Middle-East Journal of Scientific Research 24 (S2): 150-156, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.S2.136

Isolated Power System Design Using Modified P&O Technique

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Abstract: Isolated Hybrid Energy Systems are more popular for power generation and can be used as an economically feasible option to electrify remote villages where the grid extension is not possible. The combined utilization of wind and solar renewable energy sources are being widely used as an alternative for conventional energy sources. In this paper, the Hybrid energy systems employing permanent magnet synchronous generator (PMSG) driven by a variable speed wind turbine – PV array, power conditioning converters and inverter with hysteresis controller are proposed. The converters utilize a modular topology for allowing a satisfaction of electric components rating. A control strategy is based on Maximum Power Point Tracking (MPPT) with a novel three point weight comparison method is employed to track the maximum power point in both wind and solar energy sources. Design and control as well as good tracking performance are also verified through Numeric Simulations.

Key words: Wind driven PMSG-PV array · Maximum power point tracking (MPPT) · Hysteresis controller · Power conditioning converters

INTRODUCTION

Isolated renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extension is costly and the cost of fuel is increased drastically with the remoteness of the location. Research and development efforts in solar, wind and other renewable energy source technologies are required to continue for improving their performance, establishing techniques for exactly predicting their output and reliability integrating them with other conventional generating sources [1]. In order to meet required load demands during unreliable natural conditions, different energy sources and converters need to be incorporated with each other for extended usage of alternating energy [2, 3]. A single intermittent source with DG system is unpredictable due to seasonal variations. The DG systems consisting of hybrid renewable sources have a higher reliability, due to the complementary nature of the resources [4, 5]. In DFIG, the gearbox arrangement is used to match the turbine and rotor speed. The gearbox arrangement needs regular maintenance, making the system unreliable and costly. The consistency of the variable speed wind turbine can be enhanced significantly using a direct drive permanent magnet synchronous generator (PMSG). PMSG has established much concentration in wind energy applications due to its self-excitation capability, leading to an improved power factor and elevated efficiency operation [6, 7]. The presentation under steady state of a grid-connected wind and photovoltaic (PV) power system with battery storage was analyzed [8, 9]. Grid connected PMSG-PV hybrid system with battery backup was described in [10], where the DC link voltage was fixed and equal to battery voltage, but the maximum power extraction from wind-driven PMSG was not performed. In a hybrid system along with grid connection, the PV array and wind-driven PMSG were coupled to a common DC link through a multi-input DC-DC converter was proposed earlier in [11]. A PMSG-PV hybrid system with multi-input inverter consists of a buck/buck-boost combined multi-input dc-dc converter and a full bridge dc-ac inverter was described in [12]. Converters were controlled using complex algorithms for peak power tracking. In order to minimize the conduction and switching losses of the devices, it is necessary to contain the minimum number of power converters (power conversion stages) and this has been attempted in this paper. In addition, it is advantageous that power supplies in consumer sites employ fewer power electronic conversion stages in order to improve the overall efficiency. It should be noted that losses in conversion

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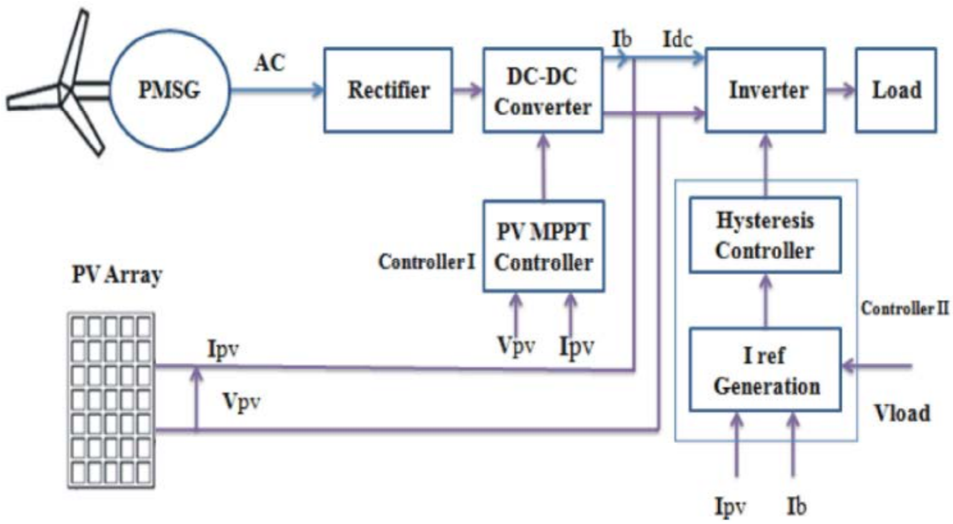

