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Design of Hybrid Energy Averaging Boost Controller (HEAB) For Renewable Applications

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Abstract: This study proposes an innovative hybrid renewable power generation operation and control strategy for Real-time applications. The proposed hybrid renewable power generation system consists of a wind turbine, a battery storage unit, a fuel cell, an electrolyzer and loads. The proposed control strategy is based on averaging the energy and power regulation system. Depending on wind and load conditions, this system generates reference dynamic operating points to low-level individual subsystems. The energy management and electricity regulation system also controls the charging scheduling operation during unfavorable wind conditions under inadequate energy storage to avoid a system blackout. Based on the reference dynamic operating points of the individual subsystems, the local controllers control the wind turbine, fuel cell, electrolyzer and storage battery units. The proposed control system is implemented in MATLAB software and tested for various wind and load conditions. Results are presented and discussed.

Key words: Battery storage, electrolyzer, energy management and power regulation system, fuel cell, load control, standalone hybrid power system, wind energy conversion system

INTRODUCTION

Hybrid power generation systems that combine different renewable energy sources and energy storage systems offer an environmentally friendly alternative for standalone operations. However, there are several challenges for the hybrid power system. Appropriate control and coordination strategies among various elements of the hybrid system are required so it can deliver required power. Renewable-energy-based hybrid systems must also be also reliable and cost-effective. Natural processes continuously replenish renewable energy sources. For example, solar energy, wind energy, bio-energy (bio fuels grown sustain ably), hydropower, etc., are some of the examples of renewable energies. A renewable energy system converts the electric power found in sunlight, wind, falling water, tidal, heat energy or biomass into a form; we can use such as heat or electricity. The wind has been used to power sailing ships for many centuries. Chemical energy is converted to electricity using fuel cell through a chemical reaction with oxygen or another oxidizing agent.

Literature review: Numerous related research works have already existed in literature which based on HRES control, THD and maximum power generation system. Some of them are reviewed here.

Best *et al.*(2007) Using of islanded method avoids out off synchronism re-closure is proposed. Islanded kept within reset are not electrically connected. And it was developed and followed in the usual single scenario on a 50 KVA diesel generator using different governor and its utilities supplementary input addition to engine speed. The result is the phase difference can be controlled within a specified limit.

Hajizadeh *et al*. (2010), The control and operational aspects of these elements and replacing the conventional load controller/dumped load unit and FC/ELZ are used for long-term balance, UC buffer storage for a transient condition. They developed dynamic modeling for each system. The result of this scheme is analysis summarized with their application to a real system and limitations are indicated.

Dalwadi and Metha (2012) here using renewable energy system and smart grids for charging in the weather condition and this says about solar and the wind to a small local load to enhance the reliability of power supply. Here dynamic performance modeling is used for hybrid power system includes charging/discharging purpose of storage devices. Here, the performance and analysis are using MATLAB and PSIM.

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Ipsakis *et al.* (2011) dealt with the concept of efficient power management scheme. The optimal power management schemes are based on the State of Charge (SOC) in the Hydrogen tank. The power consumption at the fuel cell depends on the excess or shortage of power from the RES and the level of SOC.

Zhou *et al.*, (2009) implemented the Classical wind energy conversion system which is usually a static generator. Power generation is based on variable wind condition. PI controller does control of this scheme. The result of this system is providing the dynamic wind generation can be build to provide some ancillary service to the grid.

Wang and Nehrir (2008) The proposed AC link for a stand-alone application. Wind/PV are the primary sources a fuel cell is a backup and a long-term storage system. Over system manage to power flow from different sources (Zhou and Francois, 2011). It is checked for the working load.

Wang *et al.* (2005) presented the Dynamic modeling for PEM fuel cell for using the electrical circuit. The fuel cell includes both double layer charging effect and thermodynamics characteristics; it is given response for the steady and transient condition is validated by A Vista lab SR-12- 500-W PEM fuel stack.

Garcia *et al* (2010) reviewed the advancement the cost of wind become competitive with generation fuel resource. Due to pollutant of non-renewable energy. The annual growth rate has exceeded 26% since 1990.More projects are implemented and economically beneficial to generate power .Wind condition should be controlled and this study has said about that how to reduce fluctuation in wind.

Johnson *et al.* (2006) presented the variable wind speed turbine and derived by a constant hydro turbine to supply three phase, four wire loads. It has back interconnection with PWM technique. In this system using SCIG and MPPT controller and voltage and frequency controller are modeled for various speed conditions. It is modeled for different aspects of speed condition. It eliminates the harmonics and load balancing.

