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ACTIVE POWER MANAGEMENT IN HYBRID POWER SYSTEM INCORPORATING BATTERY

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ABSTRACT

In this paper wind and solar based grid independent hybrid energy system is presented for the remote area power system applications. The wind energy conversion system, PV system and battery energy storage system are connected to the common DC bus. An AC load is connected to DC bus through a pulse width modulation (PWM) based inverter. AC voltage at load bus can be maintained at rated value by regulating dc-link voltage (V_{dc}) at its reference value and by controlling modulation index of PWM inverter. Novel control algorithms are developed to maintain V_{dc} at its reference voltage irrespective of variations in wind speed, solar irradiance and load. Along with the regulation of V_{dc}, dc–dc converter (connected between battery and dc-link) acts as a maximum power point tracker (MPPT) for photovoltaic (PV) array. Hence an extra dedicated MPPT circuit is not required to extract maximum power from PV. Control technique for the PWM inverter has been developed to make the line voltages balanced at the point of common coupling (PCC) when the load is unbalanced. Hence, efforts are made to supply quality voltage to the consumers through the stand-alone power system. Detailed modeling of various components of stand-alone system is presented. Extensive simulation results using Matlab/SIMULINK established that the performance of the controllers is quite satisfactory under balanced as well as unbalanced load conditions.

***Keywords**: Variable speed wind turbine; Permanent magnet synchronous generator; Photovoltaic (PV); Voltage control of stand-alone hybrid system; Unbalanced load compensation.*

I. INTRODUCTION

In many countries there are remote communities where connection with power grid is too expensive or impractical and diesel generators are often the source of electricity. Under such circumstances, a locally placed small scale off-grid distributed generation system can supply power to the customers. Recently hybrid power systems consisting of integrated operation of two or more different types of energy sources and storage devices are being deployed for rural electrification or electrification of remote areas in many countries across the world [1]. Autonomous wind plus solar power systems are among the most interesting and environmentally-friendly technological solutions for the electrification of remote consumers. A viable solution is to combine those different renewable energy sources to form a hybrid energy system (i.e., microgrid) [1], [2], [3], [4], [5]. Such hybrid system gives more reliability and may be cost effective.

Supplying the customers with a quality voltage is the main challenge in a stand-alone system. Voltage variations, flickers and harmonic generation are the major power quality (PQ) problems that occur in wind/solar energy conversion system. The voltage variations are mainly due to the change in load. Flicker or voltage fluctuations are primarily caused by variations in the wind speed and solar irradiation. Unwanted harmonics are generated in the voltages at the point of common coupling (PCC) due to converters connected between source and load. Moreover, in distribution system PCC voltages are always unbalanced due to single phase loads. Those power quality problems may not be tolerated by the customers and hence require mitigation techniques. Hence, in this paper, along with control of voltage and frequency, mitigation of the above mentioned power quality problems are addressed.The proposed stand-alone hybrid energy system (shown in Fig. 1) consists of a permanent magnet synchronous generator (PMSG) based variable speed wind energy conversion [6], PV array and battery energy storage. Both the sources i.e., wind and solar are equipped with maximum power point tracking (MPPT) and connected to the common dc bus. Battery is used as a storage device and is connected to dc bus through dc–dc bidirectional converter. Wind power depends on weather conditions and during night hours solar power is zero. Therefore under the situation of long term no-wind or low-wind condition, battery cater the load demand. In case of high power generation from wind and solar for a long time and the battery charged upto its upper limit of charge storage. The proposed system can feed single phase as well as three phase loads.