Fig. 1: Proposed DG system based on PMSG-PV sources

stages have to be compensated by increasing the sizes of the generator. Generally, efficiency of DC-DC converter is maximum around 95% when it is operated in full load condition [13]. The drift phenomenon for widely used P&O MPPT algorithm is thoroughly discussed and then a modification to the existing algorithm is proposed to avoid drift [14, 15]. In this paper, hybrid system has a PV array being directly connected to the DC link as an alternative for being connected through a DC-DC converter. The variation in Dc link voltage is done by a DC-DC converter interposed between the rectifier fed by PMSG and the grid connected inverter. The DC-DC converter output voltage forms the load line for the PV array. The extraction of maximum current from both the sources is done by varying the inverter current using current control strategy. The proposed topology could thus dispenses with a DC-DC converter, which in earlier schemes were connected after the PV array for maximum power extraction. Two new controllers are attempted for the hybrid scheme proposed, to extract maximum power from both the sources. A d-q axes model of the scheme has been developed and validated. The successful operation of this scheme in extracting maximum power from both the sources or from each of the sources has been established through simulation. The structure of this paper is as follows: Description of Renewable energy technology for wind-driven PMSG-PV array for hybrid energy system is presented in section II. Model of the proposed system along with mathematical description is presented in section III. In Section IV the operation of the controllers with case studies are described. Implementation of the controllers are presented in V. In section VI results of numerical simulations are reported, showing good tracking performances along with simplicity is presented in section VII.

Description of the System: The block diagram of proposed hybrid system is shown in Fig. 1. Wind driven PMSG and a PV array are the input sources for this hybrid system. The PMSG is directly connected a rectifier. So the output of the PMSG is rectified with the help of the rectifier and is given to a DC-DC sepi converter. Due to the variation of the wind speed the output voltage of the rectifier is also changed. The output of the PV array is connected with the output of the DC-DC sepi converter to form a common DC link for this system. The input terminals of inverter are coupled to this common DC link. The PV array voltage (v_{PV}) is fixed to the output voltage of the DC-DC sepi converter (v_{DC}) since the output terminals of both the PV array and the DC-DC converter are coupled together. The DC-DC converter's output voltage is automatically varied by a PV MPPT controller (controller I) to PV array's maximum power point voltage. By the use of current controller (controller 2) of the inverter, the maximum current for the given irradiation is achieved.

The Three point Weight Comparison (TWC) algorithm is employed with a reversed duty-cycle modification in controller 1. This adjustment in the proposed scheme is because of the DC-DC sepi converter is being fed by a rigid DC source (rectifier output) instead of of the PV array. The output voltage of the current controlled inverter is coupled to the load voltage and frequency, so the synchronization is automatically done. The current given by the inverter (I_{LOAD}) to the load follows the reference current signal (I_{ref}), which is automatically varied by controller 2 for extracting the maximum current based on the reference current of current controlled inverter. This leads to the maximum current extraction from both the sources, which consequences in peak power extraction from both the sources.

Model of the Proposed System: A model of the proposed DG system is developed to explore the system performance. The steady state equivalent circuit of the PMSG is shown in Fig. 2. The DC output voltage of the rectifier (VR) and current (IR) in terms of stator phase voltage VS (rms) and stator current IS(rms) are given as

$$V_R = \frac{3\sqrt{6}}{\Pi} V_S \quad (1)$$

$$I_R = \frac{\Pi}{\sqrt{6}} I_S \quad (2)$$

The stator phase voltage V_S is varied with the variation of the wind-speed and therefore the rectifier output voltage V_R is a unreliable DC. This varying DC is given to the DC-DC converter.

