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A Stand Alone PV System for Water-Pumping Application

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Abstract: In this study, a Stand-alone PV system with integrated battery for water pumping application is presented. PV system being the primary source and battery is the secondary source for the application. This can also be applied under dynamic load changes. Perturb and Observe (P&O) is applied for obtaining the Maximum Power Point (MPP) PV system. A bidirectional charge controller is implemented for charging and discharging of the battery. For water pumping application, a single-phase Induction Motor (IM) is used. The presented system is designed in MATLAB simulation.

Key words: PV system, battery, bidirectional converter, 1-phase IM, maximum, simulation

INTRODUCTION

Now a days, the demand of electrical energy is increasing day by day. The fossil fuels are decreasing exponentially throughout the world (Pachauri and Chauhan, 2012). There is a necessity for other non-conventional energy sources like solar, biomass wind, geo thermal, tidal, biodiesel and fuel cell. These sustainable Renewable Energy (RE) sources are sufficient to balance and to overcome the drawback of electrical energy. Comparing to all RE sources, solar energy high priority to taken as choice. Even though, RE sources are abundant in nature they have their own limitations. These include environmental conditions like temperature, irradiance, velocity of wind, humidity, partial shading, etc. PV source exhibits a non-linear V-I characteristic which varies with solar irradiance and temperature. As a result, tracking the maximum power point an MPPT is required in order to extract maximum power from the PV system. Several MPPT techniques have been proposed for PV systems under uniform irradiation which are summarized by Esram and Chapman (2007) and Subudhi and Pradhan (2013). Among these, the Perturb and Observe (P&O) algorithm is one of the most popular methods due to its simplicity. Similarly, battery has also having some limitations regarding SOC, charge and discharge characteristics and more over it is internally working on chemical reaction the rate of reaction is a temperature dependent. So, stand alone PV system is more desirable for the use power for the remote end which is far away from the grid (Busquet *et al*., 2002).

During the peak hours in a day, the generation of the electrical power is more due to the solar irradiation level is very high and water pump load is fed by IM. The stand-alone PV system driven IM based water pumping system is shown in block diagram (Fig. 1). Simultaneously, the battery power flow is almost reduced to zero and the water pump is fed by solar energy only. At night time, the solar irradiation is less or totally absent and now WPS is totally depending on the battery power. The battery is an electrochemical system which converts the chemical energy into electrical energy. The power electronic converters were used for interfacing the battery with PV system for WPS (Kumar *et al*., 2015).

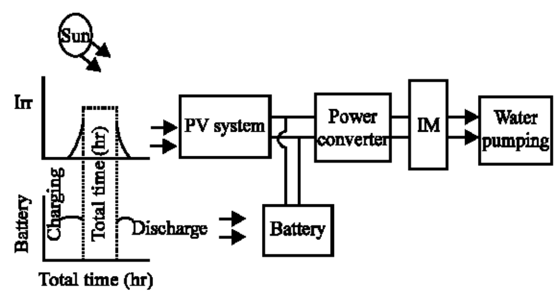

Fig. 1: Block diagram of stand alone photovoltaic system for water pumping system fed by IM

MATERIALS AND METHODS

System configuration: The presented system contains the three key parts namely as PV system and battery as power sources power converter induction motor. The arrangement of presented IM based stand alone system is shown in Fig. 1.

Stand-alone PV system: Due to the non-linear characteristic nature of a PV cell, the equivalent single diode model of a PV cell is developed and is shown in Fig. 2. For simplicity, the single diode model is studied

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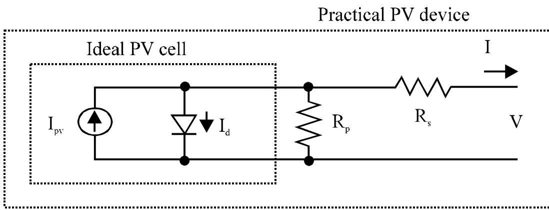

