Design & analysis of improved bus-tied photovoltaic system for marine ships

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Photovoltaic (PV) systems converts the solar energy falling on them directly into electricity. In this paper, a small-scale ship’s bus-tied PV system is proposed. The proposed methodology will track the maximum power point (MPP) of PV array using hybrid maximum power point technique (MPPT) and flyback Direct Current to Direct Current converter. The tracked maximum power is then converted into AC power using a 3-phase full-bridge voltage source inverter controlled by space vector pulse width modulation (SVPWM) technique. This three-phase power will feed the local load and the excess AC power is transmitted into the ship’s bus. Also, the necessary steps and key components needed to design and build an efficient, reliable and low cost photovoltaic system are examined.

Keywords: Photovoltaic; MPP; MPPT; Duty cycle; Flyback converter; SVPWM; Local-load; Ship’s bus

Introduction

With the exponentially increasing world energy demand and reduction in fossil fuel reserves, there is a need to shift toward the renewable energy power generation systems. In this context, PV power generation is gaining significance due to its various advantages like less running cost as there is no external fuel required, no noise, less wear and tear due to absence of any rotating parts, little maintenance, long life etc. Despite of their mainland applications, PV systems are also used in modern marine technology.

PV system consists of PV array, power converters and controllers. PV array is the series and/or parallel combination of several PV modules and are connected as per the requirement to provide desire level of DC current and voltage, these PV modules comprises of several cells which converts solar energy into electrical energy. The output characteristics of PV array depends upon irradiance and temperature of incident sunlight. PV array has a particular MPP for particular irradiance and temperature at which its output is maximum. This MPP changes with the change in irradiance and temperature. In order to track MPP, a DC/DC converter controlled by MPPT technique is connected to the PV array. The voltage output of PV array is varied by changing the duty cycle of DC/DC converter. Duty cycle of the chopper is controlled by MPPT technique. Many MPPT techniques are available in the present literature, among which 20 MPPT techniques are compared.

DC power generated by the PV array is then converted into the AC power using inverter. In order to interconnect the PV system with ship’s bus, the AC output is such that it should match the ship’s frequency, voltage level and also it should meet the interconnection requirements such as voltage and frequency equals to ship’s bus voltage and frequency, total harmonic distortion (THD), active and passive power limits, etc. fixed by the marine authorities. Ship’s typical electrical system is shown in Figure 1.

Materials and Methods

The proposed model of ship’s bus connected PV system is an improved system to feed the local load and transmit excess solar energy into the ship’s bus. To simulate the model MATLAB R2017a Simulink software is used. The block diagram of the proposed system is shown in Figure 2.

In this simulation model, variable irradiance and temperature levels with respect to time (as shown in Figure 6) are provided to a PV array of 10 series connected modules per string in 5 parallel strings. This PV array is having 700V peak DC voltage in case of open circuit, 30A peak current in case of short circuit and produces maximum power up to 18 kW.

To track the MPP of PV array an improved high power flyback DC to DC converter with silicon
carbide (SiC) switch is used and the duty cycle of this chopper is controlled by modified incremental conductance with integral regulator MPPT technique. Flyback converter is advantageous to work for different input voltage levels while maintaining desired output voltage by providing appropriate transformer’s turn ratio. It provides electrical isolation between PV array and rest of the inverter. It performs both buck and boost operation when required. The simulation model of flyback inverter is shown in Figure 3. Modified incremental conductance with integral regulator control scheme is helping to track the MPP of the PV array by adjusting the duty cycle of the chopper, which changes chopper’s output DC voltage and current values. Simulation circuit diagram is shown in Figure 4. The duty cycle of flyback converter is shown in eq. 1

\[ D = \frac{V_{out}'}{V_{out}'+V_{in}} \]  

\[ V_{out}' = V_{out} \times \frac{N_p}{N_s} \]

where, \( V_{out}' \) is the output voltage of chopper, but as seen by the primary side, and \( N_p \) and \( N_s \) are the no. of
turns in primary and secondary side of transformer, respectively.

