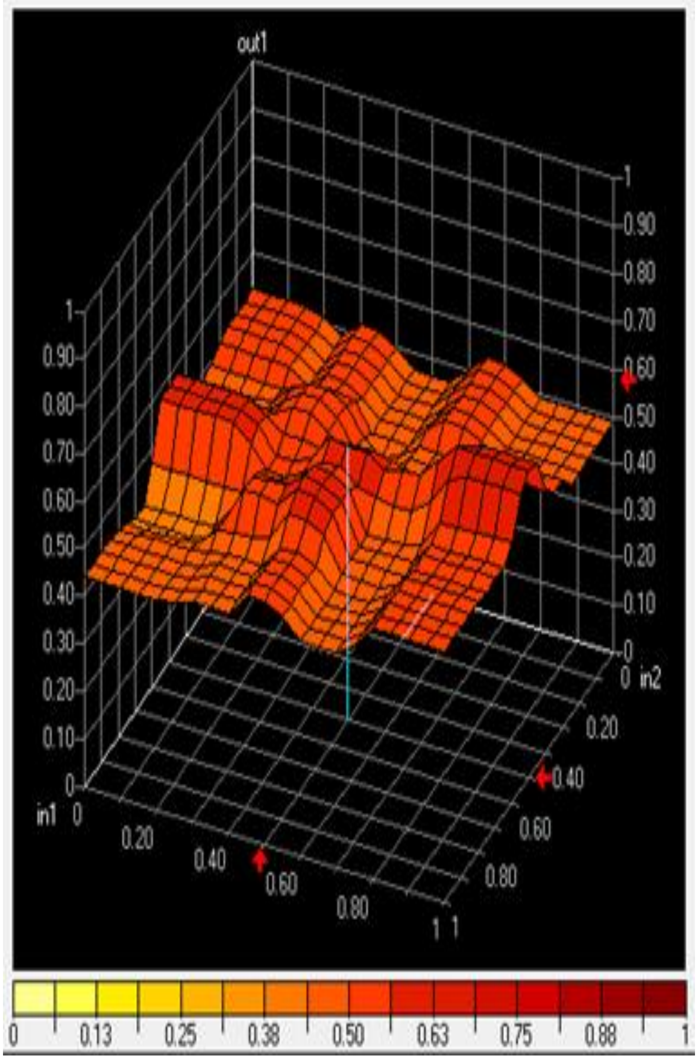

Fig 4. 3D plot of the proposed fuzzy logic membership function

The fuzzy rules are implemented using simulink block and code generated using VHDL. Figures 5 and 6 shows the fuzzification and the defuzzification process from ModelSim.