Qiao *et al.* (2009), Khaligh *et al.* (2007) and Artuso *et al.* (2011) implemented the suitable system for remote area application and it satisfies the base load by renewable and other intermittent sources by the mini electrical grid. It relies on modeling, simulation and optimization of renewable energy source. The test is carried out using Homer program.

The control and operational aspects of these elements and replacing the conventional load controller/dumped load unit and FC/ELZ are used for long-term balance, UC buffer storage for the transient condition. They developed dynamic modeling for each system (Kim *et al.*, 2008; Zhou *et al.*, 2009). The result of this scheme is analysis summarized in their application to a real system and limitations are indicated.

MATERIALS AND METHODS

The general architecture of the proposed system circuit is shown in the Fig. 1. The proposed Hybrid renewable Energy Storage System (HESS) is organized into four blocks named as topology, electrolyzer, wind energy, fuel cell and battery with hybrid boost common control. The hybrid boost control based hybrid system suggests four possible modes of operation which are wind source (mode1), Battery energy management mode (mode 2) electrolyzer mode operation (mode-3) and Fuel cell source (mode-4,). A Hybrid Energy averaging boost (HEAB)-control system monitors parameters of the each local controller and transfers control directions to the maximum power according to the mode selected by an HEB. The fuel cell is controlled by the hydrogen flow regulator and HEAB boost converter. Hybrid boost converter controls the electrolyzer. The battery storage is controlled by a bidirectional dc –dc converter. The goal of this work is to attain Flexible, intuitive knowledge based design control for the Convenient Hybrid power applications. Hence for Easy Computation, Validation, contingency, redundancy and completeness can be checked by the rule-based control algorithm. HEAB control strategies in four possible modes of operation are explained below.

Working principles of Hybrid Energy Averaging Boost controller (HEAB): The proposed HEAB control system mainly based on an innovative rule-based logic that corrects the analogue values to logical binary output between 0 and 1. The proposed control system has MOSFET switch for triggering the common boost control scheme can deal with the simplified functions that happen to be either one value or another.

Conventional HESS connects the FC via a DC/DC converter to satisfy the real time peak power demands of the power train controller. To improve the power capability, DC/DC boost converter required to have maximum possible demand value. The proposed HEAB achieves this in a different way, which can beconsidered an application of the averaging concept. The averaging concept is introduced as follows in Fig. 1 and 2. Initially, the constant speed operation of the vehicle was separated into two depending on if the power of the DC/DC converter (P conv) can cover the power demand (Pdmd).

