Efficient Power Management System with PV-Battery DC Micro Grid

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ABSTRACT

This paper presents an optimal energy management for PV/battery stand-alone system. The system comprises photovoltaic (PV) array, battery, inverter and AC loads. The PV array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when variations in irradiation and temperature occur, which make it become an uncontrollable source . In coordination with battery bank the system becomes controllable. The battery bank will define different modes of operation of the system. These modes of operations are determined by the energy balance between generated energy and load demand. This project proposes an optimal energy management strategy to improve the performance of the PV system. The proposed system performance is evaluated for varying loads in MATLAB/simulink.

KEYWORDS:
PV system, DC-DC Converter, Maximum Power point tracker, Battery, Energy Management.

I. Introduction

Due to critical situation of fossil fuel declining and the global warming effect, alternative energies become popular. In nature many renewable energy resources are available like solar, wind, tidal and hydel. But solar energy is the most popular source among the alternative energies with no emission of pollutants energy conversion is done. Demand for solar energy is increased from 20% to 25% over the past 15 years. Other advantages of solar energy is like eco- friendly, abundant availability in nature and recyclable.

Generally a PV cell generates a small voltage around 0.5 to 0.8v depending on the semiconductor device and has low energy conversion efficiency; therefore a maximum power point tracking (MPPT) system is essential to track maximum power from the PV.

Due to the intermittent nature of photovoltaic energy source, batteries are added to ensure the continuous power flow to meet the demand. The battery can store the energy or it can supply the energy system. It will define depending upon the different modes of operation. Generally these modes of operation are determined by the energy balance between the generated energy and the load demand. This paper presents an optimal energy management for PV/battery stand-alone system

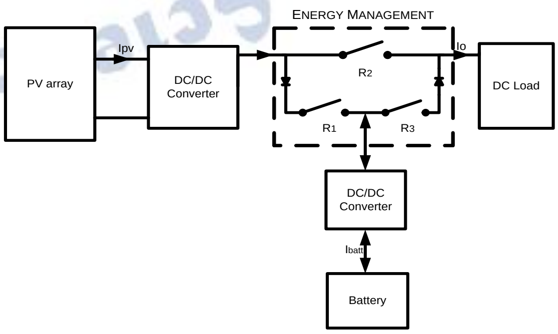

Fig 1: Proposed design of PV/Battery stand-alone system.

II. System Description

Fig.1 shows the PV/Battery standalone system for energy management system. It includes a PV array with DC/DC converters, batteries and variable DC load. DC/DC Converter, battery and load are connected trough three relays. The proposed system main function is to manage the energy between PV, Battery and load. This energy management is done by the different modes of operation which are determined by the energy balance between the generated energy and the load demand

Modeling of Proposed System

A. Dynamic Model of PV Array:

The PV array involves N strings of modules connected in parallel, and each string consists of M modules connected in series to obtain a suitable power rating. The dynamic model of PV cell is shown in Fig. 2

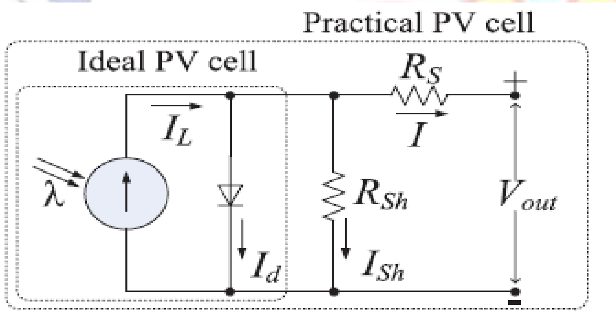

Fig 2: Equivalent electrical circuit for PV cell

The process of modeling of solar cell is developed based on the following equations. The The output-terminal current *I* is equal to

$I = I_{ph} - I_d - I_{sh}$

Where,

I_{ph}, Light generated current

I_d, Diode Current

I_{sh}, Shunt Leakage current

$I = Iph - I_{o,cell} * [exp(q*v/(akT))-1]$

Where,

$I_{o,cell}$: Reverse saturation current of the diode[A].

q : Electron charge [1.60217646×10^{-19}c].

k : Boltzmann constant [1.3806503×10^{-23}J/k].

T : Temperature of the p-n junction.

α : Diode identity factor which lies between 1&2 for mono crystaline silicon.

The series resistance R_S represents the internal resistance to the current flow. The shunt resistance R_{Sh} is inversely related to leakage current to the ground. For an ideal PV cell, R_S = 0 (no series loss) and R_{Sh} = infinite (no leakage to ground). The typical values of R_S = 0:05 to 0.10Ω and R_{Sh} = 200 to 300 Ω. The energy conversion efficiency of PV cell is sensitive to small variations in R_S , but is insensitive to variations in R_{Sh}. A small increase in R_S can decrease the PV output significantly.