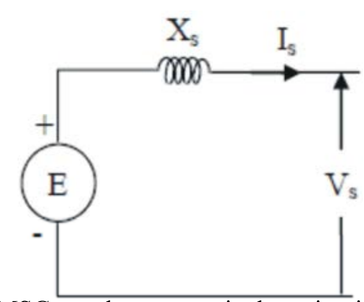

Fig. 2: PMSG steady state equivalent circuit in per-phase

The output voltage of the DC-DC converter is given as

$$V_b = V_{DC} = V_R \frac{1}{1-\delta} \quad (3)$$

The current of the DC link is given by

$$I_{DC} = I_b + I_{PV} \quad (4)$$

And the output current of PV array (IPV) is given by;

$$I_{PV} = I_{SC} - I_d \quad (5)$$

where $I_d = 10^{-9} I_{SC}(\exp \frac{20.7}{VOC}(V_{PV}+R_{se}I_{PV}))$ (6)

The d and q-axis voltage of the inverter are correlated with the DC link voltage as;

$$v_d = V_{DC}\, g_d \quad (7)$$

$$v_q = V_{DC}\, g_d \quad (8)$$

Zero power loss is considered in the inverter;

$$I_{DC} = \frac{1}{2}(i_d g_d + i_q g_q) \quad (9)$$

Assuming zero power loss in DC-DC converter,

$$V_R I_R = V_b I_b \quad (10)$$

and $I_{DC} = I_b + I_{PV} = (1-\delta)I_R + I_{PV} = \frac{(1-\delta)\Pi}{\sqrt{6}} I_S + I_{PV}$ (11)

where δ is duty-cycle of the DC-DC sepi converter. The rectifier output (1) is connected to the models of DC – DC converter, PV array and the inverter. The *d* and *q* axis circuits of the system are shown in Fig. 3 and Fig. 4 respectively.

In this scheme, δ and I_{ref} are assorted to take out the maximum current I_{DC} at any instant of time. By using the Equations from (1) to (11), the simulation of the proposed DG system can be done on any platform. In this proposed system MATLAB has been employed for the simulation.

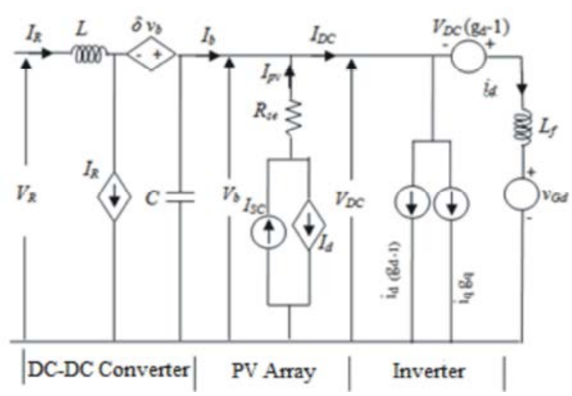

Fig. 3: d-axis equivalent of the system

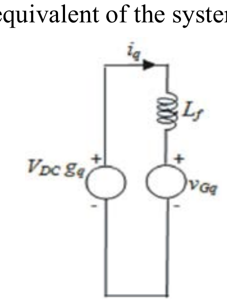

Fig. 4: q-axis equivalent of the system

Operation of the Controllers

Case 1 (Both Pv and Pmsg Generating Power): In this case both the wind and solar energy sources are generating power together in this case. The PV array's terminal voltage is varied by the deviation of duty-cycle of the DC-DC (SEPI) converter (since $V_{DC} = V_{PV}$). And also the output voltage of the rectifier is varied with the wind speed. So the duty cycle of the SEPI converter is to be automatically adjusted such that V_{DC} is identical to the peak power point voltage (V_m) of the PV array. At this point ($V_{PV} = V_{DC} = V_m$), the PV array delivers the maximum current (I_m) which is drawn by the current controlled inverter.