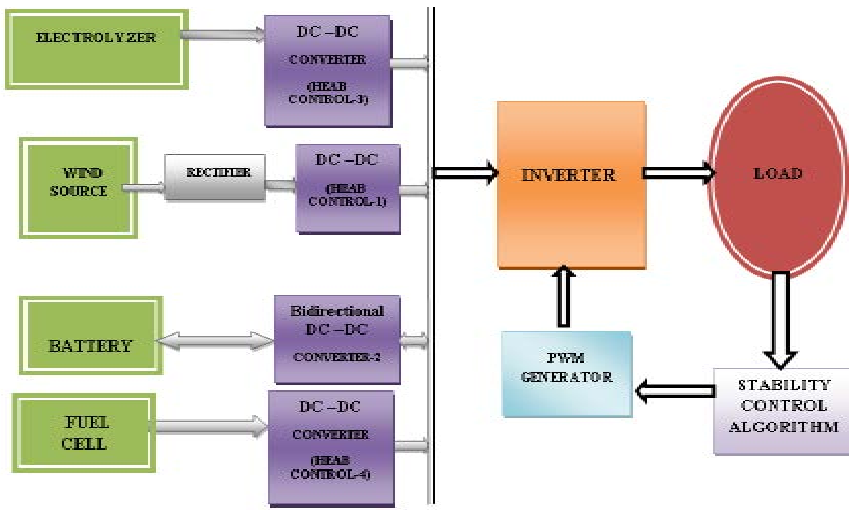

Fig. 1:Proposed architecture

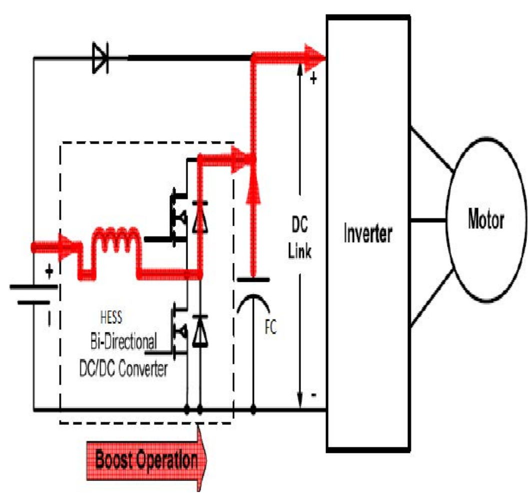

Fig. 2: Configuration HEAB controller

$$Pdmd<=P\ conv, \text{ low constant speed mode} \quad (1)$$

$$Pdmd => P\ conv, \text{ high constant speed mode} \quad (2)$$

Hybrid boost average mode,

$$\text{Assume } Vfc,e,w>V\ Batt\ V \quad (3)$$

Modes of operation

Mode I: Wind source based mode of operation: The purpose of this mode is to smooth the power fluctuation of the renewable energy sources and transfer more stable power into the grid. Wind source improves the quality of power delivered to the grid. This mode of operation mitigates the voltage and harmonic variation at the Point of Common Coupling (PCC) with the grid. The HEAB control system should include an additional control block for power averaging and instruct the resulting averaged value for power command of the grid inverter averaging unpredictable power in real-time may be a complicated issue, which requires the further and comprehensive study on weather forecasting and power estimation as well as a control technique itself. The modeling of Hybrid wind sources is described below.

Wind turbine model for optimum heab energy extraction: The aerodynamic rotor power from wind (Pw) can be expressed as:

$$Pw=0.5A\ \rho\ CP\ (\lambda,\beta)\ v3;\ v0>v>VI \quad (4)$$

Where:

ρ = Is the air density,
A = Is the rotor swept area,
V = Is the wind speed,
V0 and Vi= Are the cut-in and cut-off wind speed, respectively and
CP = Is the power coefficient which is a function of the speed ratio λ and the pitch angle β.

The speed ratio of the wind turbine can be defined as

$$\lambda = \omega rR/V \quad (5)$$

Where:

ωr = Is the rotor speed and
R = Is the radius of rotor

From Eq. 1 and 2, for a particular wind speed, the output power is proportional to the rotor speed and can be expressed as

$$PW = K\omega r^3 \quad (6)$$

From Eq. 6, optimum aerodynamic rotor power from the wind turbine can be extracted by controlling the rotor speed. For (ωr) a particular wind speed, the optimum power is given as

$$PW_{opt} = K_{opt}\omega r^3 \quad (7)$$

Where:

$$K = 0.5A\ \rho CP(R/\lambda)^3 \quad (8)$$

Demonstrates the power generated by a turbine as a function of the rotor speed for different wind speeds. The optimum power extraction from the wind refers to extracting the necessary power under varying wind speed conditions. As an example, for a particular wind speed (V6), the optimum power (PW opt) is generated by keeping the rotor speed equal to either 1 or ω3. However, as ω3 is higher than the base rotor speed ω1, the control system has to choose the rotor speed. If the wind speed drops from V6 to V5, the control system sets the rotor speed to ω2 to extract the required power. The voltage equations of the IPM synchronous generator in the axes are expressed as follows

$$Vd = idR_s + Ld\ d/dt\ (id) - \omega Lqiq \quad (9)$$

Where:

Vd and Vq = Are the d-and q-axes components of the stator voltage, respectively
Rs = Is the stator resistance
id and iq = Are the d- and q- axes components of the stator current, respectively
ω = Is the frequency and
ϕf = Is the flux linkage

The torque equation of the IPM synchronous generator can be expressed as Follows

$$Tg = -3/2\ Pn\ \{\varphi\ fiq + (Ld - L_q)\ idiq \quad (10)$$

Where:

Pn = The number of pole pairs and
Tg = The generated torque of the IPM synchronous generator

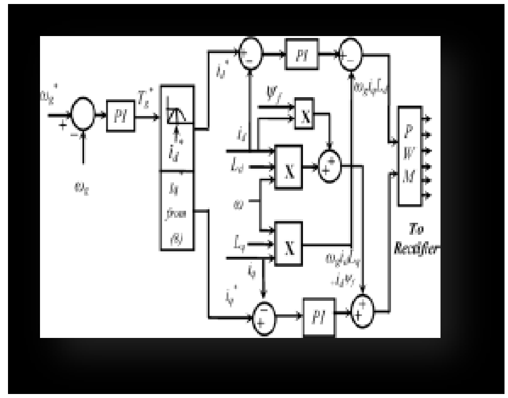

Fig. 3: Wind -HEAB converter controller

From Eq. 10, the q-axis stator current component for constant torque can be expressed as a function of the d-axis stator current component Eq. 11:

