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Hadeed A Sher, King Saud University

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Performance Enhancement of a Flyback Photovoltaic Inverter using Hybrid Maximum Power Point Tracking

Hadeed Ahmed Sher¹, Khaled E Addoweesh¹, Kamal Al-Haddad²

¹Department of Electrical Engineering, King Saud University, Riyadh, Saudi Arabia
² Department of Electrical Engineering, Ecole de Technologie Superieure, Montreal, QC

Corresponding E-mail: hsher@ksu.edu.sa

Abstract—In this paper a grid connected photovoltaic (PV) flyback inverter operating in discontinuous conduction mode (DCM) is used to test a hybrid maximum power point tracking (MPPT) method. Moreover, the design procedure of a flyback inverter is also presented as part of this paper. The proposed hybrid MPPT method is a combination of fractional short circuit current (FSCC) and hill climbing (Perturb and Observe P&O) method. The proposed MPPT use current limits to detect abrupt weather changes and hence swiftly tracks the maximum power point (MPP) under dynamic weather conditions. This MPPT method is tested using co-simulation between PSIM and simulink, where the control algorithm is implemented in simulink and the grid connected inverter is executed in PSIM. The results shows enhanced energy harvesting compared with P&O when subjected to uniform and dynamic weather conditions.

Keywords—Microinverter, Flyback Inverter, Grid Connected systems, Maximum Power Point Tracking

I. INTRODUCTION

Nowadays a lot of emphasis is on the use of PV systems for energy generation. One reason of this growing interest is quick installation and reduced impact on environment. It is estimated that by 2017 the cumulative installed capacity of PV generation will be over 400,000 MW [1]. The production of energy from PV device is however weather dependent, which means that the continuous change in solar insolation and temperature affects the output power of the PV module. In this regard, harvesting maximum power under any environmental condition is important. The methods use to hunt and operate the system at maximum available power are known as Maximum Power Point Tracking (MPPT) methods. The MPPT methods are implemented using available power converters. Currently, the use of AC module, also known as MicroInverter (MI), is targeted as an emerging research topic for enhanced PV energy production. Among various kinds of MI the use of flyback inverters for integrating PV modules with the grid has many advantages, that include, simpler structure and isolation of PV module from the grid. In literature most of the grid connected MI are designed with the following hill climbing MPPT methods.

- Perturb and Observe P&O
- Incremental Conductance (Inc)

For instance, consider the work of [2] that is about the grid connected PV inverter based on sensorless current MPPT. The work of [3] is based on conventional P&O method for tracking the maximum power. The work presented in [4] has also used the conventional P&O method. The MPPT control in [5] is a modified InC method. However, the use of conventional hill climbing methods have their own disadvantages. Their tracking speed in dependent on step change. A larger step size results in large power oscillations around the maximum power point, that consequently contribute towards a power loss, while a smaller step size leads to slow tracking speed. Furthermore, these techniques are prone to poor performance under dynamic weather conditions. The work presented here addresses the issue of fast dynamic control of MPPT for the flyback inverter.

A hybrid MPPT is designed such that it operates the flyback inverter at MPP under steady as well as dynamic weather condition. The study is performed using computer aided simulations for various environmental conditions such that the proposed algorithm along with a conventional P&O are tested on the DCM based flyback grid connected inverter. The results presented here will form the reference benchmark for future study. The rest of the paper is organized as follows. Section II explains the designing and operation of a flyback inverter. The proposed hybrid MPPT is explained under Section III followed by section IV which deals with the simulation results. The simulation results are discussed briefly in Section V. The paper concludes with section VI.

II. DESIGN OF A FLYBACK INVERTER

Figure 1 shows the basic topology of a grid connected flyback inverter. In addition to the source (PV module) and the load (AC grid) the basic topology has following components.

