A TWO STAGE CONVERSION METHOD FOR THE ACTIVE POWER CONTROL OF SOLAR PHOTOVOLTAIC PLANTS AND STORAGE IN A MICROGRID

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generated from the solar array being tracked for maximum output using an MPPT algorithm. A buck converter is utilized for maintaining a constant voltage even under low insolation levels.

1. INTRODUCTION

A micro-grid comprises of low-voltage (LV) distribution systems with distributed energy resources (DERs) such as micro-turbines, fuel-cells, photovoltaic arrays, etc. Photovoltaic systems form an important part of renewable energy generation since they are pollution free, and have long life when supplying energy. PV modules though promising in many aspects when related to energy have a low efficiency [3].

This makes the design and control methodologies to be somewhat complex and challenging when the system is being connected in a microgrid. To be able to come up with a tangible solution, we need to design and utilize a model for the solar array and an algorithm for the converter.

Various solar cells are available that can be modeled. For the purpose at hand, a particular model of the polycrystalline solar cell is simulated along with the MPPT algorithm and the dc-dc converter and inverter in a two stage approach with a battery for use under different operating conditions.

The grid connection of the solar modules has to guarantee maintenance of stability when the microgrid operates in an islanded condition. Frequency and voltage under such conditions are challenging tasks. Frequency regulation is achieved by active power control of PV power as discussed in this paper.

2. DESCRIPTION OF THE MODEL

2.1. Overview

The system being modeled is shown in Fig 1. It consists of a two stage power conversion topology with the raw power

Fig 1 The topology of the two stage power conversion method.

2.2. Photovoltaic array

The solar array selected for simulation of the module for experimental purposes is the BP solar SX-3200, 200W photovoltaic module. The general circuit selected for the purpose is shown in Fig 2.

Fig 2. The photovoltaic array circuit model

The photovoltaic equation is given by:

\[ I_p = I_{ph} - I_0 \left( \exp \left( \frac{V_p + I_p R_s}{A V_t} - 1 \right) - \frac{V_p + I_p R_s}{R_p} \right) \]

where

- \( I_{ph} \) Short circuit current
- \( V_{oc} \) Open circuit voltage
- \( I_r \) Current at Pmax
- \( V_r \) Voltage at Pmax
- \( V_t \) Thermal Voltage
- \( R_p \) Parallel resistance
2.3 Maximum power point tracking algorithm

The array voltage and current vary with the insolation throughout the day. Hence a control over the duty ratio needs to be generated for the purpose of getting a constant output voltage at the buck converter. The algorithm used is the simple perturb and observe (P&O) method that maintains a constant output voltage by changing the duty ratio for the converter. The algorithm takes into consideration the insolation values and then calculates the maximum power point from the characteristics graph [4].

The algorithm can be represented by a flow chart shown in Fig. 3.

![Flow chart depicting perturb and observe algorithm](image)

Fig 3 Flow chart depicting perturb and observe algorithm [4].

2.4 DC-DC Buck Converter Design

The topology of the converter is shown in Fig. 4 which gives a clear idea of the variables involved in its design and analysis.

![Buck converter circuit topology](image)

Fig 4 Buck converter circuit topology [4].

During the selection of the converter for the system a configuration of 5 array modules is taken with an input voltage range of 50V-122.5V. The total power being generated from the panels is theoretically equal to a maximum value of 1000 W.

MOSFET

In the design for the devices in the converter, the first step is to decide on the switch and the diode. A MOSFET is selected since it is a very fast device and not very expensive for low voltage applications. It has an average current rating of 20 Amp and a maximum voltage of 150 V. The switching frequency is selected as 100 kHz.

DIODE

For the conduction during the switch off time, a schottky diode is selected based on its advantage of low losses compared to the other diode types. The same ratings as the MOSFET are used.

INDUCTOR

The equation that governs the design is given by

\[ \Delta I_L = \frac{(V_{in} - V_{out}) \cdot D \cdot T_s}{2 \cdot L} \]

(2)

L is calculated to be 110 μH

CAPACITOR

The equation governing the design is given by

\[ C = \frac{\Delta I_L}{(8 \cdot L \cdot f_s)} \]

(3)

C is calculated as 100 μF, 55V. Both devices will have an ESR of 100mΩ and 160mΩ for the capacitor and inductor respectively. The above calculations are made taking into account the current ripple as 10% and voltage ripple as 1%.

2.5 Inverter Design

The inverter selected for the second stage is a buck design-based full bridge inverter that has a voltage conversion ratio of 0.866 [8]. Since the output voltage requirement is 120 V rms at the terminals for the load a transformer is used to step up the voltage after the conversion. Theoretically the maximum voltage that can be obtained at the transformer inputs is 24.5 V and this has to be stepped up for supplying the load.

Fig 5 shows the design circuit of the full bridge inverter that will be used in the second stage of power conversion.

![Circuit model of the inverter](image)

Fig 5. Circuit model of the inverter.

The stability factors have to be taken into consideration while designing the parameters for the inverter. An L-C filter...
is used to remove the high frequency ripples caused due to the switching of the MOSFETs.

The inverter design parameters are as follows:

- The switches used are MOSFETs rated at 60V and 50 ampere.
- The transformer is rated for 1000VA and turns ratio of 1:5. The output at the transformer secondary terminal is 120Vrms.
- The switching frequency is selected as 50 kHz.
- The min frequency of the LC filter should have to be 5 kHz.