$$iq \frac{-2Tg}{3pn\{\psi f + (Ld - Lq)id\}} \quad (11)$$

Maximum efficiency of the IPM synchronous generator can be achieved by minimizing the copper and core losses. From Fig. 3, copper (Pcu), core (Pcore) losses for IPM synchronous generator determined as follows:

$$Pcu = Rs(id^2 + i^2) \quad (12)$$

$$Pcore = \frac{w^2\{(Ldid + \psi f)2 + Ldiq\}}{Rc} \quad (13)$$

Where Rc is the core loss component. The output power from the generator can be given as:

$$Pout = PW - Pcu - Pcore \quad (14)$$

The optimum value of id can be determined from the output power (Pout) versus the d-axis stator current (id) curve based on Eq. 8-14, as shown in Fig. 3

Mode II: battery storage system modeling and control: Among different battery technologies, high energy density, efficiency, light weight and good life cycle available in Li-on. Li –ion batteries represent a suitable option for fuel-cell-based storage systems. Generic Li –ion battery model used in battery State Of Charge (SOC) indication of energy reserve and is expressed as follows:

$$SOC = 100(1 - \frac{1}{Q}\int ibdt)\% \quad (15)$$

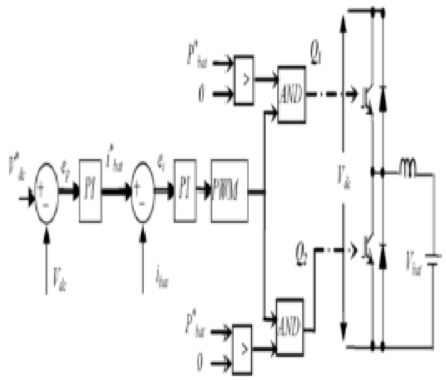

Fig. 4: Battery charger/discharger controller

Where:

ib = Is the battery current and
Q = Is the battery capacity

The battery controller is a bidirectional dc-dc converter that stabilizes the dc link voltage during sudden wind and load changes. The controller is shown in Fig.4.

Mode II: electrolyzer model and control: The electrolyzer consumes the electric power to produce hydrogen. The alkaline electrolyzer model is used in the application. The voltage drop across each electrolyzer cell is given:

$$\text{ucell}=\text{u0}+\text{IELZ}(\text{r1}+\text{r2TELZ})/\text{AELZ}+\text{u1log}\left((\text{t1}+\text{t2}/\text{T ELZ}+\text{t3}/\text{T}^2\text{ELZ})/\text{AELZ}+1\right) \quad (16)$$

Where:

ucell = Is the voltage drop across the electrolyzer,
u0 = Is the thermodynamic cell voltage,
TELZ = is the electrolyzer temperature,
u1 and tis = Are parameters for the electrolyzer over voltage,
ris = Are parameters of ohmic resistance, IELZ is the electrolyzer current,
AELZ = And is the area of electrode

The total voltage drop (UELZ) across the electrolyzer is defined as:

$$\text{UELZ}=\text{NELZ ucell} \quad (17)$$

Where NELZ is the number of cells.The total power consumption of the electrolyzer is given as

$$\text{PELZ}=\text{UELZ IELZ} \quad (18)$$

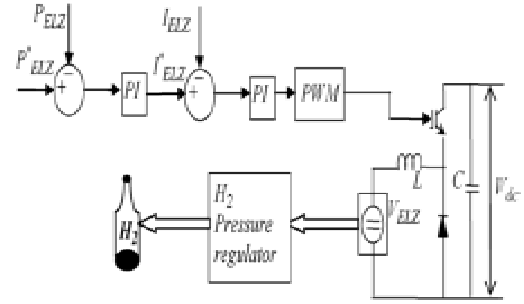

Fig. 5: Electrolyzer controller

The electrical characteristics of the electrolyzer depend on the voltage, current and t emper at ure. The nonl i near r el at i onshi p of t he electrolyzer cel l vol t age and current at a given temperature is shown in Fig 5.