- Decoupling capacitor (x1)
- Diode (x2)
- Mosfet (x3)
- Center tapped transformer (x1)
- Low pass filter (LC)

The switch \( S_{m} \) is connected on the primary side of transformer. It is switched with high frequency such that the envelop of the primary current has a sinusoidal waveform. The switches connected on the secondary side of transformer are switched reciprocally according to the grid polarity. Therefore, the switch designated \( S_{acnp} \) operates when the grid has positive polarity and switch \( S_{acnm} \) operates with negative polarity on
grid. The diodes connected on the secondary side block the current from flowing to the grid when $S_m$ is turned ON. To ensure the power quality the power conditioning circuit is connected with the grid via a low pass filter. The control diagram of flyback inverter is shown in Fig.2 and the switching pattern is shown in Fig.3. As seen from the Fig.2 the sensed parameters are converted into digital form by means of ADC. The photovoltaic current ($I_{pv}$) and voltage ($V_{pv}$) are used for MPPT. The use of MPPT ensures that maximum power is harnessed from the PV module. The grid voltage is sensed for synchronizing the inverter with the grid. The full wave rectified grid voltage (unity amplitude) is used as a control waveform for PWM switching of $S_m$. The amplitude of control waveform is multiplied by the duty cycle $D$ of the MPPT block. The switches $S_{acp}$ and $S_{acn}$ are turned ON according to the polarity of the AC grid and hence acts as an unfolding circuit. As seen from the Fig.3 the flyback inverter operates in DCM. The design steps of flyback inverter are given below.

1) Identify the input parameters, grid parameters and switching frequency
2) Identify the missing parameters and calculate them
3) Simulation of the system
4) Tuning of the calculated parameters for fine working of the system.

A. Identification of I/O parameters

The input parameters are the solar PV module under standard testing conditions. For this purpose the voltage at MPP ($V_{mpp}$) and power at MPP ($P_{mpp}$) are considered as the starting point. However, because the operating point of solar PV module displaces with the change in environmental conditions therefore, three different values of PV module voltage $V_{pv}$ are considered such that these values confines the full day range of operating voltage. Usually one value is $V_{dcmax}$, $V_{mpp}$ and $V_{dcmin}$ as shown in Fig.4. The use of these three operating points ensure that the PV module operates at MPP during the whole day operation. For example, as seen in Fig.4 three different voltage values are identified such that they encompass the PV curves for values of irradiation ranging from 50 $W/m^2$ to 1000 $W/m^2$. For a grid tied flyback inverter, the output parameters constitutes of grid voltage and frequency.
### TABLE I

**DESIGN PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{dc,p}$</td>
<td>42.7 V</td>
</tr>
<tr>
<td>$V_{dc,max}$</td>
<td>52.3 V</td>
</tr>
<tr>
<td>$V_{dc,min}$</td>
<td>32.5 V</td>
</tr>
<tr>
<td>Peak grid voltage $V_{gpeak}$</td>
<td>159 V</td>
</tr>
<tr>
<td>RMS grid voltage $V_{grms}$</td>
<td>110 V</td>
</tr>
<tr>
<td>Angular frequency of grid $\omega$</td>
<td>120 rad/Sec</td>
</tr>
<tr>
<td>Input power $P_{in}$</td>
<td>220 W</td>
</tr>
<tr>
<td>Efficiency $\eta$</td>
<td>0.9</td>
</tr>
<tr>
<td>Output power $P_o$</td>
<td>198 W</td>
</tr>
<tr>
<td>Switching frequency $f_s$</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Max. duty cycle $\delta_{max}$</td>
<td>0.5</td>
</tr>
<tr>
<td>Allowable voltage ripple $\Delta V_{dc}$</td>
<td>2 V</td>
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</table>

### TABLE II

**CIRCUIT PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$L_p$</td>
<td>11.2 $\mu$ H</td>
</tr>
<tr>
<td>$L_s$</td>
<td>92.07 $\mu$ H</td>
</tr>
<tr>
<td>$L_m$</td>
<td>11 $\mu$ H</td>
</tr>
<tr>
<td>$C_{in}$</td>
<td>6.83 mF</td>
</tr>
<tr>
<td>$N_p:N_s$</td>
<td>1:6</td>
</tr>
</tbody>
</table>