Fig. 2: Equivalent circuit of single-diode model of the theoretical PV cell

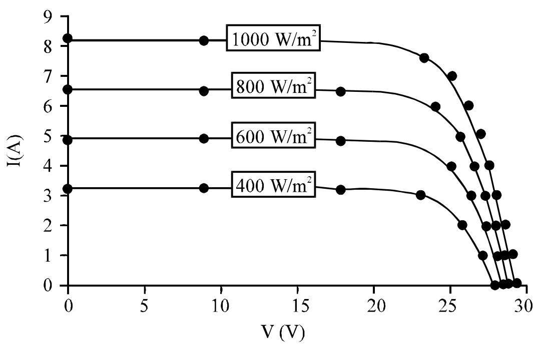

Fig. 3: For constant irradiation; Kyocera KC 200 GT-25°C

in this study. This model gives a good compromise between accuracy and simplicity (Villalva *et al*., 2009). The ideal I-V characteristic of the PV cell is derived from the theory of semiconductors. The basic equation from that mathematically can be written as follows:

$$I = I_{pv}, \text{cell} - [I_o, \text{cell} [\exp(qv/akT) - 1] \quad (1)$$

Where:

I_{pv}, cell = The current generated by incident light
Id = The equation of the Shockley diode
Io = Reverse saturation current or leakage current
Q = Charge of the electron, k-Boltzmann constant
T = Temperature (Kelvin) of a P-n junction
a = Ideality constant

Ideal PV graphs: Improving ideal model from Eq. 1:

$$Io = \frac{Isc,n + K_I \Delta T}{\exp(Voc,n + Kv\Delta T)/aVt) - 1} \quad (1)$$

MPPT algorithm: The most widely used algorithm is the Perturb and Observe (P&O) algorithm which is shown in Fig. 5. The P and O algorithm continuously finding the duty cycle which controls the power converter to find the Maximum Power Point (MPP) it takes the following flow chart steps over the PV characteristic (Fig. 3-5).

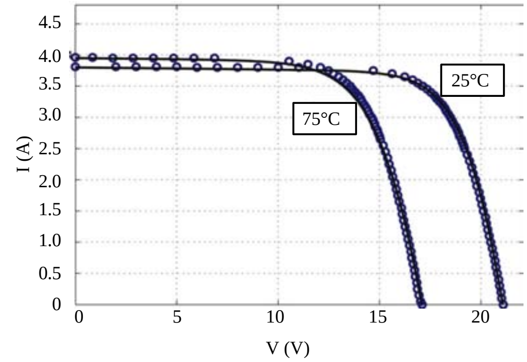

Fig. 4: For constant temperature; Solerex MS×60-1000 W/m²

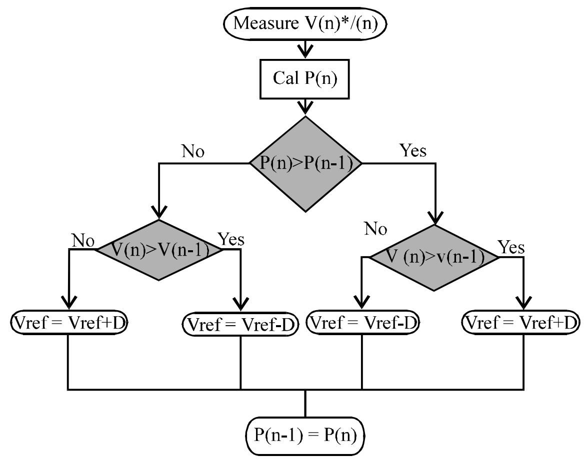

Fig. 5: Flow chart of P&O algorithm

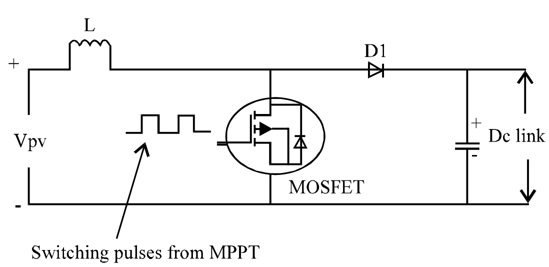

Fig. 6: MPPT based boost converter

Boost converter: In this study, the conventional boost topology is used to maintain constant power at the panel, means it operates at maximum point in the PV curve taking the panel voltage and current as input values for MPPT it gives output as duty cycle to the switching pulses for the gate of MOSFET in the boost converter shown in Fig. 6.