The operation of controller 1 is explained in Fig. 5. As shown in the Fig. 5, the DC link voltage may be, say V_1 (B) or V_2 (C) based on the present duty-cycle of the DC–DC sepi converter. The DC-DC (SEPI) converter output (DC link voltage) is adjusted to V_m by varying the duty-cycle of the DC-DC converter by controller 1 to operate the PV array at its maximum power point (A). The variation in duty-cycle of controller 1 is given by;

$$\delta_{new} = \delta_{old} + \text{sgn}(\Delta P)\text{sgn}(\Delta V_{PV})\,\Delta\delta \quad (12)$$

where $\Delta\delta$ is the perturbation in duty-cycle, sgn is Signum function. ΔP is the divergence in PV array power and ΔV_{PV} is variation in PV array voltage before and after perturbation. If ΔP and ΔV_{PV} are both either positive or negative then the duty-cycle is increased.

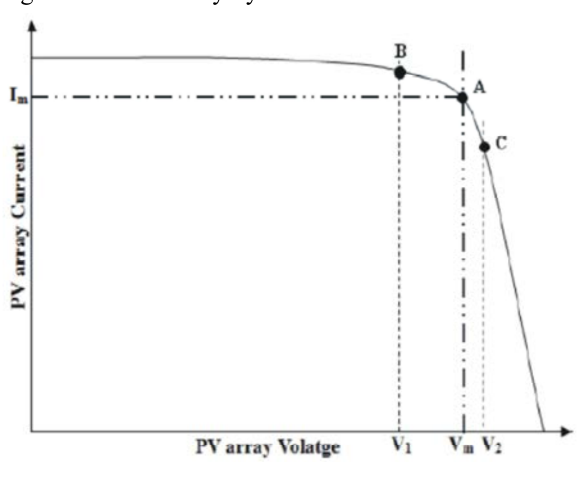

Fig. 5: VI curve of the PV array

The controller 2 (Fig. 1) is used to vary the inverter output current given to the load. Based on the available maximum power from the both the sources for an exact condition (i.e. irradiation and PMSG shaft torque), the reference current (I_{ref}) for this hysteresis current controller is derived. By the action of controller 1V_{PV} is at maximum power point value is obtained. Current taken from the SEPI converter (I_b) and PV (I_{PV}) together is maximized by changing I_{ref} as;

$$I_{ref}(new) = I_{ref}(old) + \text{sgn}\,[\Delta(I_{PV} + I_b)]K \quad (13)$$

where $\Delta(I_{pv}+I_b)$ is the change in the sum of I_{PV} and I_b and K is the increase in perturbation of I_{ref}. It is clear from (15), if current to be drained from SEPI converter increases, I_{ref} also increases correspondingly.

$$Iref = 2(VPV\,I\,PV + VR\,I\,R)\,/V_{GRID} \quad (14)$$

Case 2 (PMSG Alone Operating): During night time, the current transducer connected to the PV terminal will not produce any output. In such a case, the controller 1 will omit the PV-MPPT algorithm and work in a voltage control mode. The output voltage of transducer (V_{DC}) is taken as feedback signal, the controller 1 varies the duty-cycle of the SEPI converter to continue the DC link voltage to a DC value corresponding to the rated RMS voltage of the load. As I_{PV} is zero in this case, the (I_{ref})value is adjusted by the controller1. to take out the maximum power from the PMSG alone.

$$I_{ref}(new) = I_{ref}(old) + \text{sgn}[\Delta(I_b)]\text{K} \quad (15)$$

Case 3 (PV Alone Operating): When there is wind production then the PMSG is not generating power. So there is no input to the DC-DC converter and consequently no triggering pulse is generated by controller 1. The controller 2 varies I_{ref} such that [by substituting $I_b = 0$ in (13)] to supply the maximum power from PV array alone.

$$I_{ref}(new) = I_{ref}(old) + \text{sgn}[\Delta(I_{PV})]\text{K} \quad (16)$$

Composite Operation of Controllers: It is obvious that from all the three cases mentioned above, that controller 2 functions always to feed the maximum power either from both the sources or from any one of the sources to the load. This is done by adjusting reference current (I_{ref}). On the other hand, controller 1 is at rest when power is generated by PV alone. Different conditions of sources and the corresponding functions of two controllers are summarized in Table 1.

