DEVELOPMENT AND IMPLEMENTATION OF FPGA-BASED CONTROLLER FOR HYBRID RENEWABLE ENERGY APPLICATION.

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Abstract:
This work presents a proposed control model based on MPPT algorithm using P & O method implemented on an FPGA card. The focus of the work was to design and carry out software implementation of the proposed control strategy to track the maximum power point (MPPT) in the operating characteristics for a combine wind and solar power (hybrid wind/pv) system and extract maximum power under changing weather conditions. Model of the hybrid wind/pv system was done in Matlab Simulink and HOMER software program and simulation testing for validation and evaluation of the control strategy was carried out. The adopted control algorithm was implemented in Xilinx platform on the spartan 3 FPGA card using ISE design suite 14.7 program. The Xilinx system generated VHDL file is added to the program and downloaded on the FPGA card. The Matlab simulation results of the control strategy demonstrated an accurate operation of the control strategy and show that a smooth switching from MPPT mode to power tracking mode was obtained as the controller response's time to changes in weather conditions was in 5μs.

Index Terms: Spartan 3 FPGA card, Xilinx platform, ISE Design Suite 14.7 program, MPPT, P & O algorithm, Solar system, Wind system, Logic gates, Matlab Simulink software.

Introduction

Energy is essential to everyone's life no matter when and where they are. This is especially true in modern day society where people keep pursuing for higher quality of life [1]. Among the different types of energy, electrical energy is one of the most efficient and popular form that people need every day [2] for heating, cooling, cleaning, cooking etc. Human existence in modern day life cannot be imagined without electrical energy supply. The health sector, manufacturing, and processing sectors, and virtually all other sectors of the society need adequate, constant, and reliable power supply to operate which will create ultimately a robust economy and improved living standard of the citizenry.

In many countries, most energy demand is met by traditional energy sources such as fossil-fuels, nuclear energy, and hydropower. For example, in 2016, 86% of the world's primary energy demand was met by fossil fuels, 5% from nuclear energy and 10% from renewable energy including hydroelectricity which account for 7% approximately [3].

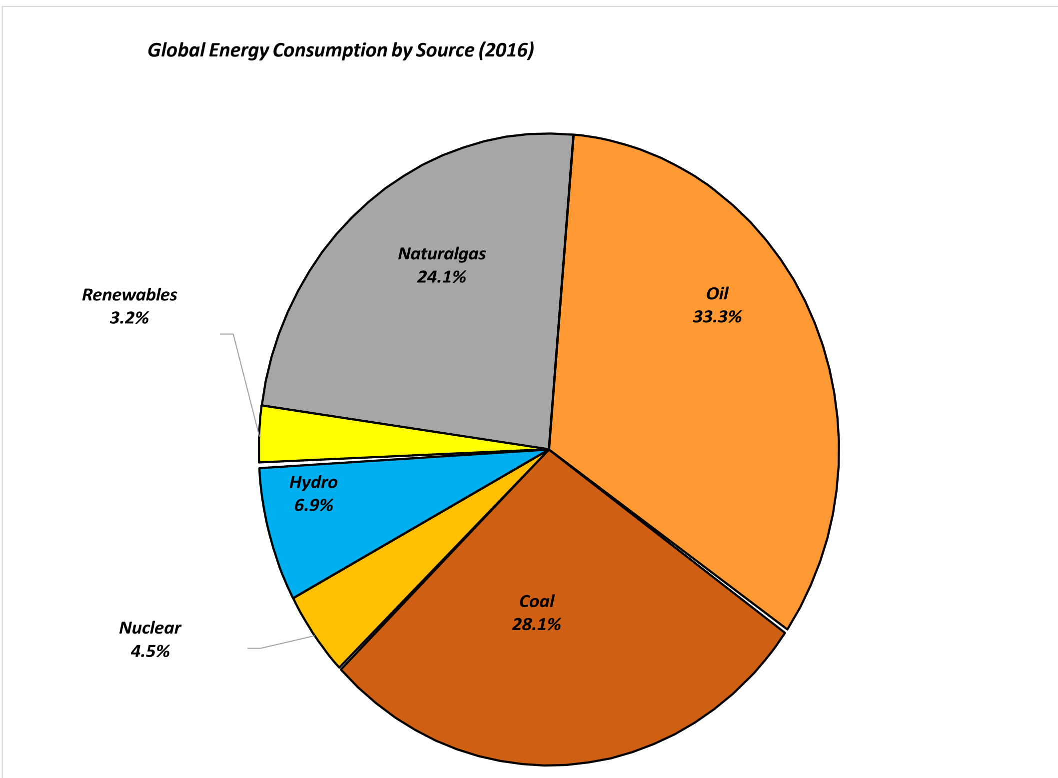

Figure 1: World energy primary consumption by source (2016) [3]

Electricity information (2017) by International Energy Agency reported that, in 2015 approximately 67% of the world's electricity was generated from fossil fuels (coal, peat oil and natural gas), 11% from nuclear materials, 16% from hydropower and the remaining 7% was produced from other sources including renewable sources [4].

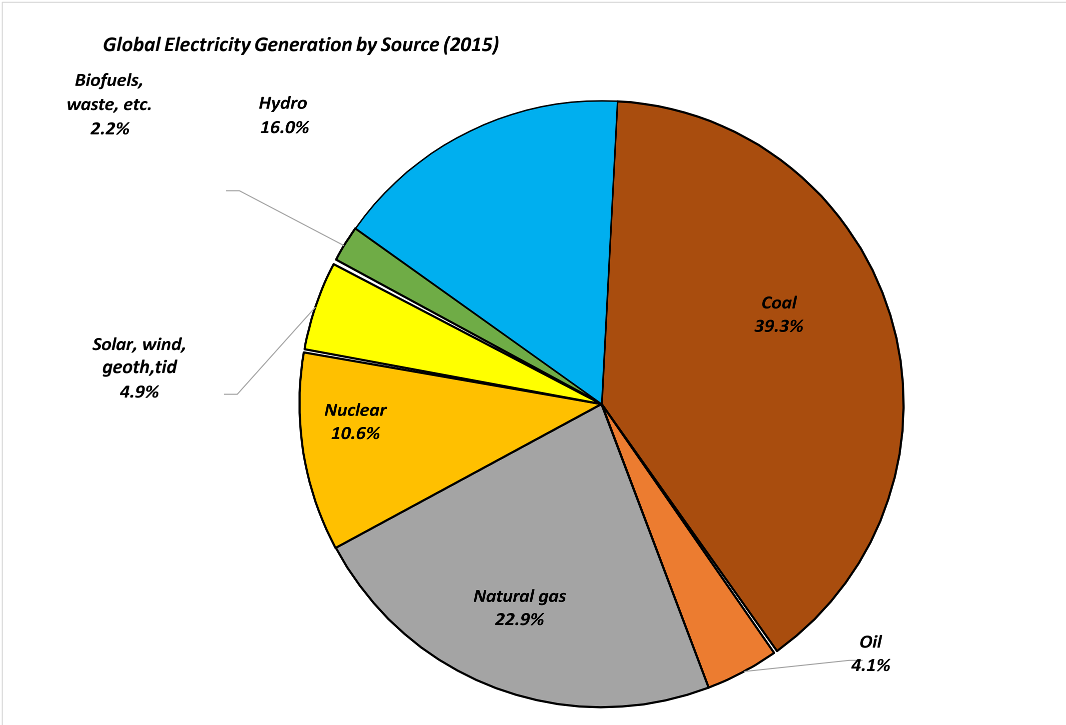

Figure 2: World electricity generation by source of energy (2015) [4]