Maximum power point is obtained when

\[
\frac{\mathrm{d}P_{\text{PV}}}{\mathrm{d}V_{\text{PV}}} = 0 \quad \ldots \quad 3
\]

where, \( P_{\text{PV}} = V_{\text{PV}} \times I_{\text{PV}} \)

\[
\frac{\mathrm{d}(V_{\text{PV}} \times I_{\text{PV}})}{\mathrm{d}V_{\text{PV}}} = I_{\text{PV}} + (V_{\text{PV}} \times \frac{\mathrm{d}I_{\text{PV}}}{\mathrm{d}V_{\text{PV}}}) \quad \ldots \quad 4
\]

The integral regulator minimizes the error (e)

\[
eq \frac{\mathrm{d}I_{\text{PV}}}{V_{\text{PV}}} + \frac{I_{\text{PV}}}{V_{\text{PV}}} \quad \ldots \quad 5
\]

Regulator output = Duty cycle correction

The tracked maximum power of the PV array is then fed to a 3-phase full-bridge voltage source inverter. This inverter is controlled by a space vector pulse width modulation (SVPWM) control scheme. The control scheme also helps to maintain the voltage and frequency of output AC power of the inverter equals to the voltage and frequency of ship’s bus. With SVPWM control scheme, inverter utilizes 15% more input DC power than that of SPWM and cause
less THD in output. Simulation circuit diagram of SVPWM is shown in Figure 5. This control scheme is also helping to maintain constant output voltage, whereas output current may vary depending upon the irradiance and temperature of the incident sun light.

To eliminate higher order harmonics a simple LC filter is used in each phase before utilizing 3-phase AC power. This filtered AC power is then feeding 10kW local load and injecting excess generated electricity into the ship’s bus. For the protection purposes, an insolation transformer is installed in between inverter and Ship’s bus to electrically isolating them.

Results

Variable irradiance and temperature input to PV array are shown in Figure 6, respectively.

PV array’s output voltage, output current and output power are as shown in Figure 7, respectively.

Duty cycle of flyback converter controlled by incremental conductance with integral regulator and perturb & observe MPPT are shown in Figures 8 and 9, respectively. Proposed system having incremental conductance with integral regulator cause very few oscillations around actual MPP than that of perturb & observe MPPT.
Steady-state waveforms of DC bus voltage, output voltage and current feeding ship’s bus are given in Figure 10. Instantaneous waveform of DC bus voltage, output voltage and current feeding ship’s bus for 0.5 to 0.6 second are shown in Figure 11.

Steady-state waveform of inverter output voltage and output current feeding local load and ship’s bus are shown in Figure 12 and instantaneous waveform for 0.5 to 0.6 second of the same are shown in Figure 13.

Voltage and current input to the local load is shown in Figure 14 and instantaneous waveform for 0.5 to 0.6 second for the same are shown in Figure 15.

**Discussion**

As observed in the proposed model, modified incremental conductance with integral regulator MPPT technique has improved MPP tracking abilities and has very less oscillations around actual MPP as compared to perturb & observe and incremental conductance MPPT techniques.

Utilization of DC input power by the inverter is dependent on type of inverter and inverter control scheme. We can apply SVPWM technique, as it utilizes 15% more DC input and cause low THD than that of SPWM and some other techniques. Also,
Fig. 9 — Perturb & Observe controlled chopper’s Duty Cycle

Fig. 10 — Steady-state waveforms of chopper output voltage, ship’s bus side inverter voltage and current outputs

Fig. 11 — Instantaneous waveforms of chopper O/P voltage, ship’s bus side inverter voltage and current outputs
Fig. 12 — Inverter side steady-state voltage and current outputs of inverter

Fig. 13 — Inverter-side Instantaneous voltage and current output of inverter

Fig. 14 — Steady-state voltage and current inputs to the local load
controller is designed such that it reduces the sags and swells in the inverter output voltage.

Conclusion

Power demand is increasing day by day. To meet the demand conventional energy source are not sufficient because of environment concern. We need to depend on renewable energy sources. It is well known from the literature that the processing of power from renewable energy source is a challenging issue and we can participate to improve the current technology in a reliable, optimal and efficient manner.

The proposed system can be used to transmit solar power into the ship’s bus in a reliable and efficient manner. The system has the ability to efficiently track the MPP of PV array with very few oscillations around actual MPP. Input DC bus voltage utilization by the inverter using SVPWM control scheme is 15% more than that of SPWM controlled inverter. Inverter controller is able to synchronize PV inverter and ship’s bus. The system has electrical isolation between PV array and inverter, and also between inverter and ship’s bus. This system will definitely prove to be a technology breakthrough for marine ships.

References