Table 1: Functions of Controllers under Different Conditions

Sources	Controller for DC-DC converter (Controller 1)	Hysteresis Controller (Controller 2)
PV and PMSG	Generates duty- cycle for PV array MPPT voltage	Generates current command to extract the maximum power from both the sources
PV alone	Triggering pulse not generated (Zero duty cycle)	Generates current command to extract the maximum power from PV
PMSG alone	Generates duty-cycle to maintain constant DC link voltage	Generates current command to extract the maximum power from PMSG

Implementation of the Controllers

Controller for DC-DC Converter (Controller 1): A 16 bit microcontroller is used to implement the controller for the DC-DC converter. The PV array terminals give the feedback signal to the controller. The internal analog to digital conversion (ADC) module digitizes these signals. The MPPT algorithm for PV array is programmed with this microcontroller. Required PWM pulses for DC-DC converter are produced with the help of the In-built pulse width modulation (PWM) module of the microcontroller.

Hysteresis Current Controller (Controller 2): The current transducers sense the I_{PV} and I_b and are digitized with the help of the internal ADC module of the microcontroller. So a digital output is obtained by the microcontroller. This digital value is consequently processed by a Digital to Analog Conversion (DAC) IC to obtain a DC value which corresponds to the peak value of Iref. This converted DC value is multiplied with the sine wave reference extracted from the load voltage, by a multiplier IC and fed to the hysteresis current- controller as the reference current signal. The load side sine wave is taken as a reference, so the inverter output current will have load frequency and will be in phase with the load voltage.

Simulation Results: A single phase current source inverter was fabricated with the available IGBTs for the hybrid generator. Firing pulses from hysteresis controller were given to IGBTs . A DC – DC SEPI converter was also fabricated with a IGBT and a hyper fast diode. The pulses from the microcontroller were given to the IGBT through the gate driver.

Wind Model: A wind model presented is considered to simulate the spatial effect of varying wind components. As indicated in Fig.6 when wind speed increases, the wind turbine rotor speed accelerates so that the output power from the wind turbine increases. On the other hand, when wind speed decreases, the wind turbine rotor speed slows down so the output power from the wind turbine decreases. The output of PMSG is shown in Fig. 7.

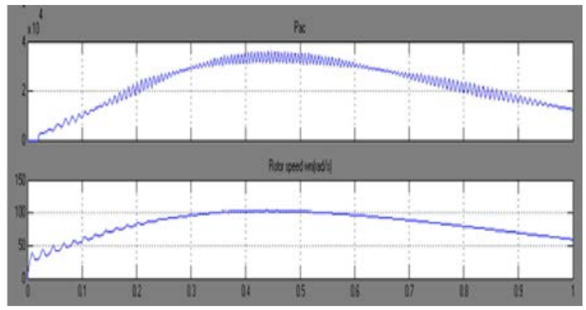

Fig. 6: Wind Turbine Output waveform

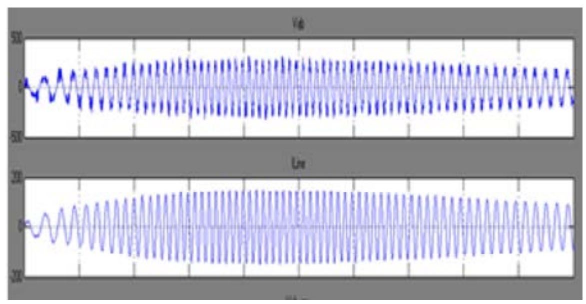

Fig. 7: PMSG Output waveform

Solar PV Model: This study also investigates the system performance with solar irradiance variations. The PV panel surface temperature is assumed to be fixed at during the entire simulation period. The PV modules operating power points are well-followed toward the MPPs.

