AN TWIN PEAK BASED FLC FOR MICRO-GRID CONNECTED INTEGRATED HYBRID RENEWABLE SYSTEM

Saravanan KUMARASAMY
Assistant Professor, Department of EEE, SKP Engineering College, Tamilnadu, India,
jaisaran1006@gmail.com

Dr. SenthilKumar AJITHAN
Professor, Department of EEE, Velammal Engineering College, Tamilnadu, India,
vastham@gmail.com

Abstract: *In this paper, the design of a micro-grid power system supplied from different hybrid renewable energy resource is proposed. The proposed system provides a highly efficient key for energy management, control and operation of micro-grid fed from hybrid energy resources like wind, solar, fuel battery and ultra-capacitor. Maximum Power Point Tracker (MPPT) is designed so as to attain maximum power output from the solar photo voltaic (PV) panel systems. The novelty of the proposed system fabrication in the method of Luo Converter for dc-dc conversion as opposed to single-ended primary inductor converter (SEPIC). A Twin Peak Detection (TPD) algorithm was introduced to determine the maximum output of renewable energy source for connect to the micro grid and other source for storage system. The Fuzzy Logic Controller (FLC) generates the signals to the converter based on the source and energy demand. The performance of the hybrid system was evaluated by simulating the models of individual units like PV panels, wind turbine, fuel, battery system and ultra-capacitor under different operating conditions.*

Key words: *Twin peak detection, Integrated renewable energy, MPPT, Fuzzy Logic Controller, micro grid.*

1. Introduction

The research interest in the development of renewable energy systems from different sources has been increasing in the recent years because of the huge benefits to the environment. Moreover, the conventional fuels like coal, crude oil and natural gas are non-renewable in nature with limited reserves and their continuous poses serious threat to the environment. However, the main areas of concern in the design of an efficient electrical power system using renewable sources involves generation, distribution, management, control and storage of power from different sources in an effective manner [1]. The intermittence nature of renewables sources like wind and solar energy necessitates that these power system has to be integrated with energy storage for interruptible supply. Thus, hybrid systems developed by integrating power input from different distributed renewable energy resources by overcoming the drawbacks in existing distributed systems is suggested [2]. The main challenge in hybrid power system relates to the design of integrated power converters which has the capability of easy interfacing, managing and controlling power from different resource terminals by employing simple, compact structure at a lower cost [3].

El-Shatter et al. have designed and simulated a hybrid photovoltaic (PV) - fuel cell power generation system. The design used electrolyzer for hydrogen generation for fuel cell. They adopted fuzzy regression model (FRM) for maximum power point tracking and extracting maximum level of solar power from photovoltaic cells. The controller designed in the model ensures continuous power supply to the load from PV array and fuel cell [4]. Sapiro et al. have developed an integrated photovoltaic – electrolyzer - fuel cell system for delivering continuous, consistent and eco-friendly power to facilities located in remote areas. The suitability of the module for telecommunications and medical facilities in remote location was also successfully tested [5]. Paul and Andrews have examined the techniques in attaining maximum power transfer between photovoltaic array by directly coupling with PEM Electrolyzer stack. They determined an optimal configuration of series-parallel connection involving PV panels and PEM cell. Practically, four PV modules with 75 W capacity was directly coupled with five PEM electrolyser stacks of 50 W capacity.

The study predicted the energy transfer between the units both theoretically and measured the actual energy transfer experimentally [6]. Li et al. (2009) have analyzed the performance of three stand-alone photovoltaic (PV) power systems by employing different energy storage technologies like Fuel Cell (FC) and Battery. The modelling of three hybrid power systems viz. PV/Battery system, PV/FC system, and PV/FC/Battery system. The results of performance evaluation indicate that PV/FC/Battery hybrid system is highly efficient, cost effective and require less PV modules [7].

Uzunoglu et al. (2009) have focused on the hybridization of alternate energy sources with FC systems. They integrated photovoltaic, fuel cell and ultra-capacitor systems using appropriate power controllers and control strategies to develop a sustained power generation system. The proposed model was developed using MATLAB, Simulink and SimPowerSystems environment. The study developed both mathematical and electrical models for the proposed system [8].

Leva and Zaninelli (2009) have developed a hybrid system consist of photovoltaic (PV), wind and diesel generation system for providing power to a remote Telecommunication installations [9]. Lagorse et al. have developed a hybrid standalone street lighting system that couples three power sources like photovoltaic, battery and fuel cell. The main focus of the work was conducting optimization analysis to identify the cheapest sizing configuration using algorithms like genetic algorithm and simplex algorithm.

A simulated model was developed and validated using various hybrid configurations [10]. Maclay et al. have developed a photovoltaic (PV) powered stand-alone system by integrating photovoltaic modules with reversible fuel cells, batteries and ultra-capacitors. Also evaluated the proposed system in terms of capital costs, sizing techniques, control strategies, etc [11].

Zervas et al. have analyzed the performance of a hybrid power generation system that includes photovoltaic array (PV), electrolyzer, metal hydride tanks and PEM fuel cells [12]. Shen (2009) performed sizing optimization of solar photovoltaic (PV) array and battery in a standalone solar photovoltaic system. Using energy efficiency model, the study calculated loss of power supply probability (LPSP) of power system for different sizing combinations of solar array and battery. Finally, the study was successful in identifying optimal LPSP for the specified load demand [13].