B. MPPT in DC-DC Converter:

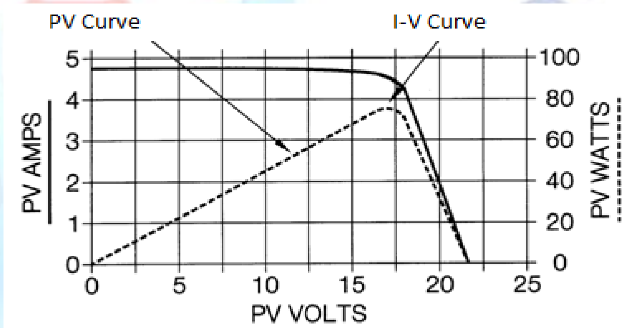

Fig 3: MPPT System

The PV cell produces the maximum power at voltage corresponding to the knee point of the *I-V* curve, as shown in Fig. 3. V_{max} and I_{max} are voltage and current at maximum power point, respectively. The dc-dc converter is set to operate at optimal voltage to achieve maximum power by MPPT algorithm. In this system P&O method is used to track the MPP from PV cell.
P&O measures the operates by increasing or decreasing the array terminal voltage, or current, at regular intervals and then comparing the PV output power with that of the previous sample point. If the PV array operating voltage changes and power increases (*dP/dV*, PV > 0), the control system adjust the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction.

C. Electrical Model of Battery

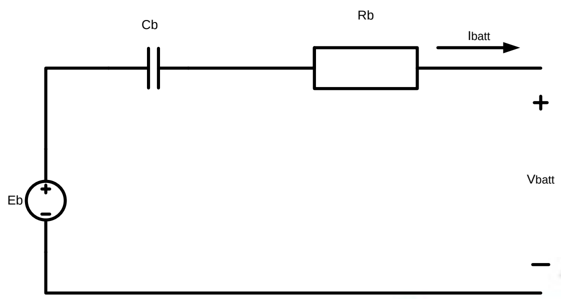

Fig.4 Equivalent circuit of battery.

Battery is an important element of a stand-alone PV system due to the fluctuating nature of PV array. Lead acid battery is used due to its performance characteristics

Electromagnetic force is kept in series with the source voltage E_b. Internal resistance R_b..

The terminal voltage of the battery is given by:

$$V_{batt} = E_b - R_b * I_{batt} - V_{cb} \qquad (2)$$

State of charge of the battery is given in the equation below:

SOC is the amount of electricity stored during the charge.

$$SOC = 1 - Q_d / C_{batt} = 1 - (I_{batt} * t) / C_{batt} \qquad (3)$$

Where,

Q_d : amphere-hours stored in the battery during a time t with a charging current I_{batt}.

C_{batt} : battery nominal capacity.

D : DC/DC converter

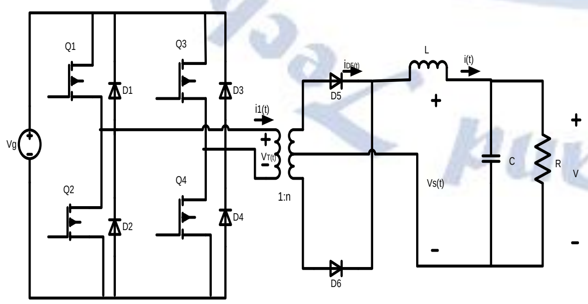

Fig.5 Isolated buck transformer.

Isolated buck is used due to its advantages over other converters. It has the following features. To convert the energy storage system to the bus. It is able to operate under a wider output power range. Bi-directional power flow, high power operation, galvanic isolation, long battery life time. A long battery life time is achieved by draining from and providing to the battery a low ripple DC Current.

III. Modes of Operation

The energy management is done between the PV system, Battery and Load. This management system controls the energy produced by the PV array and battery storage to supply the demand.

A. Operating Modes

The proposed PV/Battery stand alone system operates in any one of the five modes.

Mode 1: $P_{PV} > P_{load}$ (Battery Chargig)
In this mode PV system generates excess amount of power than the demand. At this time battery is charging with remaining power.

Mode 2: $P_{PV} < P_{load}$ (Battery Discharging)
In this mode PV system generates insufficient power and the required amount of power is taken from the battery.

Mode 3: $P_{PV} = 0$ (Battery supplies to load)
When there is no available energy from the PV then Battery supplies the load

Mode 4: $P_{PV} = P_{load}$ (Only PV supplies to load)
In this mode the PV array generate sufficient energy to feed the load without the intervention of battery.

Mode 5: $P_{PV} = 0$, $P_{batt} = 0$ (Disconnect the load)
In this mode, no PV energy production and battery are completely discharged, then the consumer is disconnected.