Mode IV: Fuel cell model and control: The model used in the study is based on the dynamic Proton Exchange Membrane Fuel Cell Model (PEMFC).This model is based on a relationship between the Nernst voltage and the average magnitude of the fuel cell stack voltage

$$\text{VFC}=\text{N0E}-\text{V}_{\text{loss}} \quad (19)$$

Where:

VFC = Is the fuel cell voltage,
N0 = Is the number of fuel cells connected in series,
E = Is the Nernst voltage and Vloss is the irreversible voltage losses

The Nernst voltage developed in the fuel cell is defined as follows:

$$\text{E}=\text{E}_0-\text{E}\frac{\text{RT}}{2\text{F}}\left(\text{i}_d^2+\text{i}_q^2\right)\ln\left\{\text{pH2pO}^{0.5}/\text{pH20}\right\} \quad (20)$$

The output voltage of a fuel cell at normal operating conditions is determined by the irreversible voltage loss (Vloss), which can be classified into three types: the activation voltage Loss (Vact), ohmic voltage loss (Vohm) and concentration voltage loss (Vconc). The output power of a fuel cell is determined as follows:

$$\text{PFC}=\text{VFCIFC} \quad (21)$$

In order to design a control strategy for the fuel cell, the hydrogen flow has to be regulated to achieve the output power based on Eq. 19-21. Moreover, as the fuel cell voltage varies according to the dynamic operating point as shown a controlled boost converter is used to

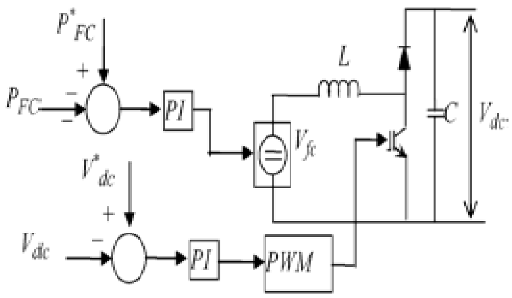

Fig. 6: Fuel cell controller

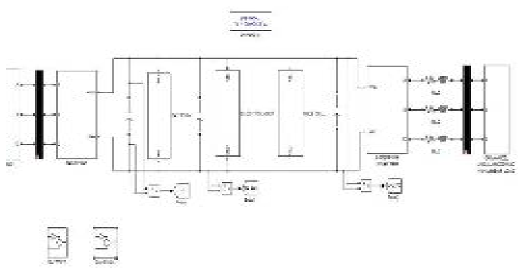

Fig.7: Simulation design of HRES circuit

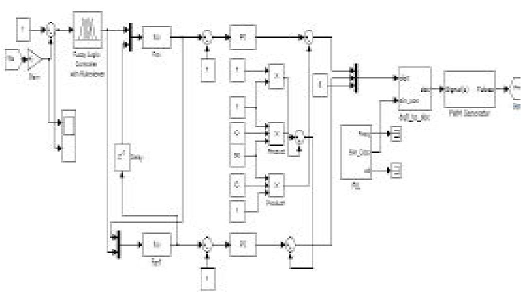

Fig. 8: Wind- Machine side controller circuit (mode1)

interface the fuel cell with the dc link of the system. The fuel cell controller is shown in Fig.5.

RESULTS AND DISCUSSION

The proposed HRES converter with HEAB controller has been designed and simulated with MATLABSimulink. The control circuit for the different HEAB control based system is shown in Fig. 6

The Fig.7, shows the simulation diagram of hybrid system which consists of several sources such as Wind, PV/Battery, Electrolyzer and fuel cell .These source units are connected to the inverter under different load finally better efficiency produced by HEAB converter methods and it shows that the proposed method has produces higher efficiency than other methods.

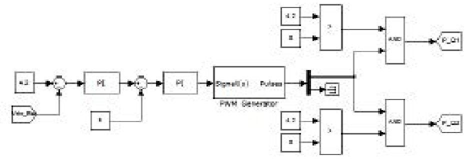

Fig.9: Battery controller circuit (mode 2)

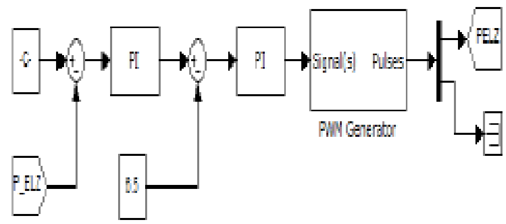

Fig.10: Electrolyzer controller circuit (mode 3)

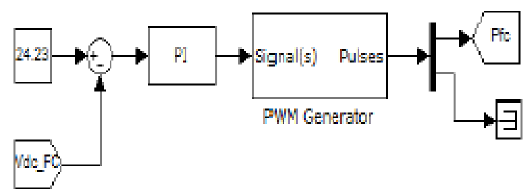

Fig. 11: Fuel cell controller circuit (mode 4)

The Fig.8 shows the simulation diagram of wind power conversion using proposed HEAB controller which is used to generate triggering pulses to the power generation circuit. The above machine side controller circuit operates in mode 1.