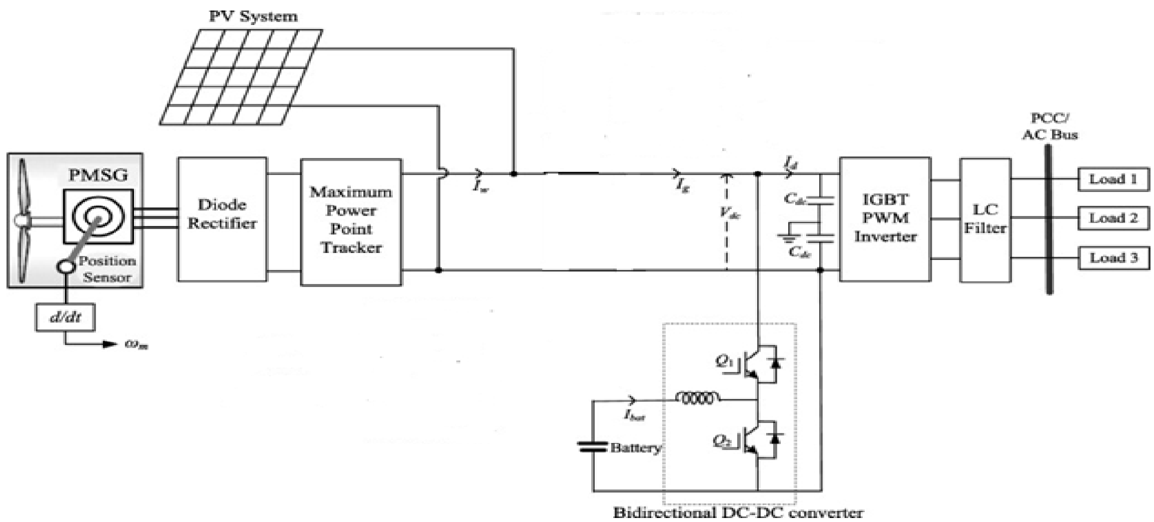

Fig. 1. PMSG and solar based stand-alone wind turbine with energy storage, fuel cell and dump load

The similar stand-alone hybrid energy system is presented earlier by few researchers [2], [3], [4], [9]. In [2] authors present the generation of hydrogen using different sources, however, authors did not mention about voltage and frequency control of stand-alone system. In [3], authors present overall power management strategy among different sources and storage units. However, in [3] the actual control of the inverter is not presented. In [4], authors present wind–PV hybrid system to the supply the dc loads. However, battery is directly connected to dc bus and its charging/discharging control is not mentioned. In [5], authors present the control of autonomous hybrid system for single phase and not for three-phase. Moreover, in [5] authors did not consider storage and dump load which will make the system unreliable. In [9], authors present the system for generating and utilization of hydrogen with renewable energy sources, however, authors did not mention the controller for unbalanced load. Moreover, in [9] various sources as well as storage systems have individual converters connected to dc bus, which makes system more expensive. In [10], authors present dc system for generation of hydrogen from renewable sources, however this system is for only dc loads. In [11] PV having own dc–dc converter for MPPT and electrolyzer is connected to AC bus through AC/DC converter, which system makes more expensive and also authors did not mention about power quality issues. In [12], authors present AC coupled hybrid system in which individual MPPTs are required to all sources and individual ac–dc converters are required for battery and electrolyzer which makes more expensive. In [13], authors present power generation system for green building; however system is valid for only single phase system. Authors used FC but electrolyzer is not incorporated as dump load since through electrolyzer hydrogen can be produced which in turn can be used by FC as input source. In [14], authors proposed energy management system for stand-alone power generation system; however, authors did not consider unbalanced load and power quality issues, moreover author did not connect MPPT for wind generation system. In [15], authors propose renewable sources based hybrid system for a green house, however proposed system is only for single phase. Moreover, in references [9], [10], [11], [12], [13], designed controllers are based on measurement of various powers (i.e., sources, storage and load), which require more number of sensors. In this paper, a stand-alone power system is developed using renewable sources with following objectives:

- To achieve intelligent control coordination among different sources and battery.
- To regulate voltage at load bus irrespective of fluctuations in wind/PV and variations in load.
- To supply quality voltage to the customers.

- To maintain constant and balanced three phase supply at load bus under condition of unbalanced load scenario.
- Along with control of dc-link voltage, dc–dc converter (connected between dc bus and battery) acts as MPPT circuit for PV system, hence extra MPPT circuit is not required to extract the maximum power from PV panels.

