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Applying Three Port Converter with Dual Battery Storage System for Hybrid Power Generation

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The proposed research work used three power sources, namely wind energy, solar energy and grid. Wind and solar constitute the primary energy sources while the grid acted as the secondary one; added to that, we have the battery storage system. The priority between the two forms of energy in the primary source is determined by their availability. The solar irradiance is available during daytime, whereas during cloudy and night times, energy extraction is impossible; besides that wind energy is also not reliable. Thus the central level controller (CLC) is used, which serves as a deciding authority for the selection of primary source. When none of the energies in the primary sources are available the grid supplies the required power to the load. When there is a surplus energy from primary sources, it is stored in a battery or exported to the grid. In addition DBSS is also introduced for effective utilization of battery storage system. The proposed model is connected with micro grid to provide utilization path for surplus power. The overall design and simulation is performed by using MATLAB/SIMULINK.

Keywords: Battery charge controller, Central level controller, Grid, SECS, WECS

Introduction

The Rapid growth of power electronics applications in hybrid power generation, it tends a rapid development in micro and small grid applications. In this paper[1] authors are introducing a hybrid power generation method without the utility grid support. In addition, the solar (PV) and induction generator model based wind mills are interconnected. In this study instead of real wind turbine variable speed DC motor was used to drive induction generator. The flywheel capacitor is used to maintain sufficient voltage level at inverter output, in addition the results are compared with other technique's results.[2,3] Implementation of two sizing algorithm is tried to design a hybrid power generating plant. In that, source sizing algorithm (SSA) is used to monitor and control the source side parameters like wind speed, solar irradiation etc.

Sizing Algorithm and Techniques

The battery sizing algorithm (BSA) was used on battery storage system (BSS). The BSS is used to store the power that is received from renewable energy converter. In addition, BSA controls the power flow in BSS based on the power availability and maximum demand on load side.[4] Stability improvement for large-scale hybrid power generation super capacitor is introduced instead of battery storage system. Here the main usage of super capacitor is to avoid power fluctuations, at inverter input point because of unstable natural environmental conditions.

The proportional-integral-derivative (PID), supplementary damping controller (SDC) scheme was preferred in this experiment.[5] In some cases power fluctuations creates a major problem on source side (wind turbine) power generation, for that, battery pair's concept is implemented to avoid fluctuation and to maintain the battery efficiency. Shallow cycling effects also compensated in this approach. One battery will get charging until reach maximum voltage level at the same time the other one will discharge up to its minimum level. Once the battery reaches deep level operations of batteries get interchanged.[3]

For power dispatch issues in renewable energy resource based power generation an optimal power flow, coat based allocation and power flow tracing based modifications improves the stability.[6] By implementing a line side converter, which works based on SOC of battery, controls voltage and frequency at load point and it ensures system stability. Doubly fed induction generator (DFIG) is connected with load and solar PV to maintain the continuous output from wind turbine.[7] To integrate hybrid

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resource sizing of solar PV and wind, machine is configured by search engine algorithm, then power storage batteries and its problems are categorized step by step. Later all are solved by algorithm based solutions. The load for that system is fully uncontrolled so utility gird support is required to fulfill the demand. Super capacitor also used along with battery to improve charge cycle.[8]

For interconnected hybrid power generation wind, hydro & solar PV, Hydropower are used in critical conditions to avoid power fluctuation and make the system stable. By this interconnection burden of computation and errors also reduced because of distribution assumption rule. Firm generation helps the system's generation interval to optimize.[9,10] DFIG is energizing by solar PV charged battery. Rotor side converter (RSC) should maintain continuous active power on stator side converter or load side. Normally Solar PV has connection with main load but here it charges the battery alone. The power stored in the battery is utilized by RSC at change of wind velocity. The problem is number of power conversion from solar PV to battery then it again converts and feed to DFIG to maintain the constant output power.[11] Homer is used for sizing and analyzing the economic effects on cost of energy and MATLAB is used for calculating all possible information for sharing load.[12] To find an economic solution for diesel generator along with renewable hybrid power generating, two rules are followed. In that ON/OFF mode of operation is better than continuous mode, efficiency and state of charge and interval trimmings are all in prefect level. However, the number of ON/OFF has to increase to find the yearly efficiency. Renewable resources like wind and solar PV is the main source, battery is used to avoid instantaneous power fluctuation in that system. Finally, diesel generator (DG) is also used to make a system reliable, whenever renewable sources are failed to full fill the maximum Demand DG will come in to system rest of the time battery maintains power flow with converters.[13,14] A three-phase hybrid buck-boost converter is used as a smoother circuit and it mitigates the unwanted distortion from output waveform.[15]