From the review or literature, it is very clear that even though significant research has been reported on the solar photovoltaic systems, yet very few work has been done in the area of integrating solar Photovoltaic, wind power, fuel cell and ultra-capacitor battery systems. Thus, the present study was structure around developing a hybrid system and optimizing the performance of the system using advanced controllers and converters system.

2. Three Phase Micro Grid connected Hybrid Renewable Power System

This paper proposes a three phase hybrid grid connected renewable power system (Figure 1) that integrates power from the renewable sources like wind turbine, solar PV panels, ultra-capacitor and battery system. As the supply of energy from renewable sources cannot be guaranteed all the time, a battery backup has been added to the hybrid system to develop an integrated micro-grid structure. One of the major advantage of the hybrid power system is that if one of the energy sources like solar energy fails to generate power and supply to the load, the other sources like wind energy, fuel cell, etc. can continue to provide uninterruptible supply at any point of time. Thus, the overall sustainability of the power system is warranted by ensuring continuous supply to the distribution system.

3. Modeling of Components of Three Phase Hybrid Renewable Energy System (HRES)

3.1 Modeling of Solar Energy Conversion System

Solar energy conversion system includes components like PV solar panels, MPPT and the Luo Converter. The input energy to PV system through solar radiation and total solar radiation on an inclined surface is estimated as

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (1)$$

where, Ib and Id are direct normal and diffuse solar radiations, Rd and Rr are tilt factors for the diffuse and reflected part of the solar radiations [14]. The total solar radiation depends on the position of the sun and shows varying temperature from month to month. The power output from PV system calculated on hourly basis for an area (m^2) on any average day of jth month, when total solar radiation of I (kWH/m^2) is incident on PV surface, is given by

$$P_{sj} = I_{Tjn} A_{pv} \quad (2)$$

where system efficiency η is given by [3]

$$\eta = \eta_m \eta_{pc} P_f \quad (3)$$

and, the module efficiency η_m is computed using equation 4.

$$\eta_m = \eta_r [1 - \beta (T_c - T_r)] \quad (4)$$

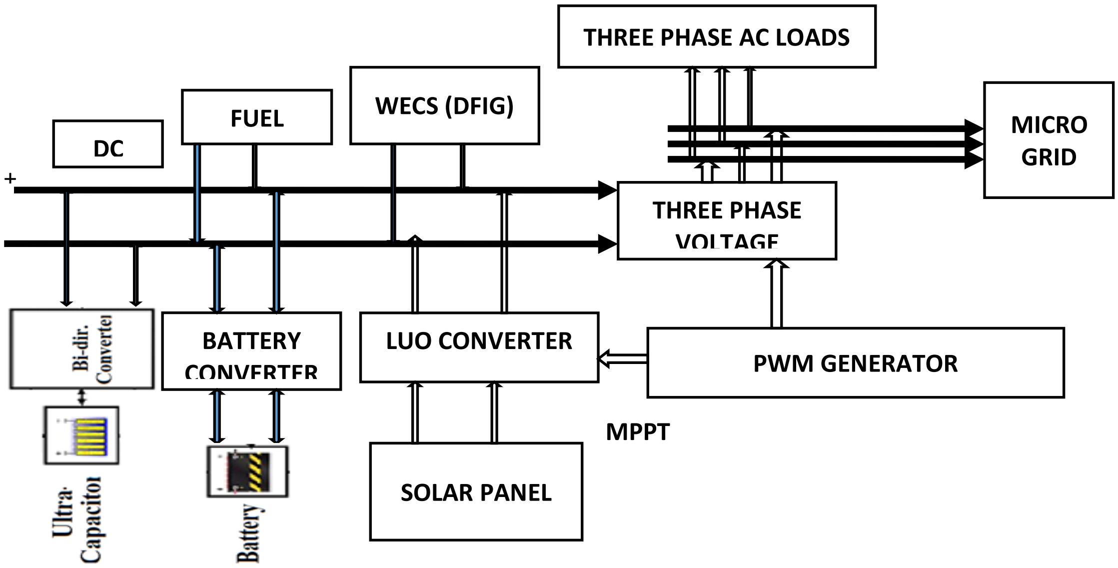

Figure 1: Block Diagram of the Three Phase Micro Grid connected Hybrid Power System

where, B represents the array η temperature coefficient, Tr denotes the reference temperature for the cell efficiency and Tc is the monthly average cell temperature [5] which can be calculated as follows:

$$T_C = T_a + \frac{a\tau}{U_L} I_T \qquad (5)$$

where, Ta is the instantaneous ambient temperature

Here the MPPT algorithm is mainly used to maintain the duty cycle and maintain it within the efficient frequency. It can also track the parameter by managing with temperature change

Table 1: Design Specifications of Solar PV Energy Conversion System

Input Voltage	70 V
Rated Current	12 A
Intensity	1000;
Temperature	32 ^{0}C
Power	666 W

3.2. Simulation of Luo Converter

The novelty of the work lies in the deployment of Luo converter for dc – dc conversion instead of single-ended primary-inductor converter (SEPIC) converter. Generally, the output of battery contains ripples and the voltage is not constant for direct application on electric vehicles or commercial use etc. DC – DC converters are used to attenuate the ripples present in the dc voltage [15]. However, several studies have shown that classical buck convertor are not effective in meeting the load requirements and are prone to parasitic effects. Thus, the advanced convertor design based on buck – boost convertor topology, named as Luo convertor has been used in this work [16]. The design specification of Luo convertor is shown in Table 2. The SIMULINK model for Luo converter is shown in Figure 2.