The Fig. 9 shows the simulation design of battery energy management controller with the specified boundary value Vdc_bat which is used to generate triggering pulses to the power DC-DC converter circuit. The above battery energy management controller circuit operates in mode 2.

Figure 10 shows the simulation diagram of Electrolyzer source based power generation using proposed HEAB controller which is used to generate triggering pulses to the power generation circuit. The Electrolyzer source based controller circuit operates in mode in mode 3.

Figure 11 shows the simulation design of fuel cell based power generation controller achieves maximum output power using proposed HEAB controller which is used to generate triggering pulses to the controller circuit. The above fuel cell controller circuit operates in mode 3.

From this Fig. 11 has the voltage and current. In that, according to the wind speed there will be a change in voltage and current. The current and voltage will be constant from 0-1 sec then there will be a fluctuation

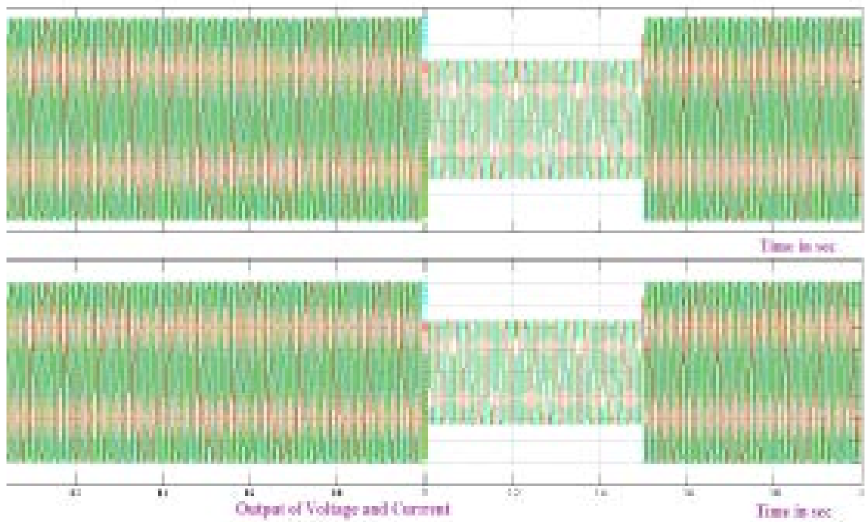

Fig. 12: Voltage and current

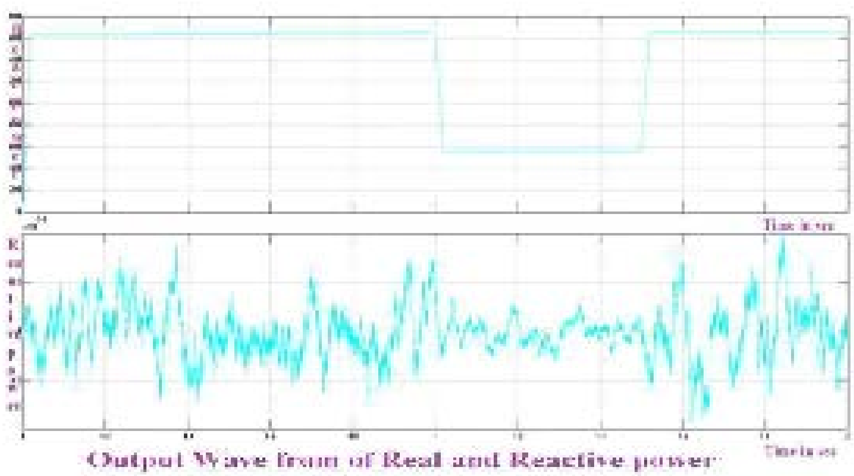

Fig. 13: Real and reactive power

in the wind so there will be a change in the voltage and current. And there is a small fluctuation in voltage and current for a particular period of time in this for 1.5 sec. After that 1.5 sec it will go back to its original position and remain constant continuously until there is no fluctuation. From this above figure has the real and reactive power. In that, according to the wind speed there will be a change in real and reactive power. The real power will be constant from 0-1 sec then, there will be a fluctuation in the wind so there will be a change in the real power. And there is a small fluctuation in real power for a particular period of time in this for 1.5 sec. After that 1.5 sec it will go back to its original position and remain constant continuously until there is no fluctuation. In the reactive power there will be approximately equal to Zero at every time or some fluctuation up to 0.5 and then it will be come back to zero.