Materials and Methods

The Renewable resources are not to be effectively controlled by human power and it is too difficult to predict its accuracy and their next behavior. But it is possible to use, by modifying and reconstructing their outputs with the application of modern power electronics equipment. Solar energy conversion system (SECS) operates during daytime so its presence is available on daytime i.e. half of the day (night time) it will not work. Then designing a wind energy conversion system (WECS) is one of a challenging task, because its size of the turbine, blades and its construction. The wind availability depends on environmental factors like temperature, climate, etc. Moreover the wind power is quite different from solar availability, seasonal issues are also present.

The synchronization of both wind power and solar power is one of important task in this proposed method. For that the two identical DC-DC boost converter is used to synchronize that power at common DC bus. The general operational block diagram of proposed method is given in Fig. 1(a). At normal operating mode DC: DC Boost conversion system gets sufficient (or) allowable minimum inputs from WECS or SECS. The power flows from renewable power source to Micro grid/Load through converters and inverter. The cost effective power flow is explained as flowchart in Fig. 1 (b). If there is no sufficient input to DC/DC converter it suddenly goes to idle mode. In that particular time interval battery supports to load with other active resource. At the time of availability of renewable sources and the load is in off position, the batteries are allowed to charge up to its rated value.

Design Consideration for Wind Mill

The wind turbine converts wind power to mechanical energy, it is feed to permanent magnet synchronous generator; output of wind plant is in the form of three phase AC power, so it requires additional AC/DC converter. Output AC/DC converter is directly processed by DC: DC Boost converter. The Eq. (1) expresses the maximum of pressure Cp, pressure difference across turbine.

$$\Delta P = 4\rho \frac{\mathrm{Vi}^2}{9}$$

In equation air density ρ is considered as 1.293 kg/m^3 i.e.it is applicable only to dry air at standard atmospheric conditions. The Fig. 2(c), explains the process of WECS.

Three Port Converter (TPC)

The three port converter plays a vital role in this proposed method to handle the power flow direction. The paths of power flow, controller breakers control and switching pulse of MOSFET's are also controlled