3.3. Simulation of MPPT Module

One of the main drawback of wind and PV based systems is their intermittent nature in terms of availability of power from these sources. Wind energy is highly unpredictable even though it is capable of producing large amounts of power.

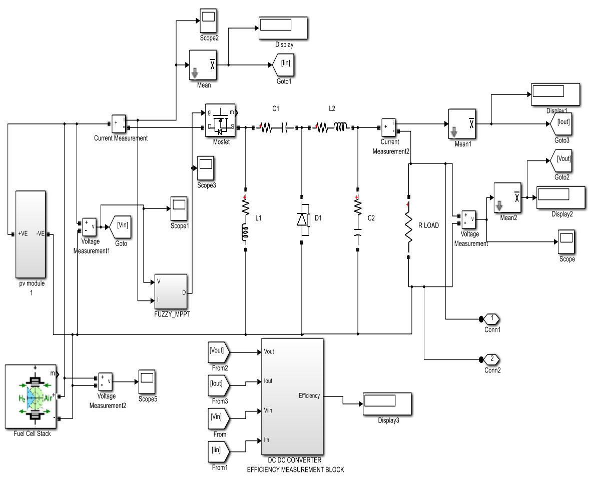

Figure 2: Simulation of Solar PV System and Luo Converter

Table 2: Design Specification of Luo Convertor

L1	L2
Resistance =0.0001 ohm	Resistance =0.0001 ohm
Inductance = 1 mH ;	Inductance = 1 mH
C1	**C2**
Resistance =0.0001;	Resistance=0.005ohm
Capacitance =4.7 µF ;	Capacitance =22 µF
Switching frequency (fs)=20 kHz	

Similarly, solar energy can be extracted throughout the day, but its efficiency is affected due to variations in sun's intensity and other obstructions to path of solar radiation on the panels. Thus, these drawbacks make renewable systems inefficient. However, by integrating maximum power point tracking (MPPT) algorithms, the efficiency of the renewable energy systems can be improved significantly [17]. The Matlab simulation of MPPT module is shown in Figure 3.

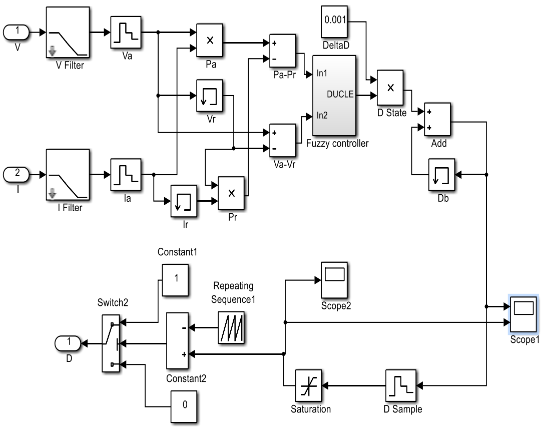

Figure 3: Simulation of MPPT Module

3.4 Modeling of wind energy system

The model uses variable speed wind energy conversion system based on a doubly Fed Induction Generator (DFIG). Space vector modulation (SVM) was used to control of active and reactive powers traded between the DFIG and the grid to ensure a Maximum Power Point Tracking (MPPT) of a wind energy conversion system and also for reducing ripples in the powers and torque components. The output power of wind turbine generator of a specific site is calculated based on the wind speed at hub height, speed characteristics of the turbine and temperature. Wind speed at hub height can be calculated by using power-law equation as given below:

$$V_z = V_i \left[\frac{z}{z_i} \right]^x \qquad (6)$$

Where Vz and Vi represents the wind speed at the hub and reference height (Z and Zi), and x is a power- law exponent. Power output Pw (kW/m2) from wind turbine generator was computed as follows:

$$\begin{array}{l} P_W = 0, \\ V < V_{ci}, \\ P_W = aV^3 - bP_r, \\ V_{ci} < V < V_r; P_W = P_r, \\ V_r < V < V_{c0}; P_W = 0, \\ V > V_{c0} \end{array} \qquad (7)$$

V_{ci}, V_{co} and V_r are the cut-in, cut-out and rated speed of the wind turbine.

Exact power generated in wind turbine is given by:

$$P = P_w A_w Z \qquad (8)$$

where Aw is the total swept area, Z is the efficiency of wind turbine system including converters.

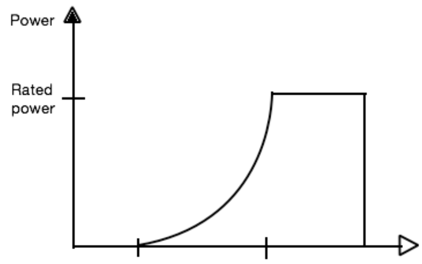

Figure 4: Wind turbine characteristics

The design specifications of Wind Turbine is shown in the Table 3.