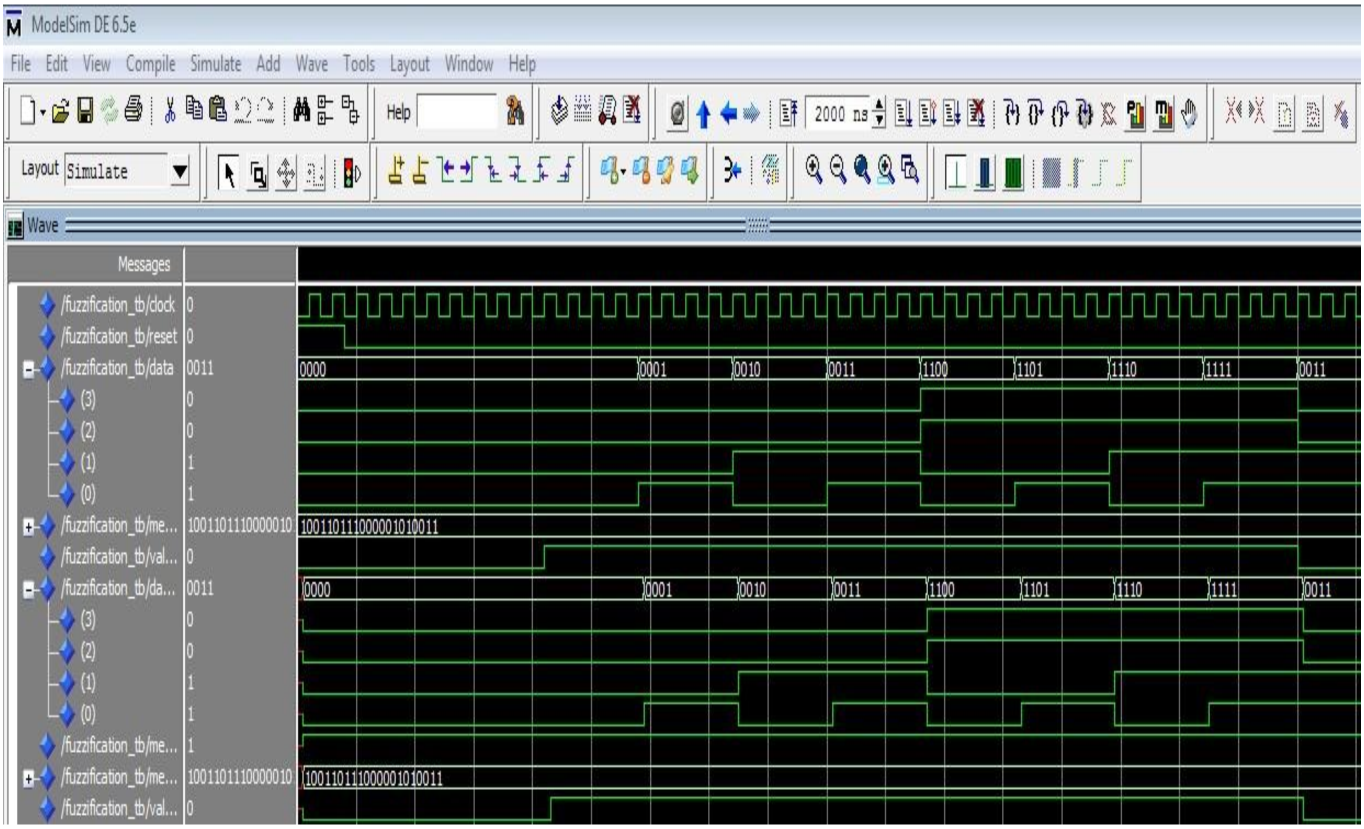

Fig 5. The fuzzification process in the VLSI controller

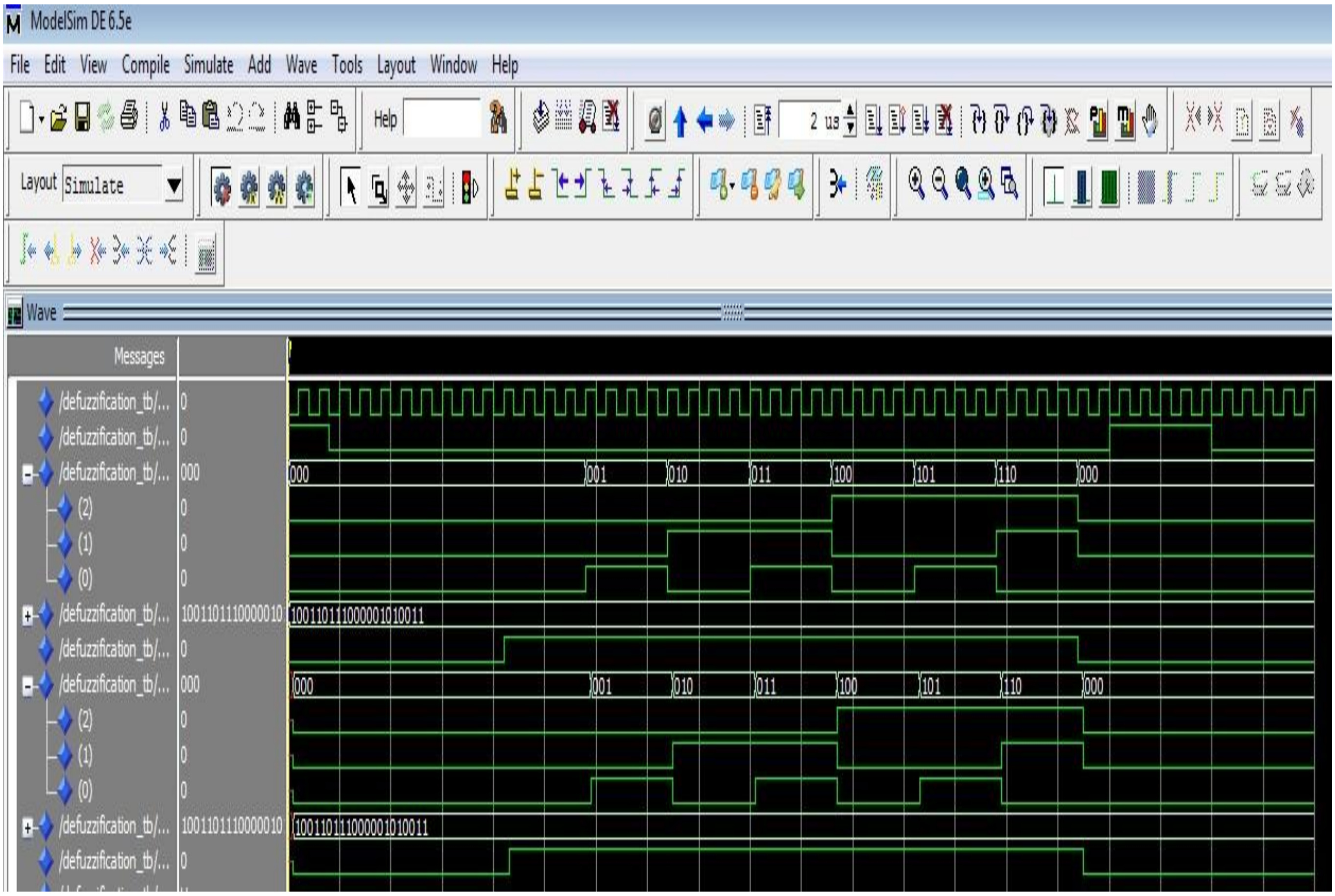

Fig 6. The de fuzzification process in the VLSI controller

Experiments were conducted with the proposed architecture with various fault conditions. The output of the PV system is shown in Figure 7.