The Fig. 14 consists of voltage , current, state of charge. In this voltage waveform shows that the voltage will be constantly increasing from zero up to the maximum range of the circuit. And the current wave form show that the current will be constantly increasing from zero up to the maximum range of the circuit. And the state of charge has the fixed amount of charge and the after a particular period of time it or the graph shows that the wave form will be continuously decreasing then, it shows that the battery discharges until the will be a increased amount of power production in the wind. The Fig. 15 shows the simulated results of voltage, current and power. In this voltage wave form show that the voltage will be constant for a particular period of time and then after 1.1 sec the voltage will be decreasing and become constant in the circuit. In this current wave form show that the current

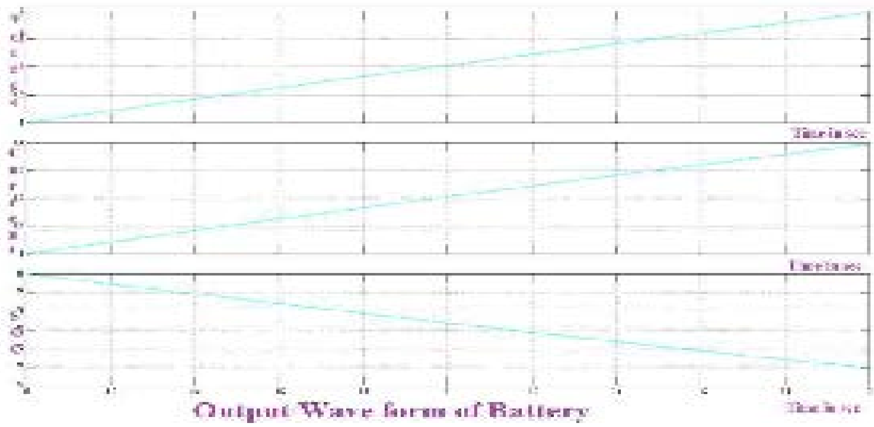

Fig.14: Battery (voltage, current, state of charge

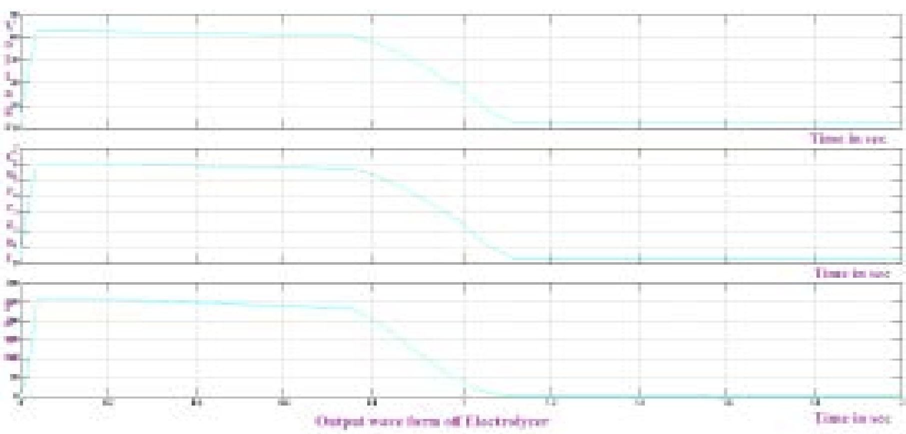

Fig.15: Electrolyzer (voltage, current, power)

Table 1: Baterry voltage

Sources	Condition
Only PV	$P_{pv} \geq 0$
Both PV and FC	$P_{fc}+P_{pv} \geq 0$
Wind+PV+Electrol	P_{pv}
Yzer+Fuelcell	$+PWind+Pelz+Pfc \geq 0$

will be constant for a particular period of time and then after 1.1 sec the Current will be decreasing and become constant in the circuit shown in Table 1.

In this power wave form show that the power will be constant for a particular period of time and then after 1.1 sec the power will be decreasing and become zero in the circuit.

The Fig. 16 consists of voltage, current and power. In this voltage wave form show that the voltage will be constant for a particular period of time and then after 0.2 sec the voltage will be decreasing and become constant voltage in 1.6 sec in the circuit and it will be maintained. In this current wave form show that the current will be constantly increasing from zero for a particular period of time and then after that period the current will be maintained constant in the circuit. In this power wave form show that the power will be constantly increasing for a particular period of time and then after that period the power will be maintained constant in that circuit.