Table 3: Design Specifications of Wind Turbine

Voltage	1.97 Kv
Frequency	50 Hz
Power	1.57 MW
Stator Resistance (Rs)	0.023 ohm
Stator Inductance	0.18 H
Rotor Resistance (Rs)	0.016 ohm
Rotor Inductance	0.16 H
Speed Input	15 m/s
Magnetizing Inductance (Lm)	2.9 H

3.5. Modeling of battery system

A fuel cell energy storage system has been proved as a promising alternative to batteries for storing energy from wind / solar PV power systems. In the proposed three phase hybrid power system, battery storage was included so as to meet the increasing load demands during the non-availability period of renewable energy sources. Battery sizing was done to determine the load withstanding capability of the battery. Battery sizing depends on various factors like depth of discharge, temperature correction, battery rated capacity and effective battery life. The equation for determining battery capacity (ampere-hr) is given below [9]:

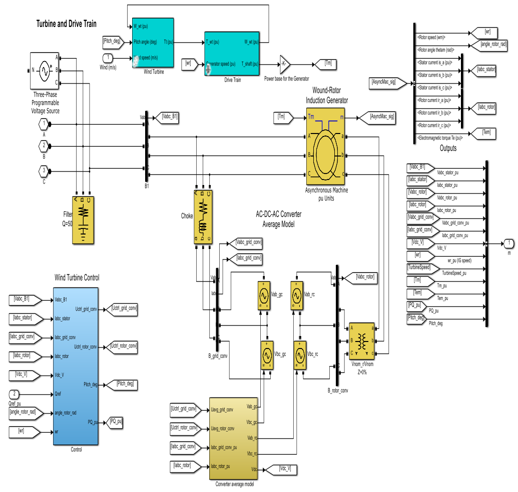

Figure 5: Simulation of Windmill

$$B_{rc} = \frac{E_{c(Ah)} D_s}{(DOD)_{max}\,\eta t} \quad (9)$$

where, $E_{c(Ah)}$ is the load in ampere-hr, D_s is the storage in days, η_t is the temperature correction factor, $(DOD)_{max}$ represents the maximum battery depth of discharge. The difference between the load and the power generated indicates if the battery is in charging state or in discharging state. At time t, the charge quantity of battery bank can be computed by [10]

$$E_B(t) = E_B(t-1)(1-\sigma) + [E_{GA}(t) - \frac{E_L(t)}{\eta_{inv}}]\eta_{battery} \quad (10)$$

where $E_g(t)$ and $E_g(t-1)$ represent the charge quantities of battery bank at time t and t-1, σ is used to calculate the hourly self-discharge rate, $E_L(t)$ is load demand at the time t, $E_{GA}(t)$ is the total energy generated by energy loss in controller by renewable energy source. Charge quantity of the required battery bank is subjected to the following constraints:

$$E_{B\min} \le E_B(t) \le E_{B\max} \quad (11)$$

where, EBmax and EBmin are the maximum and minimum charge quantity of battery bank. Here fuel cell is acting as the battery. Table 4 shows the design specifications of Lithium Ion Battery.

Table 4: Design Specifications of Lithium Ion Battery

Nominal Voltage	200 v
Capacity	1.5 AHr
Dynamic Response Time	30 Sec

The Matlab Simulink model of the fuel cell is shown in Figure 6.

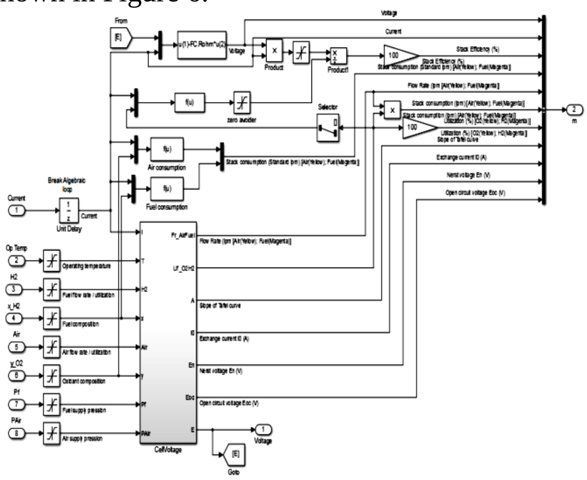

Figure 6: Simulation of Fuel Cell

3.6. Modelling of Ultra-Capacitor

Ultra-capacitors are electrical energy storage devices with high power densities when compared to batteries [18]. Ultra-capacitor banks has been included in the proposed model as an energy storage module as it has high cycling efficiency, convenience for charging/ or discharging, and can successfully handle instantaneous ripples/spikes in the load.

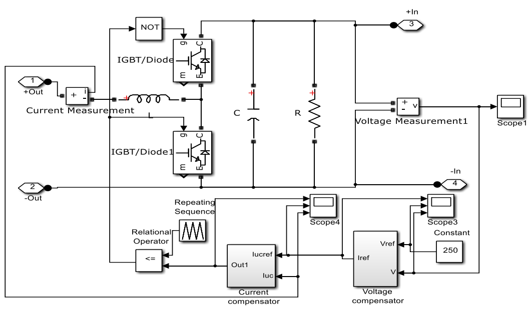

Figure 7: Simulation of Ultra Capacitor

In addition, Ultra-capacitor has been preferred as a backup to fuel cell module as fuel cells are easily affected due to overloading. Similarly, delays in load tracking and mismatches of the fuel cell can be compensated by ultra-capacitor bank. The design specification of Ultra Capacitor is presented in Table 5 and the Simulink model of the ultra-capacitor module is shown in Figure 7.

Table 5: Design Specifications of Ultra Capacitor

Reference Voltage	250 V
Output Voltage	600 V
Output Current	250 A
Capacitance Value	44 µF
Reference Current	8 A
Switching frequency (fs)	200 kHz

3.7. Modelling of Fuzzy Controller

Fuzzy logic controller has been used in the proposed model for managing the power flow between different hybrid power system modules like PV, WT, FC and energy storage elements like battery, Ultra Capacitor in order to satisfy the load requirements [19]. More specifically, fuzzy logic controller has been deployed in this work to manage distribution of power among the hybrid system and also controlling the charging and discharging current flow to achieve optimized performance. In addition, fuzzy logic controller was also used to control the temperature of Fuel Cell stack.