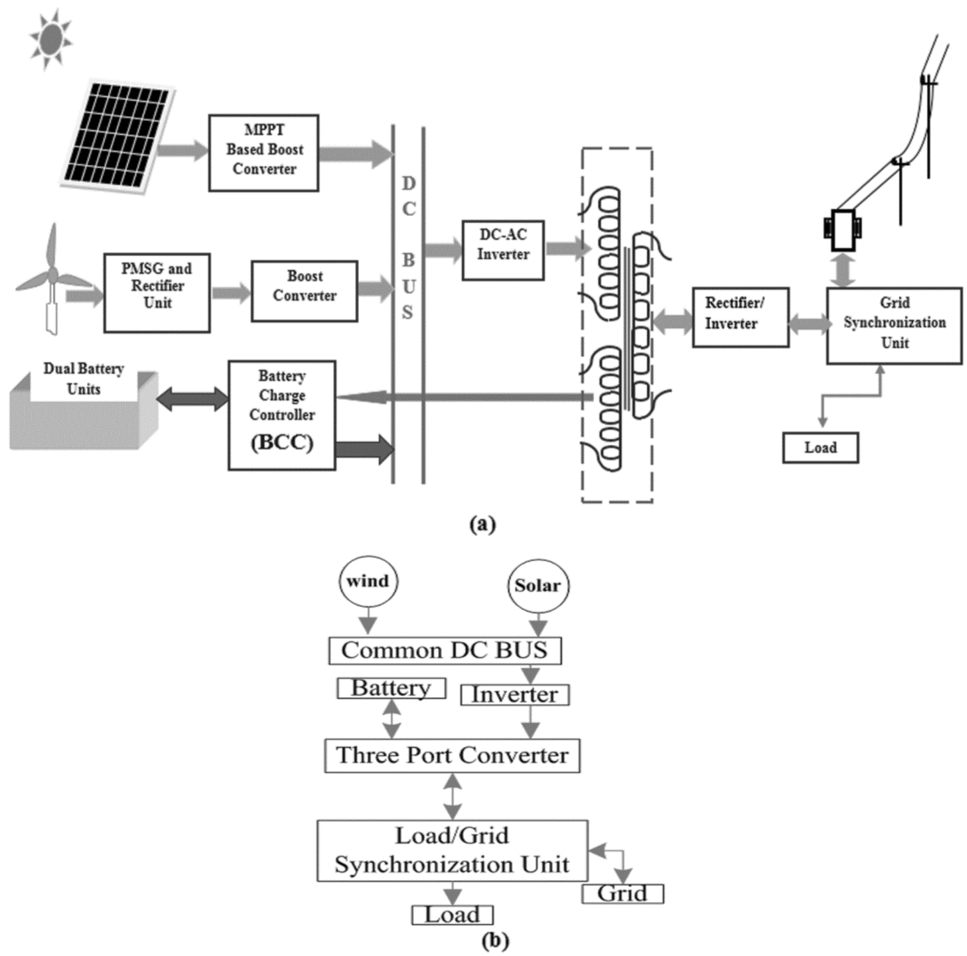

Fig. 1 — (a) Proposed General Block Diagram (b) Power Flowchart

by central level controller (CLC). The TPC is capable to feed the power for battery charging purpose even when the load is in 'ON' position. Moreover it doesn't require any extra controller to control the power flow, at the same time TPC can supply power to the load easily without any external control signal. Losses are very low compared with other power electronics converter for this same type of operation. The hybrid power conversion system, battery storage unit and load/grid are interfaced with three port converter. The Fig. 2(a) shows the three port network system's circuit diagram. The output power of WECS and SECS were regulated by two boost converters and minor fluctuations also rectified by boost converters and feed to common DC bus. An inverter is used to interface the common DC bus and TPC. The fig. 2(b) shows the entire processing cycle of SECS. Normally the TPC transfer power from RER to Load, more over this mode of operation is highly cost effective. At abnormal condition, TPC charges the batteries to avoid critical DOC so, it transfer the power from grid to battery (i.e. battery charging mode). At this interval it behave as buck converter (Vin>Vout) via battery charging unit. The central level controller drives the inverter in both mode of operation. The surplus power is feed to grid via synchronization unit.

The proposed work examines two-battery system with hybrid power system. It consists of DC-DC bidirectional buck boost conversion modules, Permanent magnet synchronous wind generator, PV Module and two battery storage systems. The solar and wind based power conversion technologies are used as main raw source of power in the present work. The Eq. (2) expresses the control strategy of BCD. The central controller controls both BCD and the Inverter operation. At the time of buck mode operation grid/hybrid system feeds power to the battery for emergency purpose. In addition, w.r.t Eq. (2) AC-DC converter will act as a rectifier and DC-DC BDC reduces the voltage level according to