The paper is summarized as follows: in Section 2, brief description of PV system and its MPPT control is presented. In Section 3, a control strategy is developed to regulate the voltage and hence coordination among sources, storages and dump load. Detailed simulation results are presented in Section 4 by presenting different case studies. The findings of paper are given in the conclusions in Section 5.

II. DESCRIPTION OF PV SYSTEM

The PV module is the result of associating a group of PV cells in series and parallel. In this paper two arrays are connected in parallel, each array consists of 22 modules connected in series as shown in Fig. 2(a). Each module having open circuit voltage as 36.90 V, short circuit current is 8.01 A, voltage at maximum power (Vmpp) is 30.3 V and current at maximum power is (Impp) is 7.10 [16]. Power vs. voltage curves of one PV array are shown in Fig. 2(b) with different level of solar irradiance. Fig. 2(b) shows that PV can generate maximum power at particular voltage called as Vmpp at corresponding level of irradiance. For best utilization, the PV cells must be operated at their maximum power point. According to perturb and observe (P&O) algorithm, MPPT is achieved by adjusting the terminal voltage of PV panels to Vmpp[17], [18], [19]. In this paper PV panel is directly connected to the dc bus and P&O algorithm for MPPT (Fig. 2(c)) is incorporated using dc–dc converter (connected between battery and dc-link). Therefore, dc–dc converter not only controls the dc-link voltage but also acts a MPPT and hence additional MPPT circuit for PV is not required.

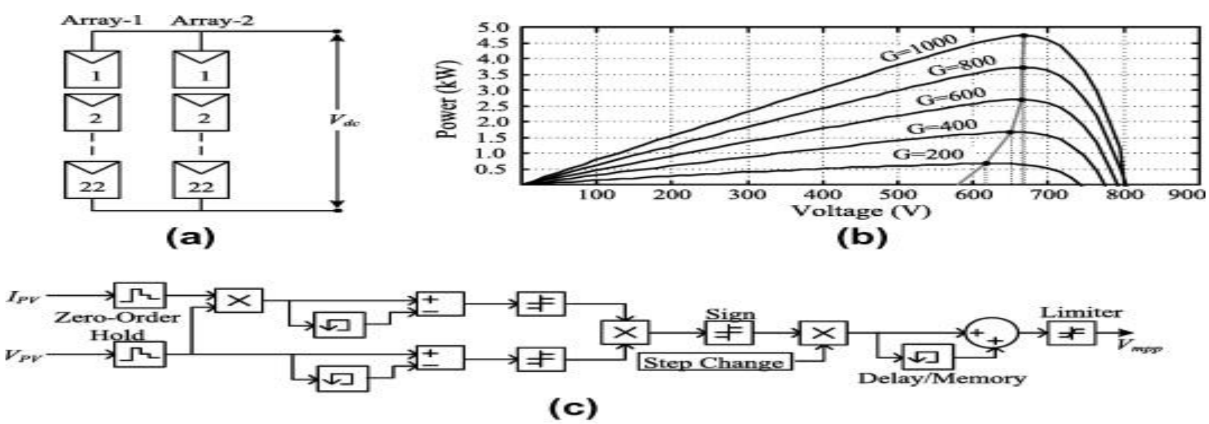

Fig. 2. (a) Arrangement of PV, (b): power vs. voltage curves at different irradiance, (c) P&O algorithm

Since 22 modules are connected in series, V_{mpp} of PV arrays will vary from 617 to 666 V according to solar irradiance (G) varies from 200 to 1000 W/m^2 and corresponding V_{mpp} will be tracked by P&O algorithm (Fig. 2(c)). V_{mpp} which is output of P&O algorithm will then act as reference dc-link voltage (Vdc*) The maximum power rating of each array is 4732 W at irradiance 1000 W/m^2 and hence by using two arrays maximum solar power generation is 9464 W.