Battery: During peak hours in a day time, the power generation from the PV panel is more, during remaining hours the power generation is less. So, we need to place a battery in the stand alone system to store and reuse the energy from it. By using the battery, nullifying the dynamic load changes at the load end or we can say supplying the electrical load as needed or demanded. The two modes of operation of the battery are:

- Charging
- Discharging

Charing was done by buck converter operation from the panel DC-link to the battery and during discharging the boost operation was done from battery to DC-link. There are some parameters which can decides the life of the battery.

Self discharge rate: Due to internal mechanism and losses which undergoes a reduction in state of charge without charge or discharge current within the battery, the whole process was going under open circuit mode.

State of Charge (SOC): The amount of energy stored as a percentage of energy to the total capacity of a full charged battery is called state of charge. Discharge a battery results in decrease of SOC while charging results in increase of SOC.

Battery should not been overcharged for a long duration, it has a adverse temperature affect on battery means should not been charged for 100% for a long period. Battery should not been over discharge, deep discharge again affects on the life of the particular battery.

There are many characteristics which are deciding the life of the battery is seen. More over MPPT controller is focussed on tracking and controlling the power output of the photo voltaic module array. The DC-link at boost converter varies according to the tracking process and the solar irradiation level. For optimal and effective utilization storage system of the battery, a bidirectional converter is used to control the charge and discharge process.

Bidirectional converter: For the better interfacing between battery and load, a bidirectional converter should be placed (Rao and Gairola, 2016). For the bidirectional converter which employs PV panel, battery charging and discharging system and load which are available in study (Wang and Li, 2013; Zhao *et al*., 2008; Zhu *et al*., 2015; Singh *et al*., 20I3; Nathan *et al*., 2015; Choi *et al*., 2013) literature survey. In PV system power generation is uncertain and its output power depends on whether condition. During light load condition bidirectional converter charges battery through the DC-link and during peak load battery feed power to the load through DC-link.

Table 1: Control logic for battery charging and discharging

Charging	Discharging
If $P_{pv}>P_{load}$ and $SOC_p<SOC_{(min)}$	If $P_{pv}<P_{load}$ and $SOC_p>SOC_{(max)}$
'S_1' is ON	'S_2' and 'S_3' ON
'S_2' and 'S_3' OFF	'S_1' is OFF

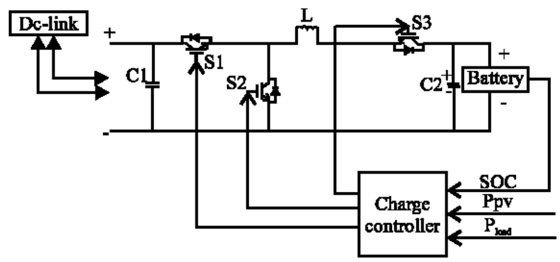

Fig. 7: Battery with bidirectional converter and charge controller

For this we must place a charge controller, combined battery, charge controller and a bidirectional converter is shown in Fig. 7 (Kumar *et al*., 2015).

Charge controller: The charge controller process is to be mainly based on the three parameters, State of Charge (SoC) of battery, Panel Power (P_{pv}) and load Power (P_l). The charge controller is shown in Fig. 7. To control charging and discharging of a battery vary the switching sequence in a bidirectional converter is as given in Table 1.