A fraction of the world population still has no electricity and its associated benefits [5]. These includes people living in the rural areas, remote villages and non-electrified sites, The traditional approach to arrest this situation has been for decades to extend the grid [6] but different characteristics such as geographical location, accessibility, reduced consumption per household, transport infrastructure and a huge capital involvement among other issues have make this kind of undertakings difficult and unattractive for utility owners. Consequently, remote communities are left isolated or may rely on expensive alternatives such as diesel generators to cater for their energy needs. These generators create a strong dependence on fossil fuels and spares supply among other problems which includes high transportation cost, storage of diesel and noise pollution [7]. More worrisome is the rapid depletion of global fossil fuel reserves and increasing global demand for clean energy technologies to reduce the greenhouse gas emission ($C0_2$, $N0_X$ and $S0_X$) [8]. The vision of long-term European strategies for global climatic actions is to achieve net-zero greenhouse emissions by 2050 through a socially fair transition in a cost-effective manner [9]. Hence, urgent search for alternative solutions to meet growing demand as well as to power rural communities and remote sites is needed.

Renewable energy technology using solar, wind and tidal energy etc appears to be a promising alternative to provide reliable, cost-effective power supply to remote areas and non-electrified sites [10]. A key impediment is the intermittent and uncertainty nature of the renewable energy output under varying climatic conditions [11]. To overcome this challenge, the hybrid renewable energy system (HRES) maybe employed and incorporated with a battery energy storage system (BESS) and fast response management system using FPGA-based controller to improve the performance efficiency and increase the availability of power supply [12]. The battery serves to supply the mismatch power between the energy demand and the operating characteristics of the solar photovoltaic/wind energy system [13] while the FPGA shall serve to provide flexibility, coordination, and control of the operations of the hybrid generator in a systematic but swift-response manner. The HRES maybe composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy sources that works in off-grid (stand-alone) or grid connected mode [14]. In this study, the HRES consist of a solar photovoltaic/wind turbine/battery energy storage system (PV/wind/BESS) as represented in a simple block diagram in figure 3, in which a fast-acting energy management system using FPGA controller is developed and incorporated.

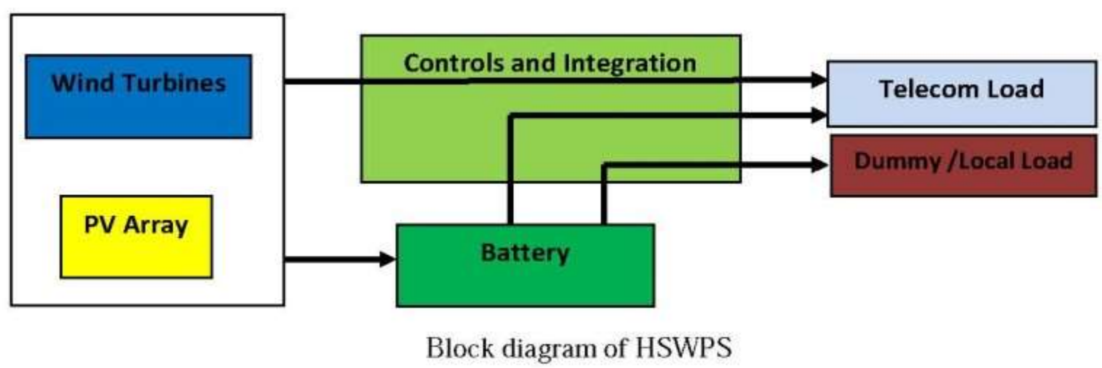

Figure 3: Block diagram of hybrid solar-wind power system (HSWPS) incorporated with battery energy storage system (BESS) [8].

In this work system design and implementation of P & O control algorithm on FPGA in Hybrid Optimization of Multiple Energy Resources (HOMER) and Matlab/Simulink Software programme is done in such a way that, if the power generation from the solar and wind energy is higher than the load, the surplus power is stored in the battery. On the contrary, when the power generated from these resources is less than the load power demanded then, the unmet power is supplied through the battery storage system. In case of the battery reaches the maximum state of full charge condition; the surplus energy is dissipated in the dummy or local load. The control strategy ensures execution of efficient power management, maximum energy transfer and avoid power quality issues in the power delivered.

Description of Material Components and Method

The proposed hybrid power system is composed of a solar panel (AMSO Solar LS390), a wind power generator (ATO-WT-400M2, 400W, 24V), a lithium-ion battery (Li FePo4, 24V), and power converters (an uncontrolled rectifier, a single-phase inverter, a filter, two buck converters, a high gain boost converter, and a bidirectional buck-boost converter). The solar and wind turbine sub-systems are model. Solar irradiance (I) and Temperature (T) are inputs to the solar system while for the wind turbine system, the wind speed (w) serve as the input. The output of the hybrid system is dependent on the prevailing environmental conditions as the input parameters are environmental factors and this tend to result in fluctuation in the system output. But for optimal operational conditions to be reached, a DC/DC converter maybe be introduced with proper controls. As a result of varying solar irradiation, insulation and the limited or no available grid source especially in remote areas (e.g rural communities), the battery may not get full charge state, from a PV source alone. The PV source integrated with a wind turbine energy source to achieve continuous power supply as the battery will now get more energy to attain full charge state.

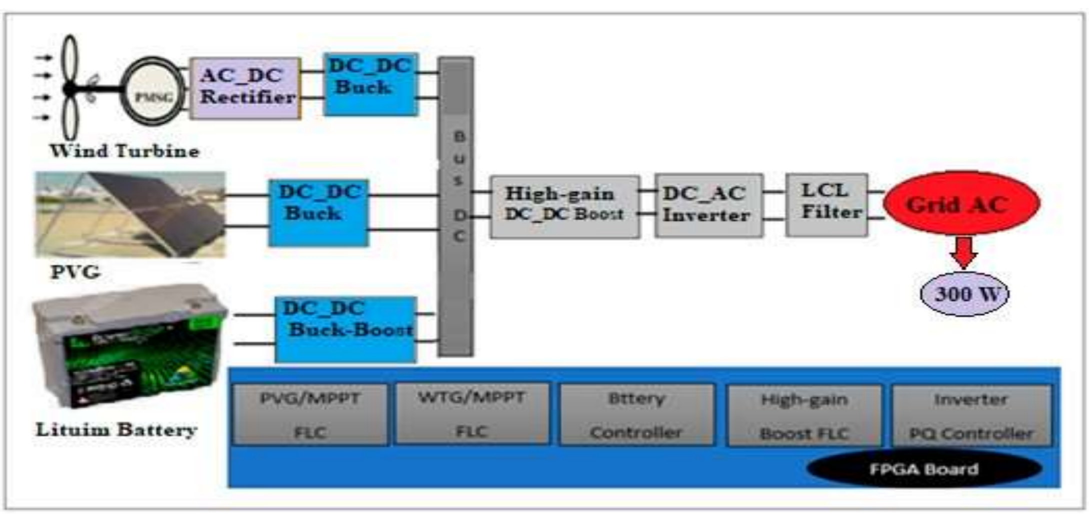

Figure 4: The Hybrid System Set-up [15]