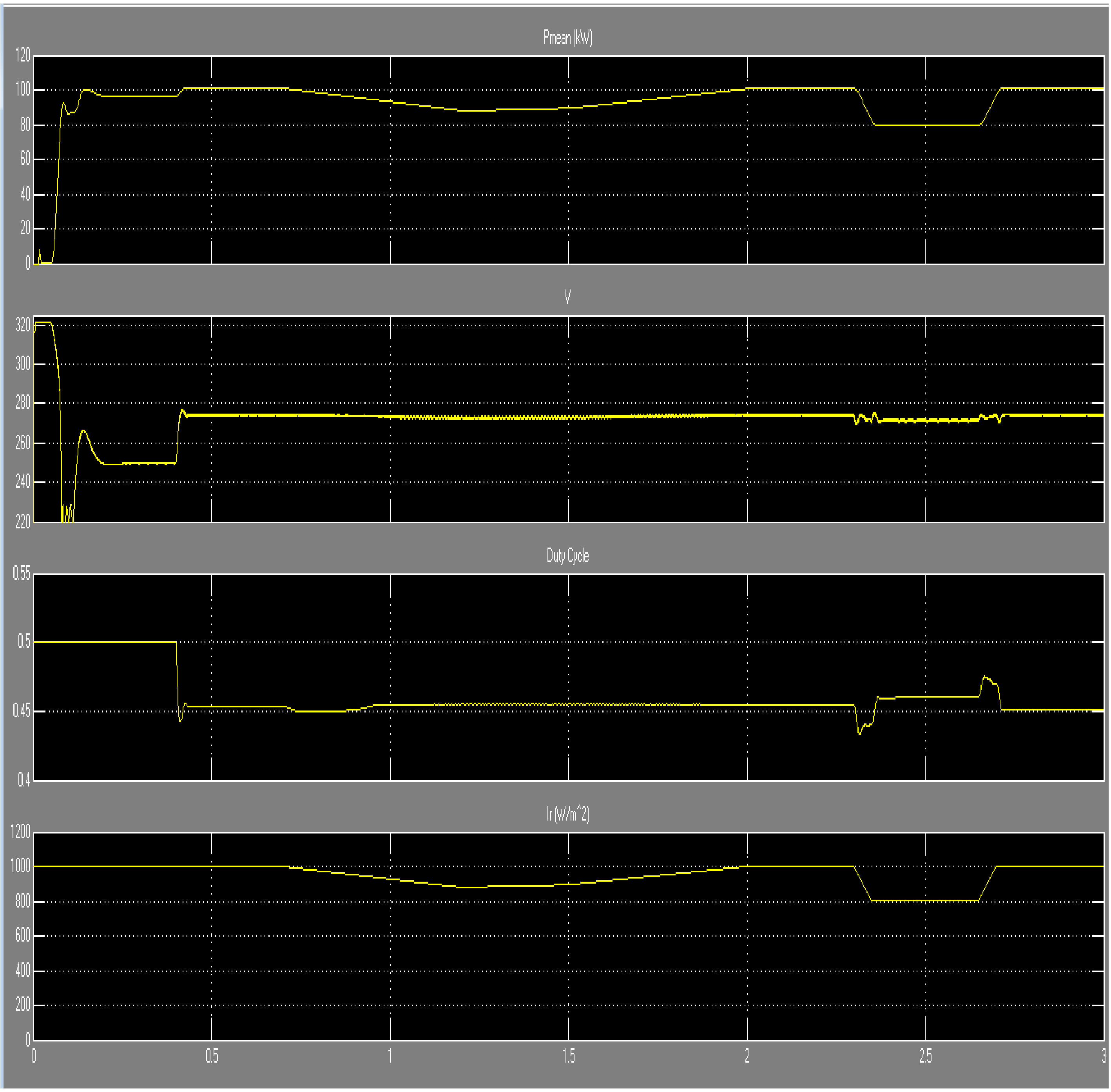

Fig 7. The output from the photo voltaic system.

Various faults including phase to ground fault, phase to phase fault and symmetric fault was introduced for a period of 0.1-0.13 seconds on the grid side for the proposed system and compared with a regular WECS system and a system connected to Statcom. The dynamic response of the system under normal and fault conditions were studied and the output is shown in figure 8.