Power converter: In this study, the conventional full-bridge converter is used to convert the DC power from panel/battery to AC power. Gate pulses are given by the gate drive circuit which is available as an inbuilt block in MATLAB simulation. Output voltage obtained from the inverter is a pulsated alternating waveform. To reduce the total harmonic distortions in the voltage waveform, a LC filter is used before the load.

RESULTS AND DISCUSSION

The switching gate pulses for the battery charging and discharging are shown in Fig. 8a-f. The operating principle for generating the required pulses is defined in Table 1.

Duty cycle for each switch is obtained by comparing the load power with the panel power. For the charging path, S1 is on and S 2, S3 are kept off with the generation of the appropriate pulses. The bidirectional converter acts as a buck converter. Similarly for the discharge of the battery the pulses are generated again by comparing the load power with the panel power then S2, S3 are on and S1 is kept off. During this mode the bidirectional converter acts as a boost converter. When the panel is unable to

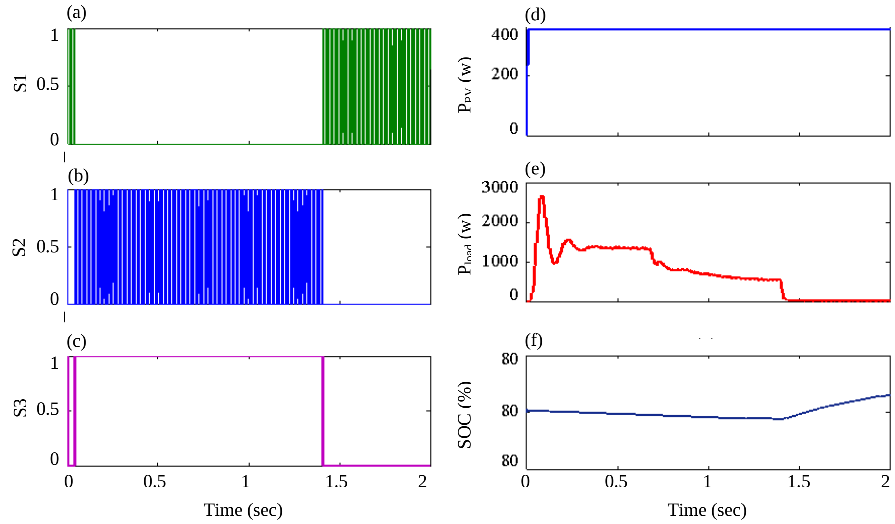

Fig. 8: a) Switching pulse for S1; b) switching pulse for S2; c) switching pulse for S3; d) panel power; e) load power and f) SOC of battery

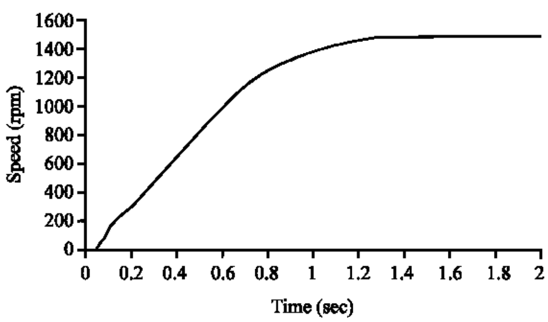

Fig. 9: Speed of the induction motor

balance or supply the load power then the battery delivers power to the load. The battery discharges linearly till t = 1.4 sec after which the panel is able to deliver the load and the battery shifts to charging mode as shown in Fig. 8.

For the whole simulation the speed of the IM is as shown in Fig. 9. Initially it was drawn power from both panel and battery from simulation point 1.4 it was taken from PV panel only. At starting of simulation (0-1.4 sec) the load was increased due to IM and connected loads. After crossed 1.4 sec the load was decreased up to 2 sec.

CONCLUSION

In this study, Stand-alone PV system for IM based water pumping system was presented. P&O method is applied for operating the system at maximum power point. IM is driven by RE source with an integrated battery for the application of water pump system has been done in MATLAB simulation. The study is carried out for a stand-alone PV system with an integrated battery and it is found to be satisfactory with IM as load for the water pumping application.

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