To optimize the hybrid energy scheme, an efficient intelligent power conditioner and optimal load management is incorporated to control the system output for a 24-hour power supply. In this paper, the perturb & observe algorithm is used to generate control signals through software program coded with VHDL and downloaded in FPGA Spartan 3 starter kit to produce base drive signals for inverter power device. The FPGA VLSI technology platform provides a fast-acting system control. The beauty of the technology is such that the software program can easily be changed to optimize and control the inverter parameters like frequency, voltage amplitude, number of generated control signals/pulses without necessarily making any change in the hardware circuit.

a. The Solar Panel Array

The solar panels consist of solar cells (Monocrystalline) which generate electricity when sunlight falls on them by photovoltaic effect.

Figure 5: Solar Basics [16]

When the sun's energy illuminates the solar cell the separation of excited electrons and holes take place giving rise to source current. This is possible because of the built in electric field of the p-n junction present at the depletion region. The current output is directly proportional to the quantity of light falling on the cell [15]. This means that the cell functions optimally during the day but at night when the sun radiation is almost zero, the cell is not active, it works as a diode (i.e.,) a p-n junction. Thus, the diode determines the I-V characteristic of the cell. Figure 6 shows the equivalent circuit of PV cell.

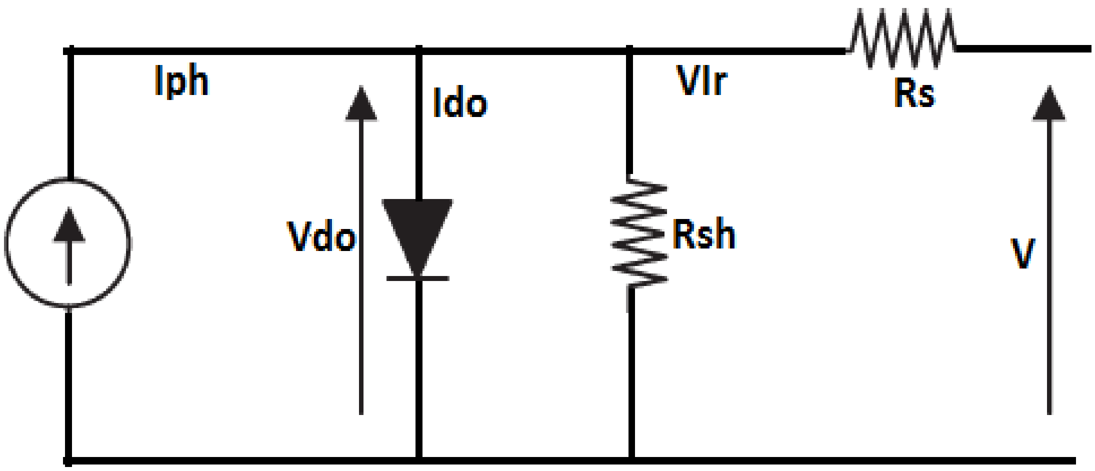

Figure 6: the equivalent circuit of PV cell.

The output current I and the output voltage of a solar cell is given by,

$$I = I_{ph} - I_{do}\left[exp\left(\frac{qV_{do}}{nkT}\right) - 1\right]\left(\frac{V_{do}}{R_{sh}}\right) \quad 1$$

Where I_{ph} is the photocurrent, I_{do} is the average current passing through the diode, q is the electron charge (1.6 x 10^{-19}C), I is the reverse saturation current, n is the diode factor, k is the Boltzmann constant, T is the solar panel temperature, Rsh is the shunt resistance and Rs is the intrinsic series resistance.

The output voltage is zero at short circuit and the average current passing the diode is neglected [15]. Under this condition the short, circuited current may be written as;

$$I = I_{sc} = \frac{I_{ph}}{\left(1+\frac{R_s}{R_{sh}}\right)} \quad 2$$

The output power is therefore given by

$$P = VI = \left(I_{ph} - I_{do} - \frac{V_{do}}{R_{sh}}\right)V \quad 3$$

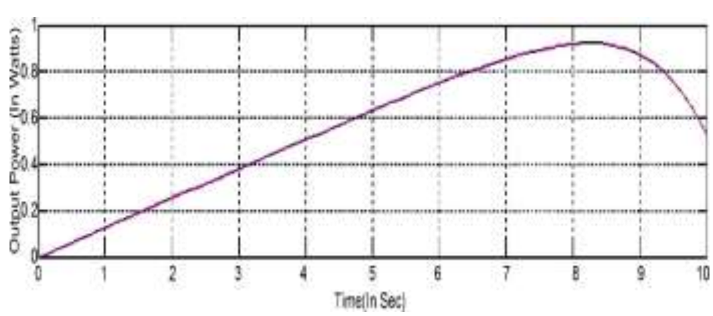

Figure 7: Typical Output Power Characteristics curve of the PV system

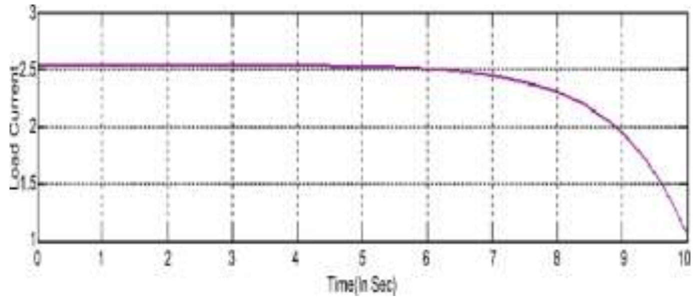

Figure 8: Typical Output Current PV characteristics curve.

b. The Wind Turbine System

The wind system consists of two wind turbine units. Each unit consists of two wind generators of 400W rating. The two wind turbines are connected in parallel to supplement PV generator power supply to the remote loads. The wind system 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 wind turbine output power is given by.

$$P_{wT} = \frac{\rho A}{2} V^3 \quad 4$$

The mechanical power out of the wind turbine is given by,

$$P_m = C_p(\lambda, \beta) P_{wT} \quad 5$$

Where $\boldsymbol{\lambda}$ is the tip speed ration, β is the blade pitch angle and Cp ($\boldsymbol{\lambda}$, β) turbine performance cooefficient.