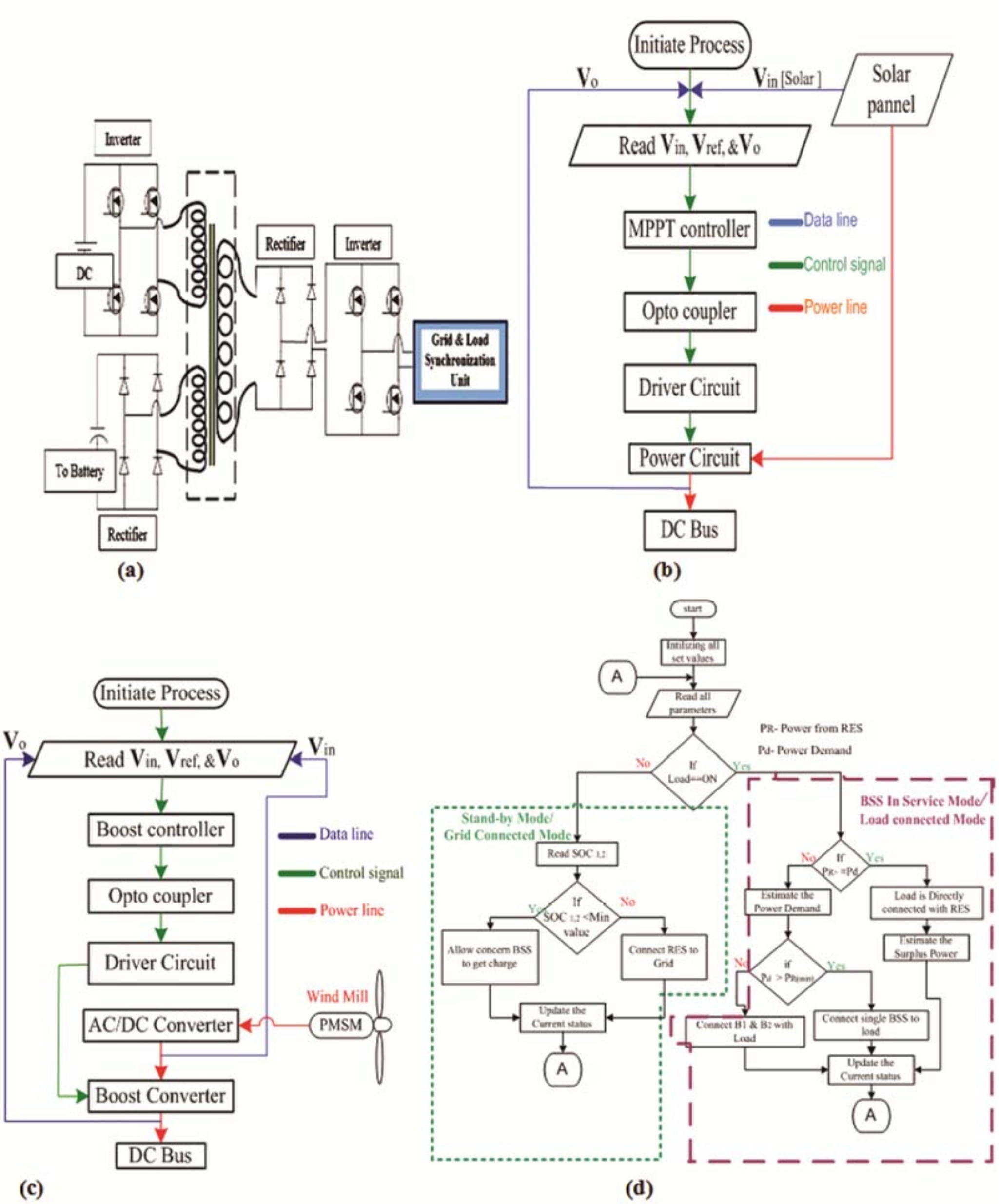

Fig. 2 — (a) Circuit diagram basic of three port converterimplementation, (b) Solar power conversion system (c) Wind power conversion system (d) Algorithm for BC

the voltage level of battery storage system. Once BSS reached maximum level this entire process will stop and load gets supply from gird via grid synchronization unit.

At Two Battery Mode:

$$B_1 + B_2(k) = \begin{cases} Pd - PR(k)min, & PR(k)\min < Pd \\ 0, & PR(k)min \geq Pd \end{cases}$$

$$\& \quad B_1 \text{ (or) } B_2(k) = \begin{cases} Pd - PR(k)min, & PR(set)(k) < Pd \quad ßßPR(k)min > Pd \\ 0, & PR(net)(k)min \geq Pd \end{cases} \quad \ldots (2)$$

The power flow direction is entirely reverse in the boost & buck mode of operations. Here, in boost mode of operation the direction of power flow is towards grid. In buck mode of operation the direction of power flow is towards battery. The major difference in this mode is, BDC is feed by BSS, RES or both based on the available natural resources. Here

BSS will support up to its maximum limit of DOC. BCC plays a vital role in overall operations. The condition for various modes of operation is presented in Table 1. Based on the availability of natural power the controller will select the mode and supply power to load.

Battery Charging Controller (BCC)

The BCC is nothing but bidirectional DC-DC Buck-Boost converter. It is a DC circuit that maintains required DC voltage at output terminals. During boost mode, the input voltage to this converter is always lesser than output voltage (Vin<Vout) and with some voltage fluctuation because of natural environmental effects. The WECS and SECS may get disturbances and may fail to produce minimum/ constant required voltage to load. In such conditions, to avoid unwanted voltage fluctuation and error in output voltage the unidirectional DC: DC Boost converter was use to feed constant voltage to common DC bus. The BCC controls the two BSS w.r.t to load demand. The Eq. (2) expresses the control statement for the k^{th} interval of time. In some interval RER fails to maintain minimum cut in voltage, therefore BCC makes entire BSS as source to the load for a short duration of time, at that condition both batteries will get discharge. Once the system is released from critical condition, BCC suddenly remove any one of the SS (storage system) from the load. The condition for single battery powered mode is expressed in Eq. (2). Selection of BSS is fully based on it SOC level.