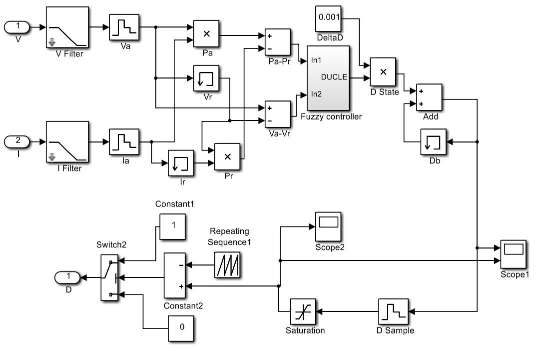

Figure 8: Simulation of Fuzzy Controller

In this paper, twin peak detection algorithm was introduced to find the maximum output voltage. The steps to define the maximum output obtained renewable source and connecting to the grid was determined by this algorithm.

step 1: Reading the tuned output voltage and current of PV and wind.

step 2: Base line value compared and eliminates the corresponding voltage renewable source.

step 3: Normalize the parameters

step 4: Check the parameters are peak or not.

step 5: if not peak and maximum parameter source connected to the grid.

step 6: Lower parameter connected to the storage system.

3.9. DQ TRANSFORMATION

Direct–quadrature–zero (dq transformation) is a mathematical transformation used to simplify the dynamic analysis of electric systems [20]. In dq transformation, phase and amplitude are treated as two decoupled components named as direct component and the quadrature component which appear as DC values in regular steady state operation. During dynamics analysis of system operation, the DC values will start oscillating. The dq transformation is commonly used in control of energy converters used in traction, power supply systems. DQ transformation is applied in this work to manage power quality issues and filtering harmonics in the power components. The Simulnk Model simulation of DQ transformation is shown in Figure 9.

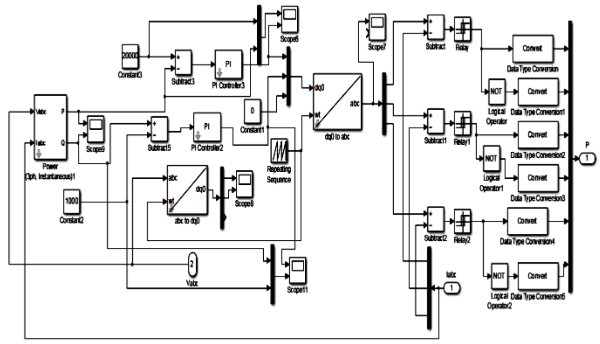

Figure 9: Simulation of DQ Transformation

3.10. Simulation of Three Phase Micro Grid Connected Hybrid Power System

The overall simulation of the 3 – phase grid connected hybrid renewable power system is shown in the following Figure 10.

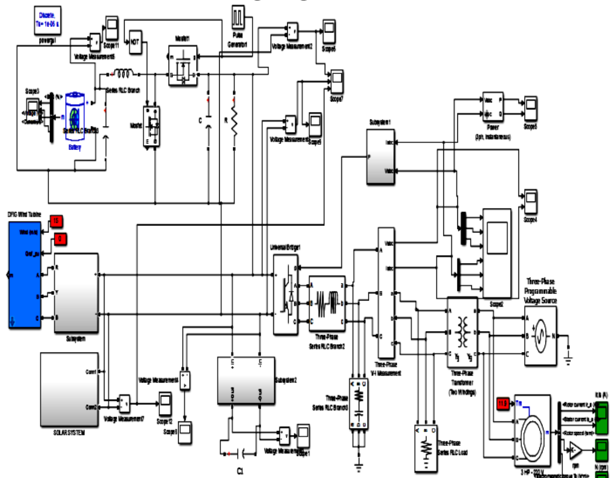

Figure 10: Simulation of the 3 – Phase Hybrid Power System

4. Simulation Results

4.1. Output Wave Form of Solar PV Panel

The output voltage waveform of the Solar PV system is shown in the Figure 11. The output voltage of the solar panel 20.82volts is achieved by tracking algorithm.

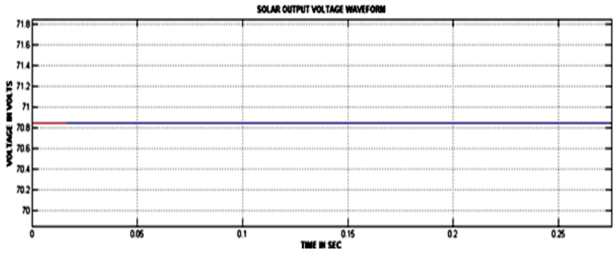

Figure 11: Output Voltage of Solar PV System

The solar output voltage is fed to the input of Luo converter to improve the output voltage of PV system. Then the simulation result of input current of Converter is shown in the Figure 12.

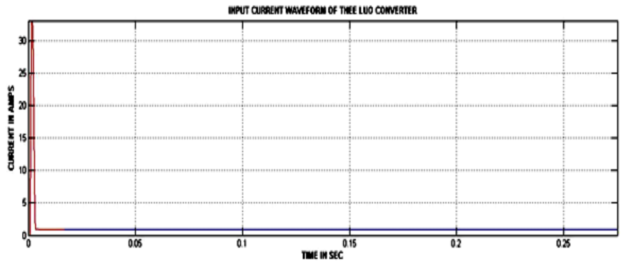

Figure 12: Input Current of Luo Converter

The output voltage Luo converter is 600Volts and the switching angle is generated by the twin peak control algorithm. The simulation results of output current and output voltage of Luo Converter is shown in the Figure 13 and Figure 14.