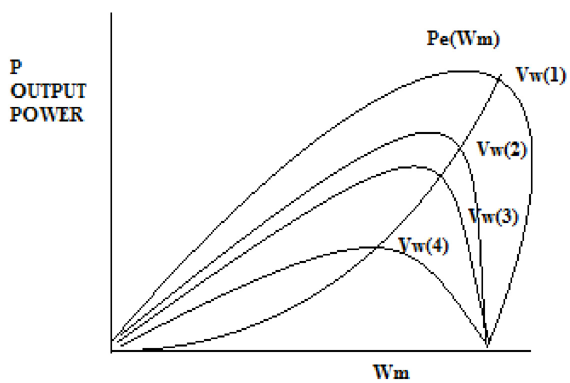

Figure 9: Typical Wind turbine output characteristic curve

c. Lithium-ion Battery

Energy storage systems are mainly used in renewable energy system, commercial and home Energ storage systems (ESS), communication centers etc. Lithium-ion battery is one of the best provides a very good solution in green energy applications because of its longer service life, superior reliability, and high-performance efficiency [16].

Figure 10: 24V lithium-ion battery [16]

The lithium-ion battery is of different types,

1. 12.8V lithium -ion phosphate battery
2. 12.8 lithium-ion battery
3. 24V lithium-ion battery
4. 48V lithium-ion battery

Each of the above batteries has different Amp-hour (AH) ratings. There is the 54AH, 80AH, 100AH and 200AH. Selection of any of these batteries for green energy application is based on the intended use and characteristics performance of the batteries. The 24V, 100AH type lithium-ion battery is chosen for this work because of fast charging and discharging feature; about 10 times faster than lead-acid batteries, long life cycle, wind temperature range (20-55^{o}C), light weight; about one third the weight of lead acid battery of same capacity, lower self-discharge rate and high strength ABS shell [16].

d. Perturb& Observe Algorithm

Pertub & Observe algorithm is a type of maximum power point tracking (MPPT) based on hill climbing concept in that, the hill climbing method considers perturbation of duty cycle whereas the pertub and observe method considers perturbation of operating voltage [17]. By this concept, increase in voltage of renewable energy generator (PV, wind) results in increase in power up to maximum power point. This means that, as the voltage rise, the power rises when the operating point is on the left of the mpp and decreases when the operating point is on the right of the mpp. The controller adjusts the voltage by a small amount from the renewable energy generator and measures power; if the power increases, then further adjustments in that direction are tried until power no longer increases. Perturb and observe introduces an initial perturbation to the voltage by changing duty cycle of converter and then observations are made using sensing circuitry.

P&O algorithm made use of voltage and current measurements to compute variation in power with respect to change in time and change in the duty cycle of the signal sent to the gate of the switch in the boost converter [18].

If we consider that the change in power and change in duty cycle can be each either positive or negative, then there are four cases under which we can determine whether the duty cycle of the gate signal should be increased or decreased. The four cases are shown in Table 1.

1. The first case, when both power and the duty cycle has increased, the duty cycle should continue to increase toward the MPP.
2. The second case is similar except the duty cycle should continue to decrease toward the MPP.
3. The third case is when the duty cycle has moved the operating voltage away from the mpp so that the power decreases.
4. The fourth case is characterized by increase in power as the duty cycle is reverse.

Table 1: Summary of P & O/Hill Climbing Algorithm

Duty cycle Perturbation	**Change in Power**	***Duty cycle Next Perturbation***
Positive	Increase	*Positive*
Positive	Decrease	*Negative*
Negative	increase	*Negative*
Negative	**Decrease**	***Positive***

The system oscillates around MPP and oscillations are minimized by decreasing perturbation step size. But decreasing perturbation step size slows down MPPT algorithm. Variable pertubation step size gets small time to track MPP and are therefore to avoid deviation from the mpp.

i. MPPT of the PV system

A PV power system usually consists of solar panels, power converters and load. The maximum power point can be captured by tuning the controller and regulating the converter. MPPT control methods have been used in PV generation system to eliminate the mismatch between load current and PV voltage and point of maximum power [19]. Tracking MPP for solar system helps to enhance the efficiency of system and reduce energy cost. Mppt algorithm by P & O method is used in this work because of its simplicity and system independency and implemented to measure the output of the PV cells with varying radiations. In this algorithm, the PV array voltage and current is measured, and the controller is designed to obtain the maximum power point mpp. Initially the output voltage Vdc and output current Id of the solar energy can be sensed since there two inputs and then compute the output power P_o. By using the P & O algorithm the value of the reference current is determined to adjust the output power towards the maximum power.

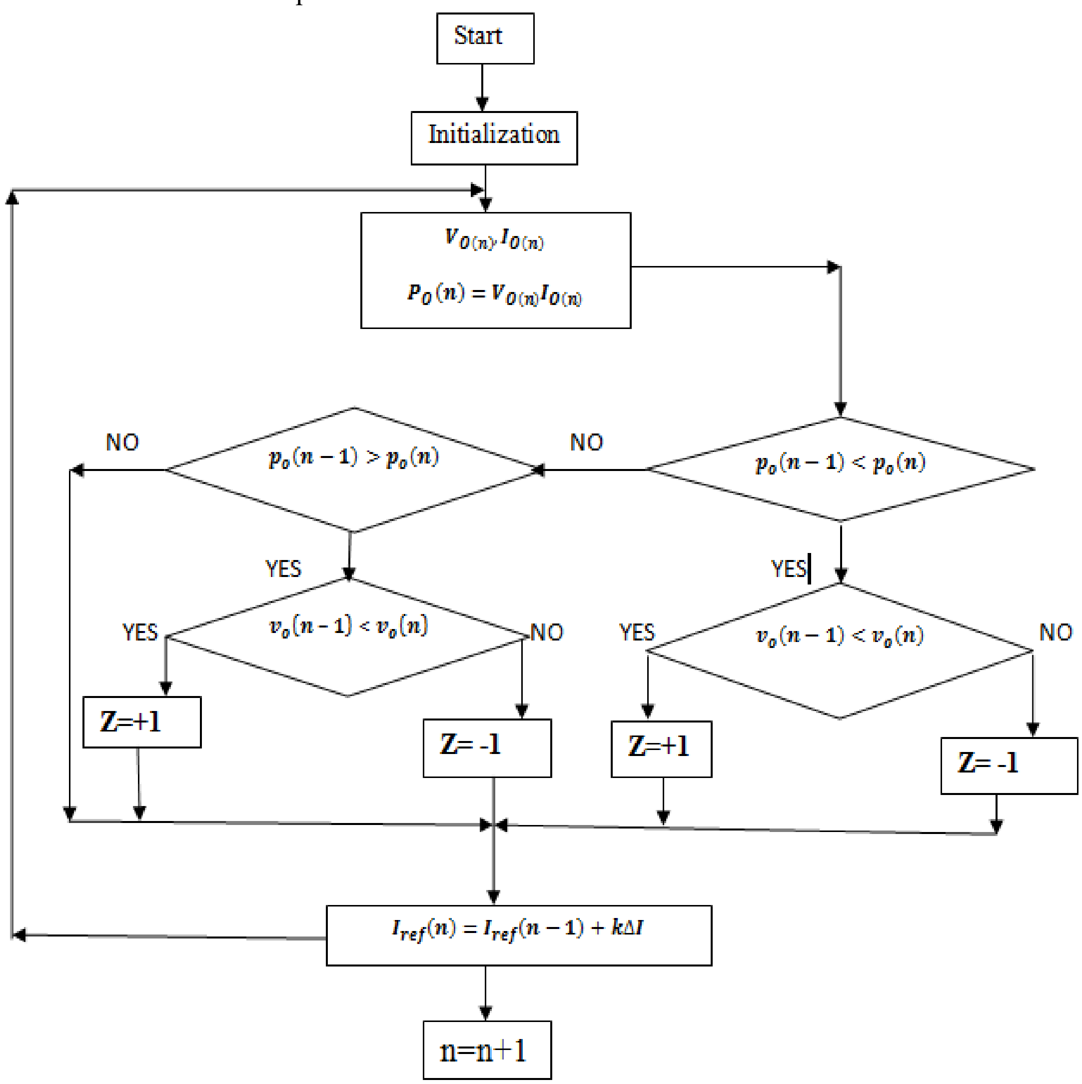

Figure 11: Flow chart of Mppt algorithm by P & O method for solar array [19]