At Single Battery Mode

In RES powered mode the load gets sufficient or more than power demand from renewable energy resource conversion system. Here the BSS is not required to load; now BSS gets charging because of surplus power or it may in stand-by condition. At this position load is fully powered by renewable resource. This duration is called as "RES powered mode".

At Standby Mode:

$$B_1 \text{ and } B_2(k) = \begin{Bmatrix} 0, & \middle| PR(k) \le Pd \\ PR(k) - Pd, & \middle| PR\ (k) > Pd \end{Bmatrix} \quad \dots (3)$$

The complete MATLAB simulation results are discussed from next part, simulation module consist of wind turbine, rectifier unit, boost converter, bidirectional converter and inverter these are the main components of the proposed system. The MATLAB 2013R/B version is used to simulate the proposed system. The flowchart of dual battery algorithm is given in Fig. 2(d).The output results are discussed in detail as separate section. The input of BCC is taken from common DC bus. Whenever battery gets charge BCC act as buck mode. Based on the dual battery algorithm results the battery was selected to charge and discharge. Similarly at time of discharge duration BCC act as boost mode and its voltage level needs to meet over the DC bus voltage range. In real-time implementation, two identical ADC modules are used to measure state of charge (SOC) of batteries. To avoid digital conversion error and for accuracy two identical modules are designed and implemented.

Results and Discussion

MATLAB 2016R/B version is used to simulate the proposed methodology; the system specification is 6 GB RAM to run the simulation. The MATLAB don't need any compiler to run the simulink file, moreover it can be easily interfaced with real-time environment. The simulation output wave forms, from various units at under the wind speed of 9m/s is shown in Fig. 3(a). In that red coloured wave form indicates the output voltage (7.7V) across any two phases of wind turbine coupled PMSG. Similarly

Table 1 — Conditions for various modes of operation

Modes/Sources	Load	Wind	solar	Battery 1	Battery 2	Grid
Mode1 : Hybrid mode	on	1	1	Charging	Charging	import
	off	1	1	Charging	Charging	off
Mode 2: Wind alone mode	on	1	0	0	0	off
	off	1	0	0	0	off
Mode 3:Solar alone mode	on	0	1	0	0	off
	off	0	1	0	0	off
Mode 4 : Battery mode	on	1	0	discharging	0	off
	off	1	0	charging	0	off
Mode 5: Grid Mode	on	0	0	0	0	import
	off	0	0	charging	charging	import