III. CONTROL OF DC LINK VOLTAGE

The proposed stand-alone hybrid energy system is shown in Fig. 1. In stand-alone mode, the output ac voltage is controlled in terms of amplitude and frequency. It can be achieved by maintaining dc-link voltage constant at its reference value and keeping modulation index of PWM inverter within a reasonably practical limit. As far as frequency of output ac voltage is concerned, it can be maintained at specified value by choosing the frequency of sinusoidal reference signal while generating the PWM pulses. Due to variations in the wind speed, solar irradiation and load; dc-link voltage varies because of power mismatch between sources and load. Hence, it is required to maintain dc-link voltage constant irrespective of variations in wind speed, solar irradiation and load. Battery and dump load (i.e., aqua-electrolyzer) are used to maintain the power balance of the system. The battery is connected to the dc-link through a dc- dc bidirectional buck-boost converter. Using bidirectional buck-boost converter, the battery voltage can be kept lower as compared to reference dc-link voltage and hence less number of batteries need to be connected in series. In the proposed system battery voltage is kept at about 300 V while (signal generated by P&O algorithm). Considering voltage drop across LC filter connected after inverter, to keep output AC voltage at 400 V rms (line–line), minimum dc voltage requirement is 640 V. As for as maximum dc voltage is concerned generally 5% is allowable (i.e., 672 V) for the sake of protection of dc bus and power electronic devices connected to dc bus. Hence in the design of dc–dc converter control, limiter is connected after generating Vmpp by P&O algorithm (as shown in Fig. 2(c)) which limits the reference voltage of dc-link (Vmpp) between 640 V and 672 V. The lower limit of dc voltage (i.e., 640 V) corresponds to 300 W/m2 irradiance. Hence, for irradiance below 300 W/m2, P&O algorithm acts as constant voltage MPPT algorithm. This is helpful to operate the system during night time and under non-sunny days, because, night time irradiance is almost zero and PV cannot work. Under such situations limiter keeps reference voltage of dc-link voltage at minimum level of 640 V. For highest possible irradiance i.e., 1000 W/m2, corresponds to 666.6 V which is well below of higher limit of dc voltage (i.e., 672 V). In [20] author proposed the control of dc–dc converter (connected between battery and dc-link) to regulate the charging/discharging of the battery to maintain Vdc constant. Consider that dump load is absorbing the surplus power (when state of charge of battery is above 0.8) and suddenly load demand becomes more than source power, in this situation battery should feed the power immediately. However, controller presented in [20] fails for this situation because switches Q1 and Q2 both are still in off position. Hence in this paper modified controller is developed as shown in Fig. 3. Treating the controller output as the reference current for the battery, a hysteresis band approach is adapted to switch either Q1 or Q2 of dc–dc converter (Fig. 1). Besides, the control signal is constrained within a limit so that actual charging/discharging current will be as per the specification of the battery as a result the longevity of the battery will be enhanced. Proper control coordination among sources, battery, FC and electrolyzer is required to maintain the dc bus voltage constant at its reference value. Battery should discharge (charge) within specified limits when there is deficit (surplus) of wind and solar energy. In case of high power from sources (solar and wind) lasting for a long time and the battery hits its upper limit of state of charge (SOC).