ii. MPPT of the wind system

The MPPT algorithm by P &O method for wind energy system is based on monitoring the wind turbine output power using measurements of the output voltage and current and directly adjusting the power converter duty cycle according to the result of comparison between successive wind output power values to obtain an optimal reference curve [20]. The optimal reference power curve $P_{e(wm)}$ is obtained by finding the optimal power (P_{opt}) and optimal generator speed (w_{mopt}) for any given wind speed (V_m). For a given Vm, the generator speed w_m is swept, and the output power P is observed. The w_m and P that would give the $dp/dw_m=0$ is selected as w_{mopt} and P_{opt} for the specific V_m. By repeating the same procedure for different values of V_w a fitting curve can be obtained by connection of all optimal operating point (w_{mopt} , P_{opt}). The fitting curve can be used as a reference curve by way of being stored in form of lookup table in the controller. The controller is easy to implement for tracking of the best rotor speed to generate the corresponding power reference value without the need for wind speed measurement.

In this case the reference electrical power Pe is dependent on w_m according to the polynomial,

$$P_e = b_1 w_m^3 + b_1 w_m^2 + b_1 w_m b_4 \quad 6$$

where the coefficients b_1 to b_4 are determined by the fitting curve of optimal operation point connection. The mechanical model that connects the wind turbine shaft and generator rotor can be written as:

$$j\frac{dw_m}{dt} = T_m - T_e - Bw_m \quad 7$$

where J denote the inertia of the combined system, B is the damping coefficient, wm is the generator rotor speed, and Tm and Te represent the turbine and generator torques, respectively.

The turbine performance coefficient Cp(wm, Vm) and is expressed as follows,

$$C_p(w_m - v_w) = C_1\left(\frac{C_2}{\lambda_p} - C_3(R) - C_4\right)e^{\frac{C_5}{\lambda_i}+C_6\lambda} \quad 8$$

where λ = (wm R/VW), β is the pitch angle, and C1~C6 are the coefficients determined by individual turbine characteristics.

The P&O technique mainly generates a rotor speed perturbation and observes the variation of the output power to search for the point of maximum power. The advantage of the P&O method is that it requires neither wind turbine characteristics curve nor the generator parameters, so the control system can be used even under parameters changes [21].

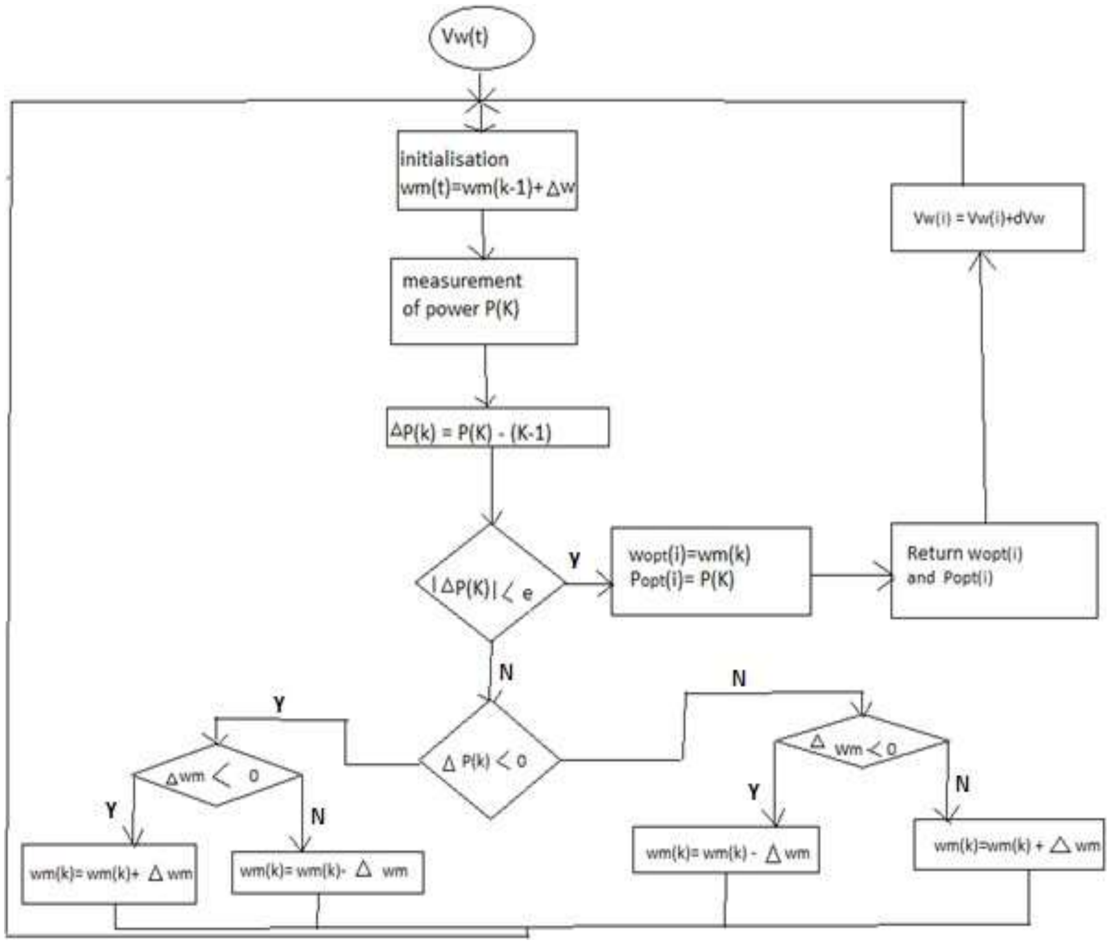

Figure 12. Flow chart of Mppt algorithm by P & O method for the wind system [20]

e. Field Programmable Gate Arrays (FPGA)

FPGA is a logic device which contains programmable switches and 2D-arrays of common logic cells [22]. FPGA can perform many tasks and complex operations some applications ranging from automated systems, mathematical operations such as multiplication, division, subtraction, addition, and other tools [22]. The Input Output Blocks (IOBs), programmable interconnects and Configurable Logic Block (CLB) are the basic components of FPGA [23].