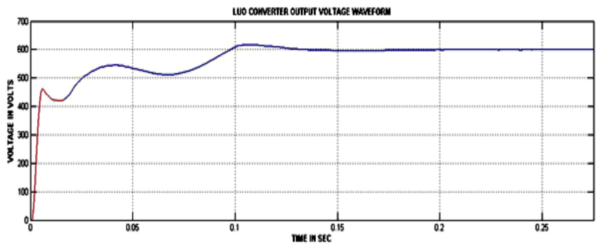

Figure 13: Output Voltage of Luo Converter

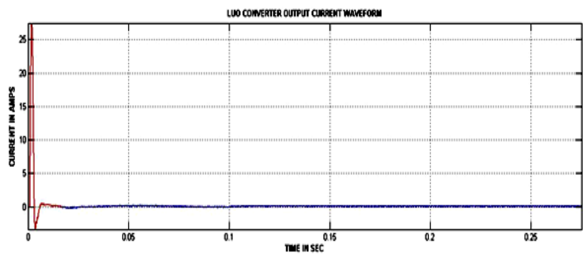

Figure 14: Output Current of Luo Converter

Similarly, the output of wind generator was controlled by indirect voltage control method and the peak output was achieved by the proposed control scheme. The simulation results of output voltage of double field induction generator is shown in the Figure 15.

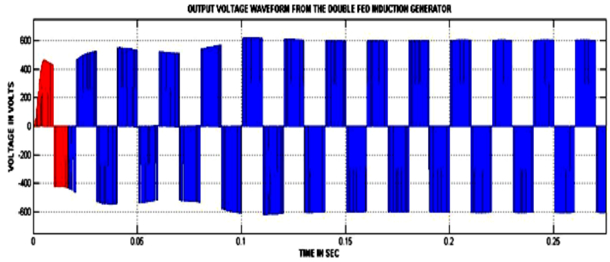

Figure 15: Output Voltage of Double Feed Induction Generator

The zero voltage switching scheme was implemented to reduce the switching losses of PWM rectifier and the simulation results of output voltage of PWM rectifier of WECS is shown in the Figure 16.The output voltage rectifier is 600 V stable voltage was obtained at the 0.14sec.

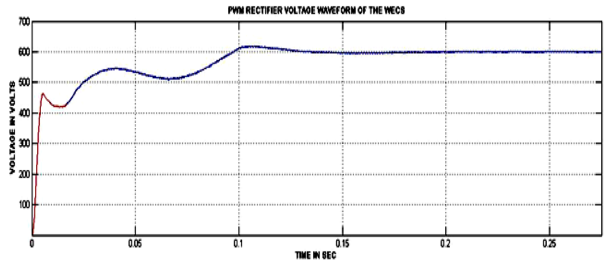

Figure 16: Output Voltage of PWM Rectifier of WECS

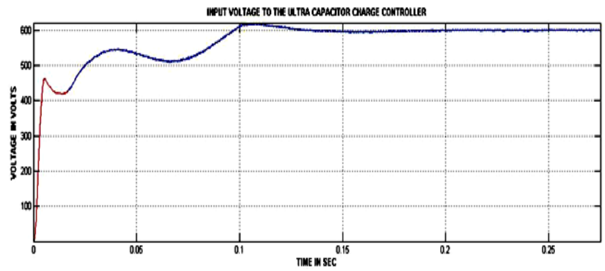

Figure 17: Input Voltage to the Ultra Capacitor Charge Controller

The demand energy needed by the grid was supplied by the renewable energy system and the short or small range of demand is supplied by the ultra capacitor. The off load renewable system of wind or solar is connected to the ultra capacitor to stored the energy. The simulation result of input voltage to the Ultra Capacitor Charge Controller is shown in the Figure 17.

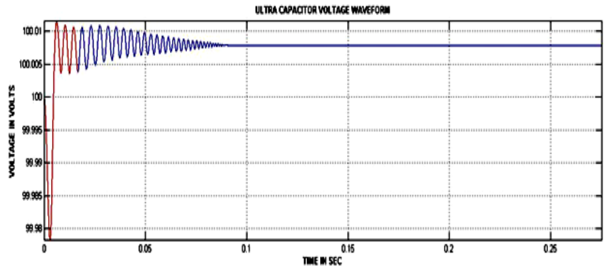

Figure 18: Output Voltage of Ultra Capacitor Charge Controller

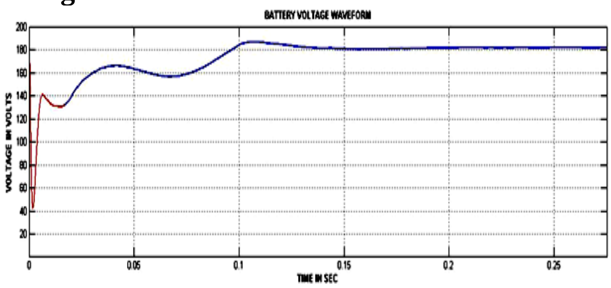

Figure 19: Battery Voltage Output

The simulation results of output voltage of Ultra Capacitor Charge Controller is shown in the Figure 18.The output voltage of ultra capacitor was fluctuated at the period of t =0 sec to 0.086sec.The closed loop PI controller settle the oscillated waveform and made the system voltage as stable. The corresponding battery output voltage waveform is shown in Figure 19.