Switch/Mode	*R1*	*R2*	*R3*
Mode 1	*1*	*1*	*0*
Mode 2	*0*	*1*	*1*
Mode 3	*0*	*0*	*1*
Mode 4	*0*	*1*	*0*
Mode 5	*0*	*0*	*0*

IV. Proposed Method

PV Management Programming:

```
function [R2,R1, R3] = fcn(Vbattery,
Ppv, Plo)
R1=0; R2=0; R3=0;
```

```
Pav=0;
Vhvd=190;
Vlvd=100;
Pav=Ppv-Plo;
if Pav>0
    if Vbattery<Vhvd;
    R1=1;
    R2=1;
    R3=0;
else
    R1=0;
    R2=1;
    R3=0;
    end
else
    if Vbattery>Vlvd
        R1=0;
        R2=1;
        R3=1;
    else
        R1=0;
        R2=0;
        R3=0;
    end
end
```

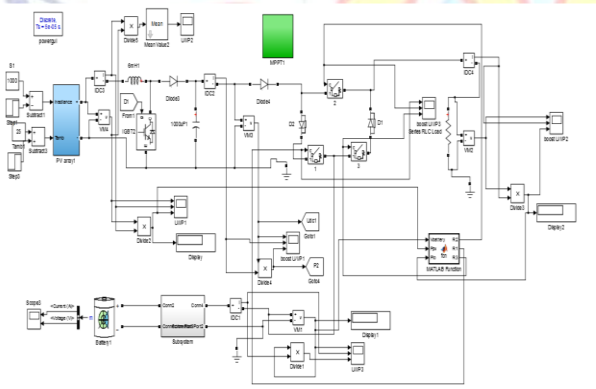

Fig.6 Proposed Simulation Circuit.

V. Simulation Results

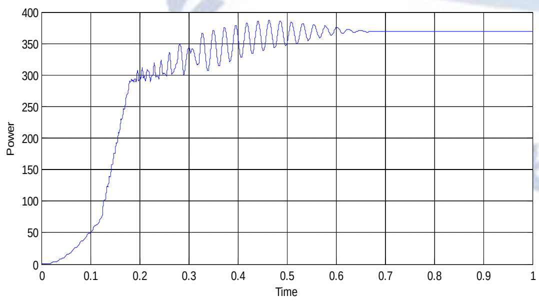

Fig.6 PV Power v/s Time

The Fig.6 shows the power-time characteristics. Where the raise time is from 0 to 0.2 sec, transient state starts from 0.2 to 0.6 sec and from 0.6 to 1 it shows the steady state.

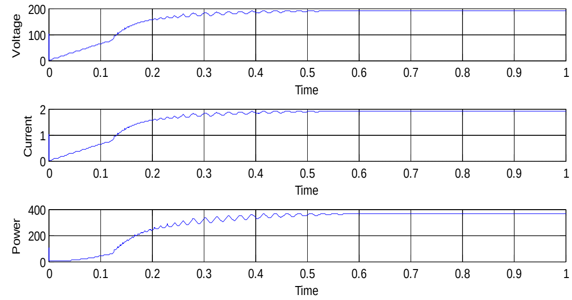

Fig.7 Load characteristics

Load characteristics are shown in the Fig.7 where the curves are plotted between Voltage and time, current and time, power and time. The raise time is from 0 to 0.11, transient state is from 0.12 to 0.5 sec and the steady state characteristics are from 0.5 to 1 sec as shown here.

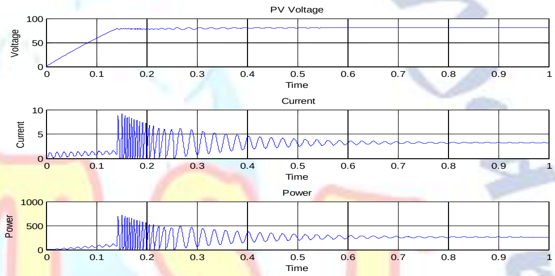

Fig.8 PV Characteristics

Fig.8 shows PV characteristics which are plotted between the Voltage and time, current and time, power and time. . The raise time is from 0 to 0.14, transient state is from 0.15 to 0.6 sec and the steady state characteristics are from 0.61 to 1 sec shown here.

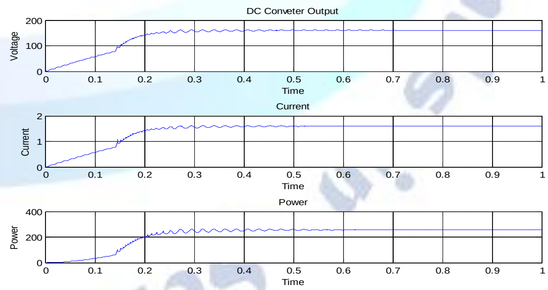

Fig.9 DC Converter Output

Fig.9 shows characteristics of DC Converter, which are plotted between the Voltage and time, current and time, power and time. . The raise time starts from 0 to 0.14, transient state is from 0.15 to 0.7 sec and the steady state characteristics are from 0.7 to 1 sec shown here.

An optimal energy management algorithm was developed for PV/battery stand-alone system. The algorithm has capable to manage and coordinate the different modes of operation. The modeling of PV cell is studied with the MPPT technique. Battery is connected with bi-directional DC-DC converter to compensate the load. The simulation results shows the energy management algorithm will operate correctly for the battery charging and discharging and in compensation of the load demand.

VI. Conclusion

An optimal energy management algorithm was developed for PV/battery stand-alone system. The algorithm has capable to manage and organize the different modes of operation. The modeling of PV cell is studied with the MPPT technique. Battery is connected with bi-directional DC-DC converter to compensate the load. The simulation result shows the energy management algorithm will operate correctly for the battery charging and discharging and in compensation of the load demand

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