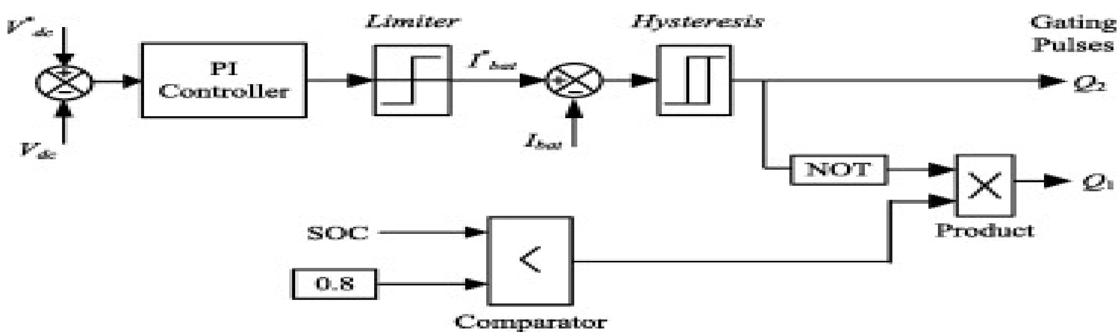

Fig. 3. Control of dc–dc converter connected between battery and dc-link

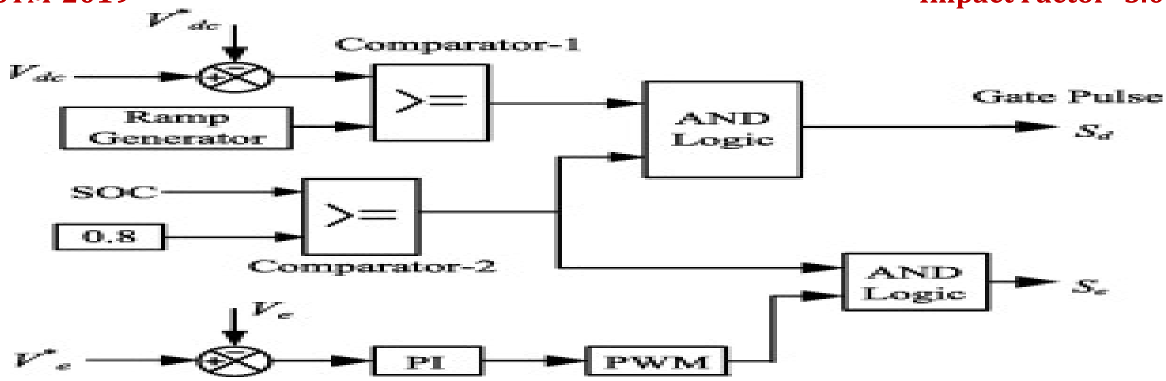

Fig. 4. Dump load (i.e., electrolyzer) controller

Generally charging/discharging of battery is limited between certain lower and upper limit of SOC. As charging continues above upper limit of SOC, charge acceptance begins to decrease and more of the charging current goes to the decomposition of water [21], [22]. Moreover, small increase in charge current can create a large increase in battery terminal voltage [21]. On the other hand, discharging of the battery below lower limit of SOC increases its internal resistance [22], [23]. Hence, battery life hampers if the operation is not kept within limits of SOC. In case of modern lead acid batteries charge acceptance is very high, typically the SOC range is between 20% and 80% [21], [22]. Therefore, in this paper the charge/discharge of the battery is considered with above mentioned range of SOC.

IV. RESULT AND DISCUSSION

The solar-wind constructed power system is demonstrated and realized in MATLAB/Simulink. The particulars of the forming are specified in section II. In this section the suggested structure is exposed to inconstant solar irradiance as well as inconstant wind speed. In addition to this flexible load is associated to the system. These will lead to the endless difference between supply and demand. So BESS overcome this difficult and the results are shown in the following figures.

For examining the legitimacy of the solar-wind based power system is exposed to altered levels of solar irradiance. For the time interval 0-2 second the solar irradiance level is 1000 W/m^2. For second time interval between 2-6 second the solar irradiance level is reduced to 800W/m^2 shown in the figure 3. As the irradiance level is reduced the output current and the output power of the PV system also decreased. For the ease merely one time change in the solar irradiance is done else the other waveforms will be congested and cannot be evidently observable.