The simulation results of input voltage to the three phase voltage source inverter is shown in the Figure 20. The simulation results of inverter output voltage is shown in the Figure 21.

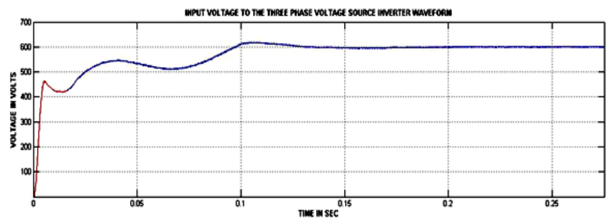

Figure 20: Input Voltage to the Three Phase Voltage Source Inverter

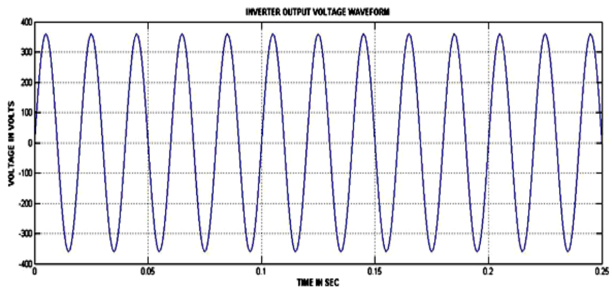

Figure 21: Inverter Output Voltage

5.9. Real and Reactive Power Waveform

The simulation results of real output power of hybrid power system is shown in the Figure 23. The simulation results of reactive output power of hybrid power system is shown in the Figure 24.The 600 w of real power is maintained constantly even though the hybrid system failed to supply the energy demand on grid. At the sametime, reactive power is 70 to 200 VAr at the hybrid system output.

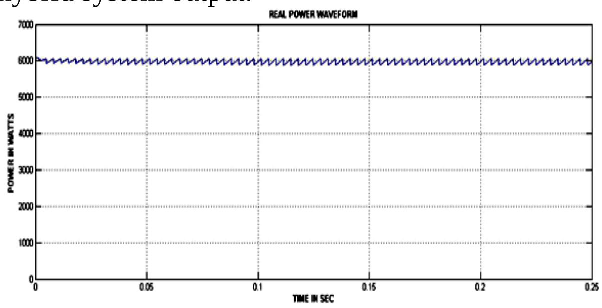

Figure 23: Real Power Output of Hybrid Power System

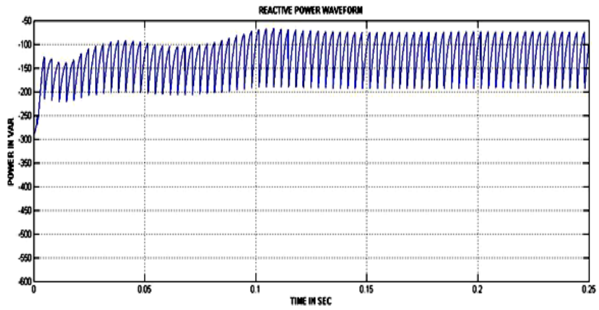

Figure 24: Reactive Power Output of Hybrid Power System

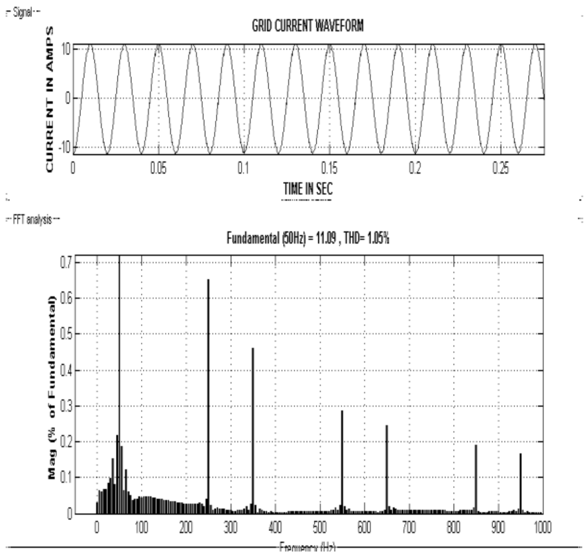

Figure 25: FFT Analysis - Grid Current Output

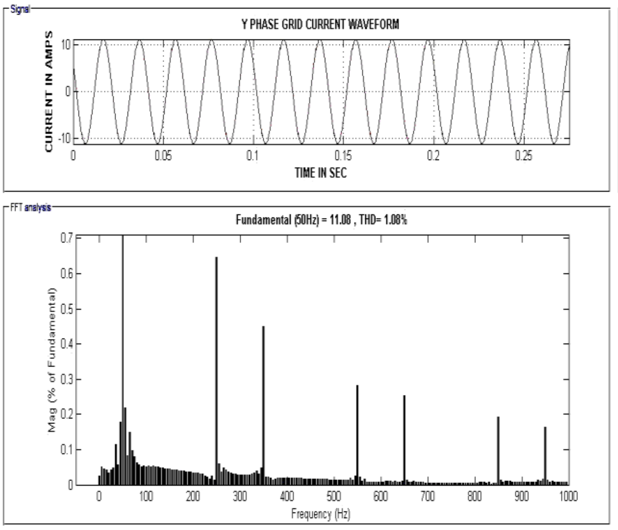

Figure 26: FFT Analysis For Y Phase Grid Current Waveform

The output current or grid current harmonics was reduced and this proposed scheme was achieved the less than 5% of IEEE standards of harmonics. The phase current THD are 1.05% and 1.08% in Figures 25- 26 respectively.