*Note: 1-availability/functioning mode, 0- non availability/ideal mode

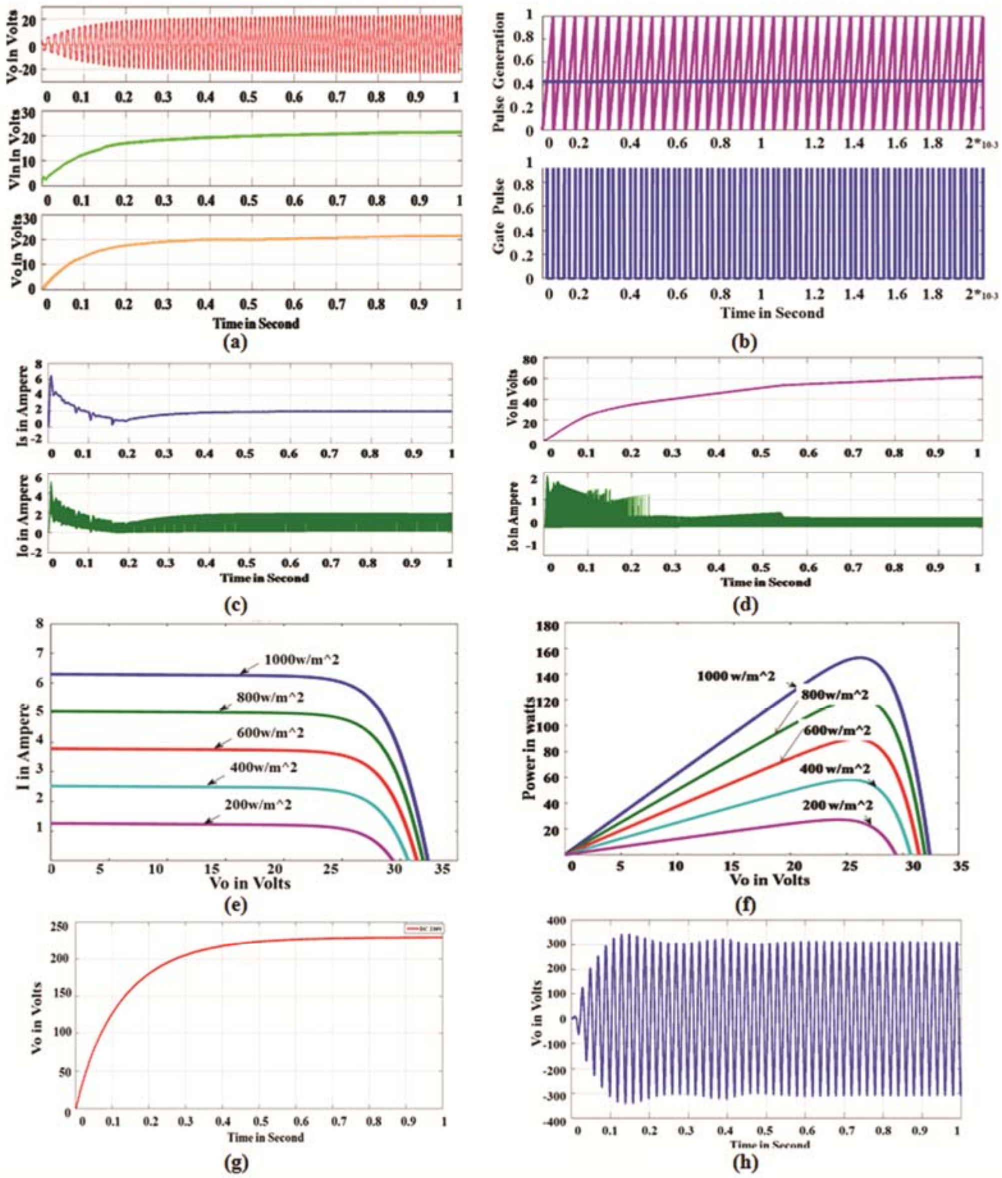

Fig. 3 — (a)Output voltage of PMSG at wind speed in 9 m/sec.,(b) Gate pulse to BCD, (c) Boost converter input current and output current @ 11 m/sec., (d) Load side voltage and current, (e) Solar IV curve for various irradiance,(f) Solar PV curve for various irradiance, (g)Second stage rectifier output voltage (h) Final stageInverter output

green coloured wave form indicates the rectifier output voltage (18 V) i.e. PMSG output is followed by rectifier output. The final waveform (orange coloured) is the normal boost converter's output voltage (19.49 V). The ratio of boost converter is very less while compared with BDC's boost mode ratio.

The Fig. 3(b), deals with gate pulse generation for boost converter in that the above wave forms explain the condition for pulse generation. The below waveform is the gate pulses of the power MOSFET, boost converter output is 19.43V it is directly feed to common DC bus. The inverter input is taken from common bus. In fig. 3(c), the above waveform shows the input side current at voltage level at 19.49 V (input voltage). Similarly, in Fig. 3(c), the second waveform shows the load side current structure of boot converter. The BDC's load side voltage (56 V boosted voltage) in above waveform are shown in Fig. 3(d). The second waveform represents the current shape.

For different solar irradiance the IV curve is shown in Fig. 3(e).The first curve is drawn for the value of 1 sun (1050 w/m^2 at 25 degree Celsius).The following curves are developed for different solar irradiance.

In addition, solar PV curve is shown in Fig. 3(f); in that the waveforms represented the actual power output of PV module according to irradiance. The second and third waveform represents power peak at 800 w/m^2 and 600 w/m^2. The output of SECS is feed to boost converter to maintain constant voltage at DC bus the both renewable sources are connecting at common DC Bus. From the common DC bus a simple inverter is used to convert the DC power to AC Voltage, then AC voltage is applied to port 1. An uncontrolled rectifier is connected with port 3 (step-up winding). Again, AC voltage is converting in to DC power by using second stage of rectifier.