The design circuit will function only if we choose a floating duty cycle controllers for all the four switches. L and C values range are selected such that

$$\frac{1}{2 \pi \sqrt{(L \cdot C)}} = 5 \times 10^3$$


2.6 Battery storage

For storage of the PV energy, lead acid deep cycle batteries are used. Deep cycle batteries are used because of their slow discharge rate to depths of 80% of full capacity and then to be recharged many number of times.

For the purpose at hand, a C100 battery would discharge for 100 hours or for 4 days. [11] The following important points should be considered:

1. Application of constant power to charge it before discharge cycle begins.
2. PV plant should be used during the peak load and only if necessary, the battery should be discharged.
3. If the battery SOC (state of charge) is full then all the power from the PV array should be used to serve the load.

The charging and discharging profiles will be simulated in Matlab/Simulink and verified for the specified load. A standard Glen Electronics or Sportsman marine batteries can be used for this purpose [12].

3. SIMULATION AND RESULTS

3.1 MATLAB/Simulink model of the PV array.

The Simulink model of the PV array simulated for the verification of the BP solar array with specific standard parameters specified in the data sheet is modeled as shown in Fig 6.

The model of BP SX-3200 is tested for different values of the insolation and the maximum power in each case along with the output current generated. The model is simulated with reference to the model as suggested by Chowdhury [6]. The various values generated for different insolation over a period of time for the selected PV array is tabulated as shown in Table 1.

<table>
<thead>
<tr>
<th>INSOLATION (W/m²)</th>
<th>MAXIMUM POWER (W)</th>
<th>Ipv (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>196.2</td>
<td>8.7</td>
</tr>
<tr>
<td>900</td>
<td>174.9</td>
<td>7.8</td>
</tr>
<tr>
<td>800</td>
<td>159</td>
<td>7</td>
</tr>
<tr>
<td>700</td>
<td>141</td>
<td>6.1</td>
</tr>
<tr>
<td>600</td>
<td>121</td>
<td>5.2</td>
</tr>
<tr>
<td>500</td>
<td>99</td>
<td>4.4</td>
</tr>
</tbody>
</table>

The results also show that the power requirements are met within the constraints and the voltage remains constant at 30V. The variation of the voltage and power outputs for different values of insolation can be better understood with the simulated values as depicted in Fig 7.

![Fig 7(a) Current –Voltage characteristics](image)

![Fig 7(b) Power-Voltage characteristics. Both curves are drawn for an insolation of 1000 W/m²](image)
3.2 DC-DC Buck Converter simulation

While designing the converter the ESR of the capacitance and the inductance is also taken into consideration, thereby removing the ideality factor for the model. A better understanding of the converter is achieved when it is simulated in PSCAD as shown in Fig 8.

![Fig 8 The PSCAD model of the dc-dc buck converter](image)

The 5 solar panels are grouped together to give a total output voltage that varies from 50V - 122.5V. The PV output power varies from 910W - 1000W. The following assumptions are made with respect to the design calculations.

- The voltage ripple tolerance is assumed to be 1% and the current ripple assumed to be 10% so as to allow for flexibility while calculating the inductance and capacitance.

The buck converter model shows that the output voltage followed the input voltage for a given duty cycle and stayed within the bounds as seen in Fig. 9.

![Fig 9 The waveforms of the switch and the output with variation in PV inputs. Duty ratio is constant.](image)

The voltage waveform suggests effective control over the output with the regular variations of the PV array voltage. When the duty ratio is controlled by the P & O algorithm, a constant output voltage can be maintained that will be used to charge the battery bank for future usage.

3.3 Simulink model for the Perturb and observe algorithm

The Simulink model of the perturb and observe algorithm is shown in Fig. 10. It has to be integrated with the PSCAD model of the buck converter for testing it using the duty cycle variation in the range of 0.328 to 0.8.

![Fig 10 Simulink model of the perturb and observe algorithm](image)

3.4 Inverter simulation

The PSCAD model of the inverter is shown in Fig 11. This model is integrated with the dc-dc converter. The design parameters which have been selected in section 2.5 are implemented and checked for the operation of the inverter.

![Fig 11 PSCAD model of the dc-ac inverter](image)

The model shown in Fig 11 is integrated along with the converter in PSCAD for verifying the conversion of power from dc to ac. The design parameters which have been selected in section 2.5 are implemented and checked for the working of the inverter to achieve the required output.

4. FUTURE WORK

The inverter design in PSCAD will be verified for the desired voltages at the load. The integration of the simulation modules in Simulink and PSCAD are to be completed. This step will generate a full simulation model of PV-battery system for use in a microgrid. A major task would be to unify the models with reference to time frame chosen for the modules.

5. CONCLUSIONS

This paper provides a model of the PV array simulation and reserve power storage methodology for use in microgrid application. The reserve power is necessary to provide frequency response capability in the microgrid when loads vary. The control algorithm allows the increase or decrease of power output from the PV array as desired. The two stage converter-inverter topology allows the incorporation of energy storage capability with the PV array which will provide higher
flexibility, albeit at a higher cost. The models of the PV array and the converter have already been verified by simulation. However, the inverter simulation as well as the full system simulation within a microgrid still remains to be completed.

6. ACKNOWLEDGMENTS
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7. REFERENCES


[12] www.allbatterycenter.com