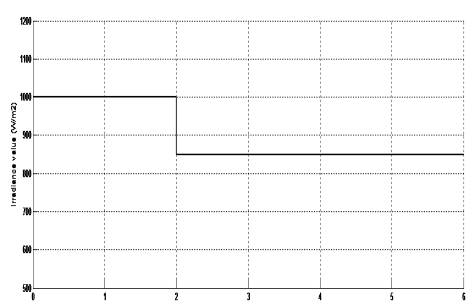

Fig. 5.Solar Irradiance level

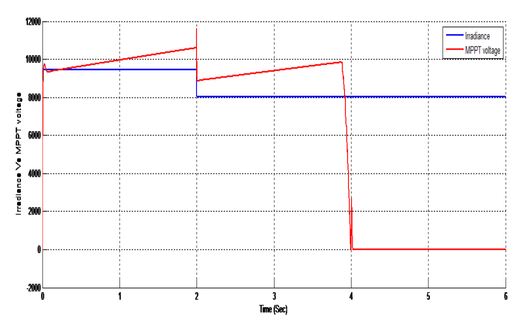

Fig.6.Solar Irradiance level Vs PV MPPT voltage

Figure 6 is showing solar irradiance against MPPT voltage waveform. From this it is obviously implicit that the irradiance level picks the MPPT voltage. As the irradiance level decreased the MPPT voltage also reduces.

This fragment should obviously state the foremost conclusions of the exploration and give a coherent explanation of their significance and consequence.

For compensating the deficit in the PV system power BESS responds conferring to the need. For these persistence BESS controllers gives the command to the converter circuit and further it supply power to the demand. If the BESS state of charge (SOC) less than the minimum value then BESS does not comes in to action. In the figure 7 BESS current waveform is shown. From the figure it is found that when the PV system output decreases, BESS power increased to compensate this shortfall.

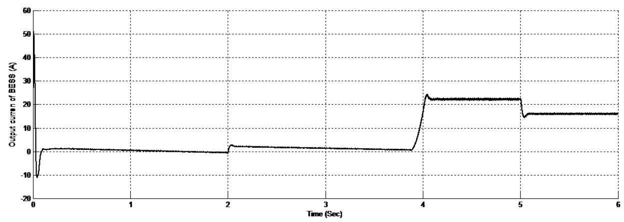

Fig. 7 Output current of the BESS

For the second case, there is variation in load is made at the time 4 sec. firstly the system is connected to the 10 KW resistive load. There is a step increase of additional 3 KW load is made at time 4 sec. this extra load is removed at time 5 sec. Figure 8 shows the waveform of the power drawn by the load.

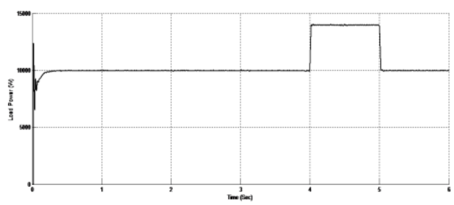

Fig. 8 .Power drawn by the load

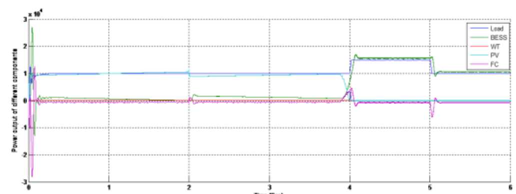

Fig. 9 Power waveform of load, WECS, PV and BESS

When the load is greater than before the HPS system start providing more current to come across the requirement. In the earlier case it is described that deficit in the PV system is recompensed by the BESS. Here also when the load surges, this extra requirement is satisfied by the BESS if the PV system WECS are not capable of meeting the need.

V. CONCLUSION

The modeling and performance analysis of stand-alone hybrid Wind/PV/Battery power generation system with MPPT Controllers using MATLAB/Simulink environment is presented in this paper. The variations in wind velocity, solar irradiation and dynamic load conditions are considered for the simulation study. Perturb and Observe (P&O) technique is used for maximum power tracking for wind power system. For PV system MPPT algorithm based on incremental conductance is used to get maximum power output. The algorithm changes the duty cycle of the DC/DC converter to maximize the power output of the array and make it operate at the peak power point of the array. The PV control strategy of a DC/AC converter connected to the load has been proposed. The system is also able to meet the variable load demand while maintaining dc-link voltage constant. It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. The power balance between wind, PV power system, battery and load has been maintained while extracting maximum power for both sources. The simulation results showed the effectiveness of the integrated control strategy adopted.

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