CLB Consists of a variety of tiny logic gates/modules which are simple construction units that have interfaces inside the CLB. FPGAs have tens of thousands of Configurable Logic Blocks and are defined by a more robust overall architecture that can be implemented and reprogrammed and logic blocks can be connected to fundamental CLBs inside the global programmable interconnection row/column [24]. The logic module consists of the Lock Up Table (LUT) and the corresponding logic. LUT is a type of memory that can be reprogrammed and used to construct a flip-flop and a Sum of Product (SOP) combination logic function [25].

There are two ways to program or configure the FPGA board; by schematic editor or by Hardware Description Language (HDL) such as Verilog language and VHDL [26].

We have Xilinx, Altera, Atmel, and Lattice types of FPGA based on their manufacturers; however, the Xilinx type is most used. Xilinx FPGA has many versions and specifications; FPGA spartan kit is one of them for low-cost and high-volume applications.

Figure 14: FPGA Spartan 3 Card [26]

Proposed Control Strategy

For a hybrid dc energy system where the feed-in is from more than one energy source such as wind turbine and solar panel arrays, power is shared among the sources according to their output power characteristics [27]. A fast-acting controller is realised to track the maximum power generated by the power sources and coordinate the performances of the generators to meet the load demanded. Consider maximum power delivery to the load, the energy balance equation may be given as

$$P_{comb} = P_{wind} + P_{solar} - P_{load} \qquad 9$$

Where P_{comb} is the net power of the combined system (wind and Solar), P_{wind} is the output power of the wind system, P_{solar} is the output power of the solar system and P_{load} is the s the load power demanded. There are two scenarios of the control strategies.

1. When P_{comb} is lesser than or equal to zero (i.e $P_{comb} < 0$)
   This means that there is no maximum power in the output characteristics of the system, and this happens at some point under certain circumstances due to varied environmental conditions. The combine system cannot meet the load demand, then the battery supply the power demand to the load. In such a case, the combine system must work in MPPT mode to generate the maximum power under varied environmental conditions to avoid prolonged power outage to the load.
2. When P_{comb} is greater than zero (i.e $P_{comb} > 0$)
   This means that, maximum power is available as the combine generation system can conveniently send maximum power demand to the load with surplus energy stored in the battery [28]. In such a case of the generators maybe selected and deployed to operate in the MPPT mode while the other source is made to operate in the power tracking mode. By using the smart controller, the current reference value may be given as

$$I_{ref} = \frac{P_{load} - P_{mppt}}{V_{load}} \qquad 10$$

Where P_{mppt} is the output power of the source which operates in mppt mode and V_{load} is the output load voltage.

The schematic diagram for the overall system which takes both wind and solar inputs consist of a buck/buck boost converter fused together to receive two inputs simultaneously.

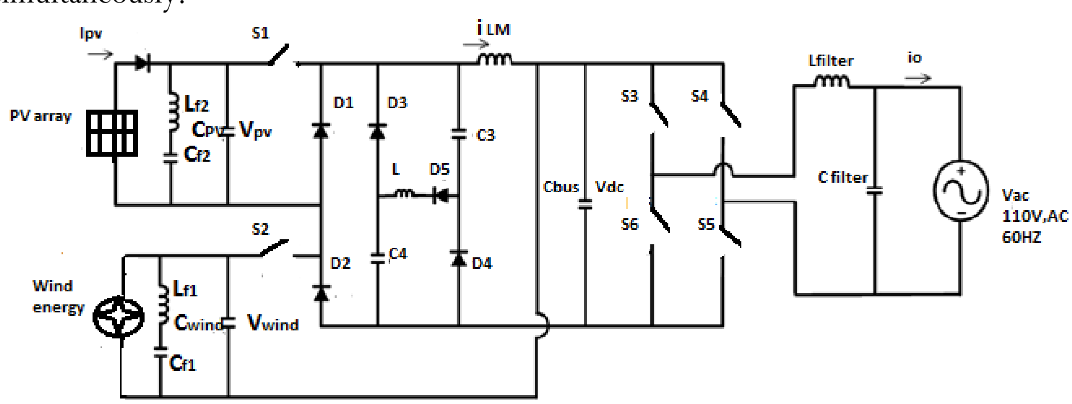

Figure 15: Schematic diagram of the buck/buck boost converter system with 2 inputs

The input for the wind system is the wind speed (w), the input for the solar system is the irradiance (I), the temperature (T). The FPGA controller takes the input signals from the MPPT algorithm to extract maximum power to the load.

Simulation of Proposed Control System

The proposed hybrid renewable generation system consisting of wind turbine, solar panel arrays with battery backup is modelled along-side FPGA protype controller in Matlab Simulink and HOMER software packages. The idea is to validate and evaluate the use of the controller and its strategy by ensuring negligible or minimal output power fluctuations in the face of changing weather conditions. The outcome of the simulation was compared with an already simulated hybrid system consisting of a solar PV system with battery backup which simulation carried out in Matlab Simulink and HOMER software program.