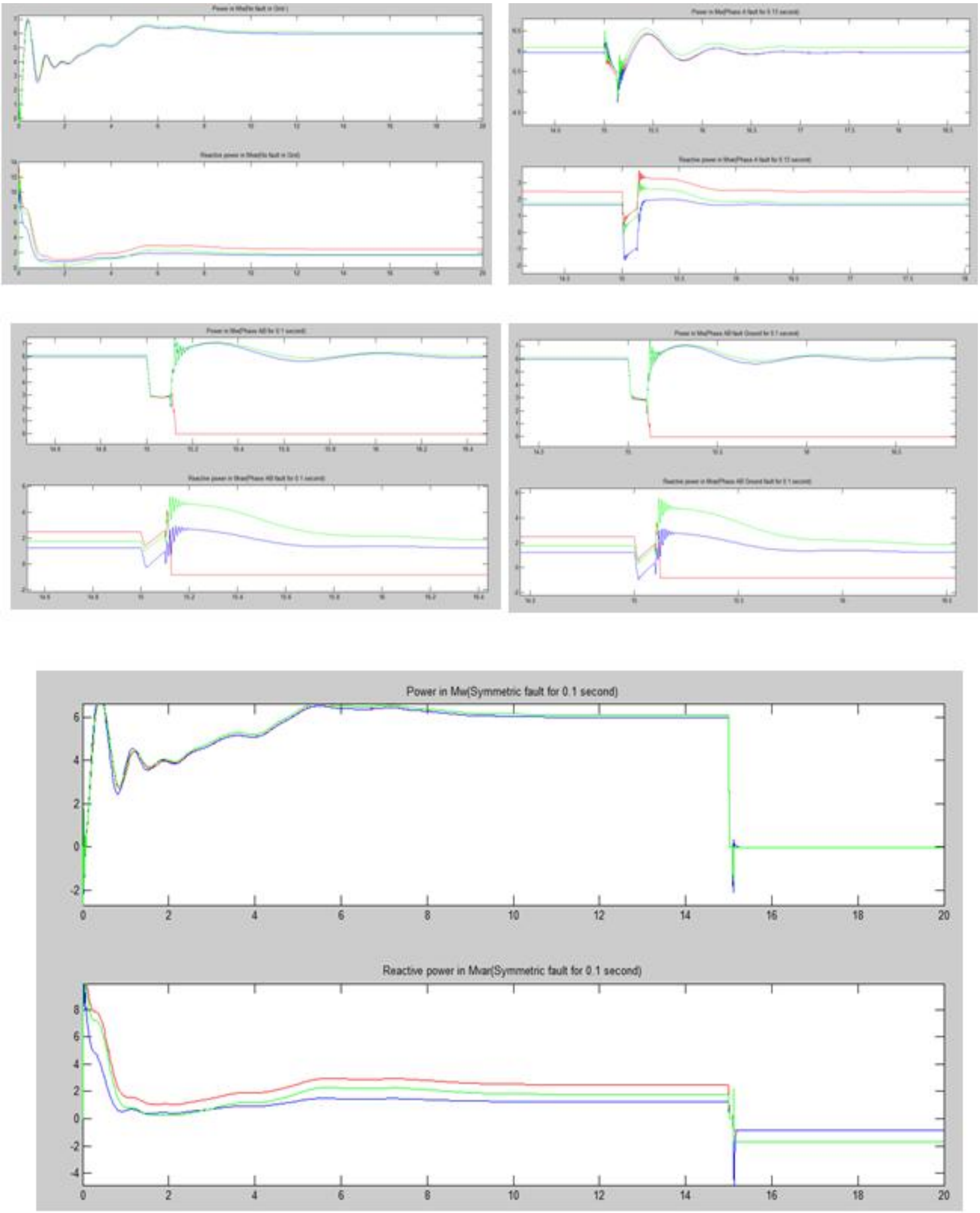

Fig. 8: The performance of the proposed hybrid system under various fault conditions (Red - WECS, Blue – WECS with Statcom, Green – Hybrid system)

From figure 8 it can be seen that the hybrid system is able to recover from all types of faults except for symmetric faults as in the case of statcom.

IV. CONCLUSION

In this paper a novel hybrid system based on PV and WECS was proposed. A novel VLSI based fuzzy logic controller was designed to improve the transient stability of the proposed control system due to the inherent vagaries of nature. The proposed system was simulated using Simulink blocks and Modelsim. The proposed fuzzy outputs were measured and the performance of the control system studied. It is found the proposed system was able to recover from most of the faults as in the case of Statcom. However the transients in the proposed system are much lower than the statcom based system. The research shows the elimination of statcom for low power generation systems where statcom's can be substituted by PV system and additional capacitor banks. Further work needs to be carried out in the areas of hybrid models which can replace Statcom and provide stable power to the grid even during faults.

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