6. Conclusion

This paper proposes a three phase micro grid connected hybrid renewable power system that extracts power from the renewable sources like solar PV arrays, wind turbine and fuel cell. The proposed system also included energy storage elements like battery and ultra-capacitor modules for effectively storing and managing power from the renewable sources. The maximum power point was tracked from the solar and wind system effectively. The twin peak detection algorithm was successfully identified the maximum power generated source and connected to the micro grid from the integrated system. The rest of source was efficiently utilised by TPD for storage system. The gating signal converter was generated based on the micro grid by FLC and the additional energy demand was effectively supplied from the storage system. The advantage the proposed system lies on the use of Luo converter for step up/down and balancing the voltage instead of single-ended primary-inductor converter (SEPIC) converter.

References

1. Kabalci, E.: *Design and analysis of a hybrid renewable energy plant with solar and wind power*. Energy Conversion and Management, Vol. 72, p. 51-59, 2013.
2. Saravanan, K., Kumar, A. S., & Nandini, N.: *Design and simulation of Hybrid Renewable Energy System (HRES) to supply three phase induction motor using fuzzy logic controller*. Journal of Chemical and Pharmaceutical Sciences, Vol. 9, No. 4, p. 1922-1929, 2016.
3. Merabet, A., Ahmed, K. T., Ibrahim, H., Beguenane, R., & Ghias, A. M.: *Energy management and control system for laboratory scale microgrid based wind-PV-battery*, IEEE transactions on sustainable energy, Vol. 8, No. 1, p. 145-154, 2017.
4. El-Shatter, T. F., Eskandar, M. N., & El-Hagry, M. T.: *Hybrid PV/fuel cell system design and simulation.* Renewable Energy, Vol. 27, No. 3, p. 479-485, 2002.
5. Shapiro, D., Duffy, J., Kimble, M., & Pien, M.: *Solar-powered regenerative PEM electrolyzer/fuel cell system.* Solar Energy, Vol. 79, No. 5, p. 544-550, 2005.
6. Paul, B., & Andrews, J.: *Optimal coupling of PV arrays to PEM electrolysers in solar–hydrogen systems for remote area power supply*. International journal of hydrogen energy, Vol. 33, No. 2, p. 490-498, 2008.
7. Li, C. H., Zhu, X. J., Cao, G. Y., Sui, S., & Hu, M. R.: *Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology.* Renewable energy, Vol. 34, No. 3, p. 815-826, 2009.
8. Uzunoglu, M., Onar, O. C., & Alam, M. S.: *Modeling, control and simulation of a PV/FC/UC based hybrid power generation system for stand-alone applications*. Renewable energy, Vol. 34, No. 3, p. 509-520, 2009.
9. Leva, S., & Zaninelli, D.: *Hybrid renewable energy-fuel cell system: Design and performance evaluation.* Electric power systems research, Vol. 79, No. 2, p. 316-324, 2009.
10. Lagorse, J., Paire, D., & Miraoui, A.: *Sizing optimization of a stand-alone street lighting system powered by a hybrid system using fuel cell, PV and battery*. Renewable Energy, Vol. 34, No. 3, p. 683-691, 2009.
11. Maclay, J. D., Brouwer, J., & Samuelsen, G. S.: *Dynamic modeling of hybrid energy storage systems coupled to photovoltaic generation in residential applications*. Journal of Power Sources, Vol. 163, No. 2, p. 916-925, 2007.

12. Zervas, P. L., Sarimveis, H., Palyvos, J. A., & Markatos, N. C. G.: *Model-based optimal control of a hybrid power generation system consisting of photovoltaic arrays and fuel cells.* Journal of power sources, Vol. 181, No. 2, p. 327-338, 2008.
13. Shen, W. X.: *Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia*. Renewable energy, Vol. 34, No. 1, p. 348-352, 2009.
14. Feroldi, D., Degliuomini, L. N., & Basualdo, M.: *Energy management of a hybrid system based on wind–solar power sources and bioethanol.* Chemical Engineering Research and Design, Vol. 91, No. 8, p. 1440-1455, 2013.
15. Qian, Z., Abdel-Rahman, O., & Batarseh, I.: *An integrated four-port DC/DC converter for renewable energy applications*. IEEE Transactions on Power Electronics, Vol. 25, No. 7, p. 1877-1887, 2010.
16. He, Y., & Luo, F. L.: *Analysis of Luo converters with voltage-lift circuit*. IEE Proceedings-Electric Power Applications, Vol. 152, No. 5, p. 1239-1252, 2005.
17. Hui, J., Bakhshai, A., & Jain, P. K.: *A hybrid wind-solar energy system: A new rectifier stage topology*. In Twenty-Fifth Annual IEEE Conference in Applied Power Electronics Conference and Exposition (APEC), 2010, p. 155-161.
18. Burke, A. J.: *Ultracapacitors: why, how, and where is the technology*. Power Sources. Vol. 91, No. 1, p. 37–50, 2000.
19. Natsheh, E. M., & Albarbar, A.: *Hybrid power systems energy controller based on neural network and fuzzy logic.* Smart Grid and Renewable Energy, Vol. 4, No. 2, p. 187, 2013.’
20. Meyer, M.: *Concepts for measurements of "dq" frequency responses*. 12-0459, 2012.