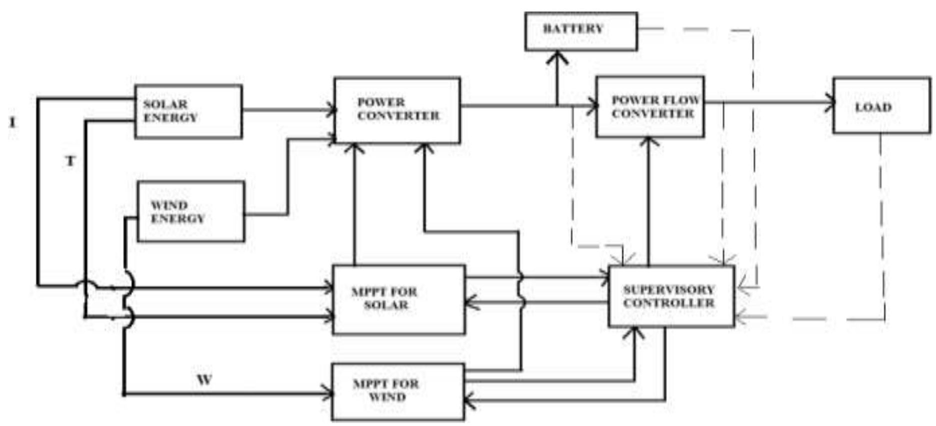

Figure 16: Block diagram of the proposed combined system

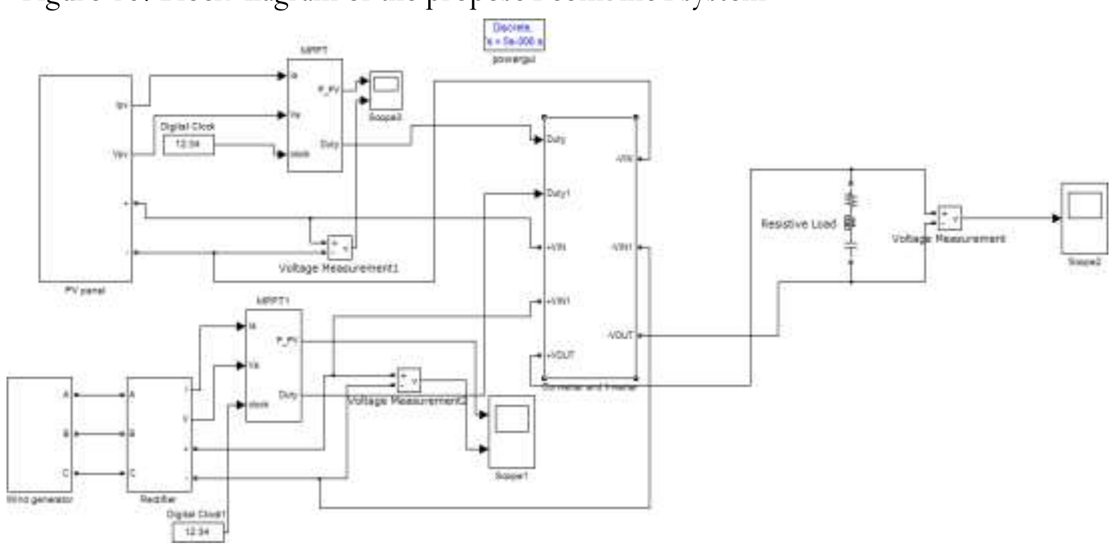

Figure 16: Model of the combine system

Results

The results show that, the proposed controller provide better controls and less output power fluctuations during load variation and performance disturbance than conventional controller. The time response between transactions of the FPGA controller was found to be about 5μs.

Upon the validation and evaluation of the FPGA control system progress by simulation, the adopted algorithm is implemented in Xilinx platform. Spartan 3 FPGA card is chosen for this implementation.

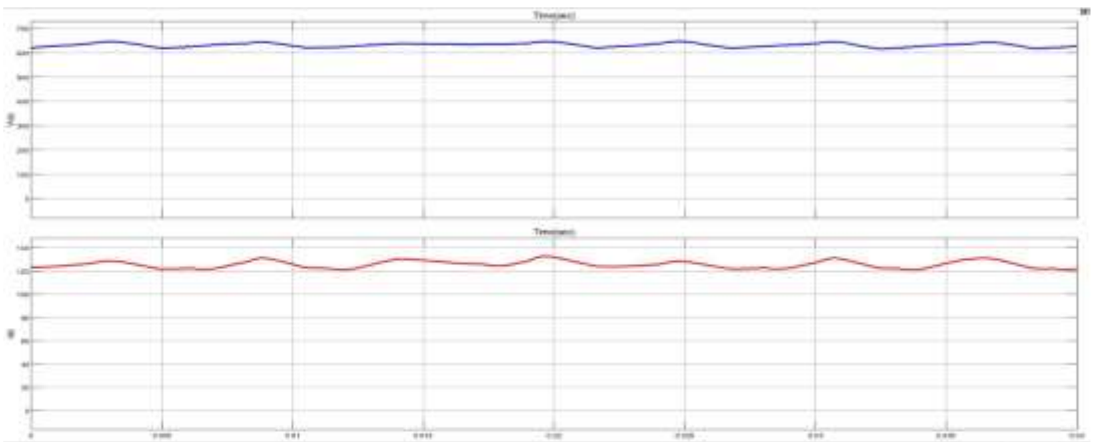

Figure 17: output dc voltage and current of combined system

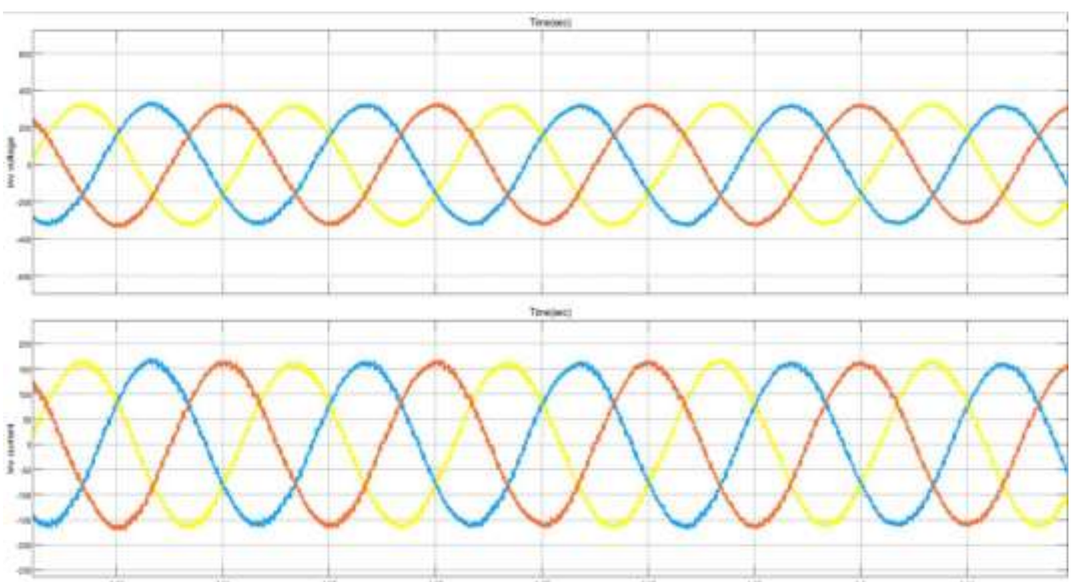

Figure 18: Output inverter voltage and current of combine system.

Implementation

The FPGA control strategy is tested using Xilinx system generator by connecting ISE 14.7 design suite program to Matlab Simulink environment. The configurable file is obtained by converting the control design strategy into a FPGA synthesizable module. On the token window dialogue box of the system generator, the compilation type is selected and define the FPGA part (Spartan 3). The tool for synthesizing the design and the HDL compilation language (VHDL) are specified. The VHDL file is generated by the system generator from an HDL test bench and added to the programme to generate the programming file which is downloaded on the FPGA card. The VHDL programme is transformed at the register transfer level into basic electronic element such as logic gates and flip-flops etc.

The programming process is in various stages,

- ❖ Design summary specifications
- ❖ Design synthesis
- ❖ Design Implementation
- ❖ Generation of programming file
- ❖ Configuration of Target device

Table 2: Device Utilization Summary

Summary of logic utilization

S/N	Names	Number used	Number available	% Utilization
1.	Register (slice)	203	12,680	1.6
2.	Logics (AND/OR)	203		
3.	LUTs (slice)	2,655	6,330	42
4.	Pairs of Flip-fliop	2,610		
5.	IOBs	12	196	6.1
6.	MUXCYs	2,505	2,920	86

Discussion/Conclusion.

Globally, there seems to be increasing interest in the use of renewable energy as viable substitute to conventional energy sources with the unwavering goal to meet global energy needs especially at grid compatible reference values. The need for efficient and fast-acting intelligent controllers would be aa serious challenge to achieving the widely advertised global renewable agenda.

An FPGA controller for wind/solar PV hybrid energy system with battery backup was proposed, modelled, and simulated using MATLAB Simulink and Homer software programmes.

P & O control algorithm was adopted, and the method was implemented for the combined wind and solar PV system to demonstrate a stable and effective tracking performance under changing wind speed and solar irradiation while connected to a point oc common coupling. This was done by implementing the P & O algorithm on the spartan 3 FPGA card using ISE design suite 14.7 program and the results show that, the fast-acting, intelligent controller's response to changes in environmental conditions was in 5μs and a smooth switching from MPPT to power tracking mode was obtained.