Comparison of proposed and other converters: The following Table 2 shows the comparison of different converters with proposed novel converter using proposed controller system. The efficiency of the proposed model has been evaluated and tabulated. Table1. Comparison of the proposed model. Table 2 shows the details of simulation operating conditions used

Table 2: Comparison of the proposed model

Converter type	Controller used	Sources	Output power in per unit	THD(%)	Efficiency(%)
Multilevel boost converter	SVPWM	PV+WIND	0.8	10	84.12
boost onverter	MPPT	PV array+battery	0.85	6	89.10
proposed boost converter	HEAB controller	WIND+BATTERY+E+FC	0.92	5	94.50

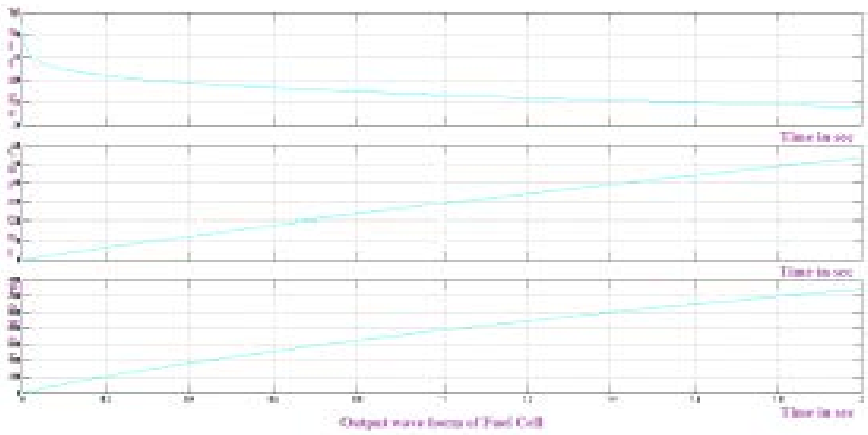

Fig.16: Fuel cell (voltage, current, power)

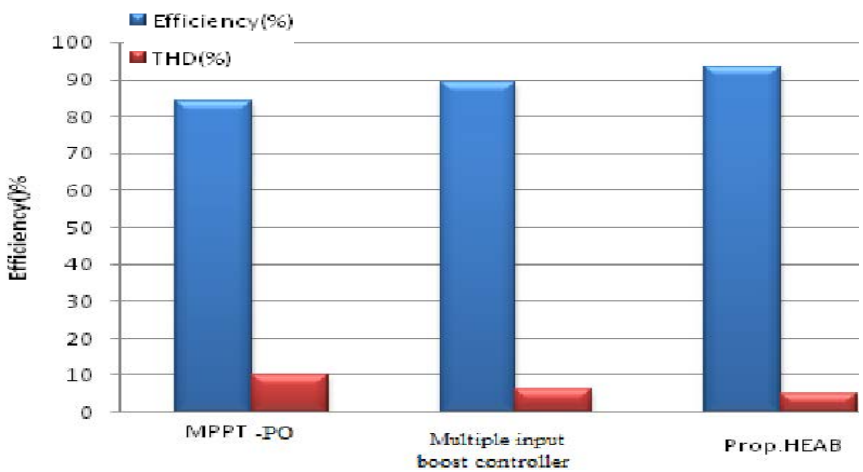

Fig.17: Comparison of different HRES system

to evaluate the maximum power efficiency and THD of the proposed methods. Simulations are done for various values of modulation index and the corresponding THD% are observed using FFT block. THD results of output voltages for three methods are calculated by Eq. 22:

$$THD = \frac{1}{V_1} = \left[\sum_{n=2,3,\ldots}^{\infty} V_n^2 \right]^{1/2} \tag{22}$$

The presented methods are compared to each other for different modulation indexes. The modulation index is defined as follows:

$$m_\alpha = \frac{A_m}{A_c} \tag{23}$$

Where:

A_m = Peak amplitude of reference or modulation signal,
Ac = Is the carrier (triangular) peak value

The following table shows the comparison of different Hybrid renewable energy based maximum power track converters with proposed HRES controller system. The maximum power output efficiency of the proposed model has been evaluated and tabulated. The following graph shows the efficiency comparison of different converters with proposed converter system.

CONCLUSION

The performance analysis and regulation of a hybrid stand-alone renewable energy system. The performance of the proposed control strategy is evaluated under different wind and load conditions. It is revealed that the machine side converter can extract the optimum power. It is also able to operate the PM synchronous generator with maximum efficiency. A bidirectional converter successfully controls the battery storage system. The fuel cell andelectrolyzer are controlled using boost and buck converters, respectively. Here the fuel cell used is proton exchange membrane (PEM). EMPRS develops the overall coordination. From the simulation studies, the fuel cell gives the maximum power of the no/low wind condition. The advantage is to avoid/prevent the system block out at the inadequate energy reserve. The system from blackouts in the event of low wind conditions or inadequate energy reserves.

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