The steady-state DC link voltage and current waveforms are shown in Figs. 8 and 9.

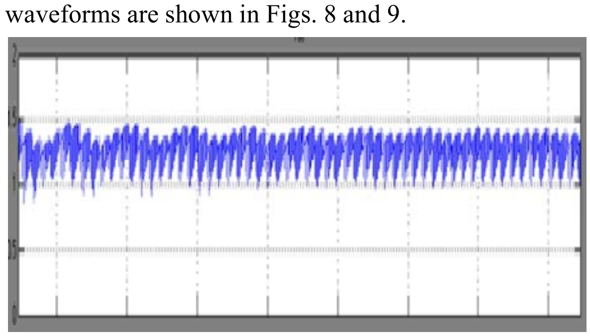

Fig. 8: DC link voltage waveform

Fig. 10 illustrates three phase ac load voltage waveform. The load-side PWM inverter generates enough power required for the variable local ac load and dispatch power to the load.

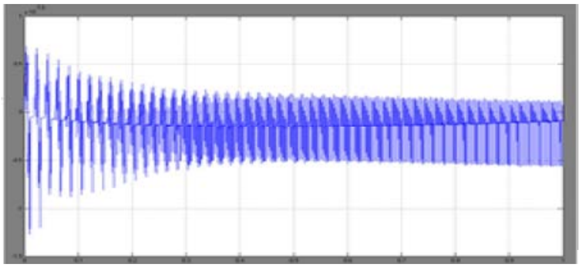

Fig. 9: DC link current waveform

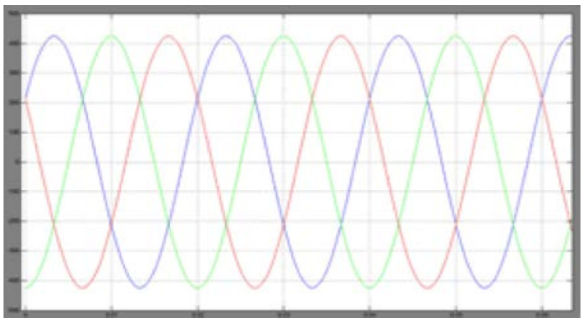

Fig. 10: Output voltage waveform

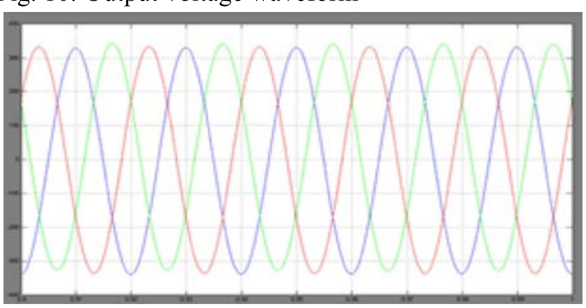

Fig. 11: Output Current waveform

Fig. 11 illustrates the three phase ac current waveform. This current value is measured by the load side inverter. The Hysteresis current controller produces the required current pulses for the PWM inverter to control the output voltage and current.

CONCLUSION

In this project a novel reliable hybrid DG system based on PV and wind driven PMSG as sources, with only a SEPI converter followed by an inverter stage, has been successfully implemented. The Three Point Weight Comparison algorithm is implemented to take Maximum Power Point from both the solar and wind sources. The mathematical model developed for the proposed DG system has been used to study the system performance in MATLAB. In addition, it has been established through simulation that the two controllers, MPPT controller and hysteresis-current-controller which are designed specifically for the proposed system have exactly tracked the maximum power from both the sources. This system requires little maintenance, high reliability and low cost are the important features required for the DG employed in secondary distribution system. It is for this reason; the developed controllers employ very low cost microcontrollers and analog circuitry. The proposed scheme finds application in hospital isolated power systems.

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