FPGA are the best microprocessor for achieving fast and intelligent controls in hybrid renewable energy systems to cover the supply of global energy needs.

Recommendation.

The application and performance evaluation of the proposed FPGA control strategy for combine wind and solar PV hybrid energy system should be carried out for a functional poultry birds and fish farm as future work.

References

[1]. Gan L.K, Shek J.K.H, Mueller M.A (2015) "Hybrid wind –photovoltaic-diesel-battery system sizing tool development using empirical approach, life cycle cost and performance analysis: A case study" Energy conversion and management. vol. 106, pp: 479-494.

[2]. Sandeep Kumar, N., (2014) "Power Quality Issues and its mitigation Techniques" A Dissertation Submitted to the Faculty of Engineering Technology, National Institute of Technology, Rourkela.

[3]. British Petroluem (2017) "BP Statistical review of world energy" no 66, pp: 1-52

[4]. International Energy Agency (2017) "Electricity Information Overview" IEA statistics availableonline: https://www.iea.org/publications/freepublications/publication/electricityinformation2017overview.pdf

[5]. Franco canziani, Raul vargas, Jose A. Gastelo-Rogue (2021) "Hybrid photovoltaic-wind microgrid with battery storage for rural electrification: A case study in Peru. Front Energy Res. 8:528571.

[6]. Sawle et al (2015) "Review of hybrid energy systems with comparative analysis of off-grid hybrid system" Renewable and sustainable energy reviews, pp: 2217 -2235

[7]. Olumuyiwa O Fagbohunl, Bankole A. Adebanji (2014) "Integrated renewable energy sources for decentralized systems in developing countries" IOSRJ Electr. Electron. Eng. Vol. 9, no 2, pp: 26-35.

[8]. Subodh Paudel, Shrestha J.N, Fernando J. Neto, Jorge A.F. Ferreira, Muna Adhikar (2011) "Optimization of hybrid pv/wind power system for remote telecom station. Reprint submitted to IEEE International Conference on power and energy systems (ICPS)

[9]. European Commission (2018) "A clean planent for all; A European strategic long-term vision for a prosperous modern competitive and climate neutral economy, Brussel 2018.

[10]. Bartolucci et al (2018) "Hybrid renewable energy systems for renewable integration in microgrids influence of sizing on performance. Energy, 2018, pp: 774-758.

[11]. Rui Huang, Steven H. Low, Ufuk Topcu, Mani Chardy K (2019) "Optimal design of hybrid energy system with pv/wind turbine/storage; A case study" Conference paper on virtual power plant, distributed generation, microgrid, renewables and storage. IEEE SmartGridComm.

[12]. Gui Xiong, He Ling Cheng, Jin Xu, Lei Chen, Wen-Quan Tao (2017) "Optimal configuration of a wind/pv/battery hybrid energy system using HOMER software" Chemical Engineering Transactions. Vol. 61, pp: 1507-1512.

[13]. Rachelin Sujae (2014) "FPGA-based battery energy storage system using solar cells" Middle east journal of scientific research, Vol. 20 (4), pp 436-441

[14]. Rajalakshmi R, Mynavathi M, Booma J. (2020) "Optimization techniques-based hybrid renewable energy systems: A review"

[15] Allani M.Y, Riahi J, Vergura S, Mami A. (2021) "FPGA-Based Controller for a Hybrid Grid-Connected PV/Wind/Battery Power System with AC Load" Energies 2021, no 14, pp. 2108. https://doi.org/10.3390/en14082108

[16] Zargar M.Y, Mufti M.U.D., Lone S.A. (2017) "Modelling and control of wind solar hybrid system using energy storage system" Proceedings, IEEE International Confereence on Computing, Communication and Automation. ICCCA 2016. pp.965–970. https://doi.org/10.1109/CCAA.2016.7813855.

[17]Vinod Bachhao (2018) "Supervisory Control Interface for Experimental Hybrid Wind & Solar Energy System" A Thesis Submitted to Saint Mary's University, Halifax, Nova Scotia in Partial Fulfillment of the Requirements for the Degree of Master of Science in Applied Science April 19, 2018, Halifax, Nova Scotia.

[18] Lu Y, Wu H, Sun K, Xing Y, (2016) "A Family of Isolated Buck-Boost Converters Based on Semi-active Rectifiers for High Output Voltage Applications" IEEE Transaction on Power Electron. no 31, pp. 6327–6340.

[19] Chakraborty S, Reza S.M.S, Hasan W, (2015) "Design and analysis of hybrid solar-wind energy system using CUK & SEPIC converters for grid connected inverter application" Proceedings, International Conference on Power Electron, Drive System. pp. 278–283. https://doi.org/10.1109/PEDS.2015.7203442.

[20] Zou Y, Elbuluk M. E., Sozer Y. (2013) "Stability analysis of maximum power point tracking method in wind power systems," IEEE Transaction on Industry Applications, vol. 49, no. 3, pp. 1129- 1136.

[21] Sakthivel, B.K, Devaraj, D. (2015) "Modelling, Simulation and Performance Evaluation of Solar PV-Wind Hybrid Energy System" IEEE Electrical, Electronics, Signals, Communication and Optimization, pp. 1-6.

[22] Pang A, Membrey P (2017) "Beginning FPGA: Programming Metal Your Brain on Hardware" USA: Springer New York.

[23] Farooq U, Marrakchi Z, Mehrez H, Farooq U, Marrakchi Z, and Mehrez H. (2012) "FPGA Architectures: An Overview, in Tree-based Heterogeneous FPGA Architectures" Springer New York, pp. 7–48.

[24] Mealy B, and Tappero F. (2013) "Free Range VHDL" 1st edition. USA: freerangefactory.org.

[25] Chettibi N, Mellit A, (2019) "Study on Control of Hybrid Photovoltaic-Wind Power System Using Xilinx System Generator in Solar Photovoltaic Power Plants" Springer, Singapore, pp. 97–120.

[26] XilinX, (2015) "Spartan-3 FPGA Configuration User Guide" (UG380).

[27] Natsheh E M, Natsheh A R, Albarbar A. (2013) "Intelligent controller for managing power flow within standalone hybrid power systems" IET Science, Measurement & Technology, vol.7, no 4, pp. 191-200.

[28] Petreus D, Daraban S, Cirstea M.N (2016) "Modular Hybrid Energy Concept Employing a Novel Control Structure Based on a Simple Analog System" Advances in Electrical and Computing Engineering, no 16, pp 3-10

[29] Nair N.R. (2014) "Mabel Ebenezer Operation and Control of Grid Connected Wind/PV Hybrid System" IEEE Advances in Green Energy (ICAGE), pp. 197-203.

[30] Dondon P, Carvalho J, Gardere R, Lahalle P, Tsenov G ,Mladenov V.M, (2014) "Implementation of a feed-forward artificial neural network in VHDL on FPGA" Proceedings of the 12th Symposium on Neural Network Applications in Electrical Engineering NEUREL pp 37-40 DOI: 10.1109/NEUREL.2014.7011454