The rectifier is used to maintain the fixed DC voltage (V_{DC}) at input terminal of final stage inverter. The stage one rectification voltage level is in the range of 56 V because of hybrid sources. But in the second stage port 3 pickups the voltage value is up to 230 V. In Fig. 3(g) the final rectifier voltage (230V) is shown. It is the final rectification process in the proposed model. It never changes due to any hybrid power failure condition. The Fig. 3(h) is representing the final stage inverter output waveform.

Conclusions

The proposed method proved that single CLC has the caliber to control all sub systems based on voltage level, load position and resource availability. Hybrid power (solar and wind) generation with battery control controller have a quick response to change in primary energy. Based on the program logic, central level controller controls the bidirectional DC-DC converter operation from boost to buck & vice versa according to the need. The proposed methodology is successfully operating the system which is able to provide continues and stable power to load. The overall design and simulation is initially performed by using MATLAB/SIMULINK. In the simulation platform, proposed system has maintained the system stability. Advanced power management, effective utilization of hybrid power and smart dual storage-battery based system also fulfilled. This proposed system fed the surplus power to grid and also extract required power from the grid effectively

References

1 Prakash S L, Arutchelvi M& Jesudaiyan A S, Autonomous PV-array excited wind-driven induction generator for off-grid application in India, *J Em Sel Top P*, **4(4)** (2016) 1259–1269.

2 Alam T, Biswas S, Giri J R & Mishra D K, modeling and analysis of hybrid solar-thermal based frequency control in three area power system, *J Adv Res Dyn Cot Sys*, **2** (2018) 73–86

3 Rajalakshmi R, Rajasekaran V & Selvaperumal S, Reactive power compensation and harmonic mitigation through quasi z-source converter for marine applications, *J Sci Ind Res*, **45(7)** (2016) 897–910.

4 Karunambigai S, Geetha K & Shabeer H, "Power quality improvement of grid-connected solar system", *J Sci Ind Res*, **74** (2015) 354–357.

5 AkramU, Khalid M& ShafiqS, Optimal sizing of a wind/ solar/battery hybrid grid-connected micro grid system, *Ren Pow Gen*, **12(1)** (2018) 72–80.

6 WangL, Vo Q S & ProkhorovA V, Stability improvement of a multi machine power system connected with a large-scale hybrid wind-photovoltaic farm using a supercapacitor, *Tran Ind Appl*, **54(1)** (2018) 50–60.

7 Archana N &Vidhyapriya R, A novel SRF based UPFC in grid connected wind and solar hybrid system", *J Sci Ind Res*, **75** (2016) 720–724.

8 Menaka S & Muralidharan S, Novel symmetric and asymmetric multilevel inverter topologies with minimum number of switches for high voltage of electric ship propulsion system, *J Geo Mar Sci*, **46(09)** (2017) 1920–1930.

9 Tiwari S K, Singh B & Goel P K, Design and control of micro-grid fed by renewable energy generating sources, *Tran Ind Appl*, **54(3)** (2018) 2041–2050

10 BtPungut N A F, Hannoon N M S & Ibrahim P B, Power analysis of autonomous grid, *J Sci Ind Res*, **76** (2017) 626–630.

11 LiuY, Tan S & JiangC, Interval optimal scheduling of hydro-PV-wind hybrid system considering firm generation coordination, *Ren Pow Gen*, **11(1)** (2017) 63–72.

12 Parida A & Chatterjee D, Model-based loss minimisation scheme for wind solar hybrid generation system using (grid-connected) doubly fed induction generator, *Elec Pow Appl*, **10(6)** (2016) 548–559.

13 Reddy J N, Lenine D & Kumar M V, Experimental study of seven level magnetic coupled impedance source inverter, *J Sci Ind Res*, **77** (2018) 705–709.

14 Sekar K &Duraisamy V, Efficient Energy Management System for Integrated Renewable Generation Systems, *J SciInd Res*, **74** (2015) 325–329.

15 MoulaliS K, Muni T V, Subrahmanyam Y B & Kesav S, A flying capacitor multilevel topology for PV system with APOD and POD pulsewidth modulation, *J Adv Res Dyn Cotr Sys*, **02**(2018) 96–110.