### III. PROPOSED HYBRID MAXIMUM POWER POINT TECHNIQUE

The proposed hybrid MPPT is shown in Fig. 5. The proposed MPPT has two stages. The first stage provides a rough estimate of the MPP location using short circuit current measurement, while the second stage fine tunes the approximated MPP and operates the system around the exact MPP. Therefore, additional circuitry is added to measure short circuit current in a conventional flyback inverter as shown in Fig. 7. The use of hybrid MPPT requires amended control scheme that is shown in Fig. 8. The working of the algorithm is explained below.

#### B. Identification of missing parameters

Based on the data given in table I the design equations for flyback transformer are given below [4], [5].

$$I_{op} = \frac{2P_o}{V_{gpeak}}$$  \hspace{1cm} (1)

Next, the turn ration “N” of the flyback transformer is determined

$$N = \frac{\eta V_{dc}V_{pp}}{V_{grms}}$$  \hspace{1cm} (2)

The peak current on primary side of flyback transformer can be calculated as

$$I_{pp} = \frac{I_{op}V_{gpeak}}{V_{dc} + \frac{1}{N}}$$  \hspace{1cm} (3)

The value of $I_{pp}$ is used to find the primary inductance. In order to make sure that the inverter operates in DCM the maximum value of duty cycle $\delta_{max}$ is limited to 0.5

$$L_p = \frac{V_{dc} \delta_{max}}{I_{pp} f_s}$$  \hspace{1cm} (4)

The secondary inductance can be determined by

$$L_s = \frac{L_p}{N^2}$$  \hspace{1cm} (5)

The magnetizing inductance can be calculated using the following equation

$$L_m = \frac{V_{dc}^2 \delta_{max}^2}{4P_{mmp} f_s}$$  \hspace{1cm} (6)

The value of input capacitor is calculated using

$$C_{in} = \frac{P_{in}}{\omega V_{dc} \delta_{max} \Delta V_{dc}}$$  \hspace{1cm} (7)

#### A. Operating mechanism of Stage 1

Stage 1 works using the fractional short circuit current MPPT. It isolates the PV module from the system and measures the short circuit current. It can be noted in the Fig. 6 that
Fig. 7. Modified flyback inverter topology for proposed MPPT

Fig. 8. Modified control scheme of flyback inverter topology for proposed MPPT

the $I_{mpp}$ is present in the close vicinity of $I_{sc}$. Mathematically, this can be expressed as shown in eq.8

$$I_{mpp} = k_1 \times I_{sc} \quad (8)$$

Therefore, the stage 1 measures the $I_{sc}$ and multiply it by $k_1$ to get an approximated $I_{mpp}$. The value of $I_{mpp}$ is then compared with the $I_{pv}$. The error is calculated and is fed to the PI controller for duty cycle calculations. Once the error is confined within the limit, the system shifts to stage 2. Stage 1 then waits for the signal from stage 2 to initiate this process again.

B. Operating mechanism of Stage 2

After attaining the approximated MPP from stage 1, the duty cycle is stored and is used as a base value for this stage. Because of the approximated MPP the system needs less time to reach the actual MPP, therefore in this stage a very small step change in duty cycle is applied. This results in very small power oscillations around the MPP and hence better energy harvesting as compared to the conventional P&O method. Between the instants of perturbation, this stage checks if the difference in $I_{sc}$ and $I_{pv}$ is within the limit. If the limit is surpassed then the system will initiate the stage 1 for a fresh measurement of the $I_{sc}$. This makes it sure that the dynamic weather conditions are detected intelligently.

IV. Simulation results

The simulation is performed using co-simulation between PSIM while the MPPT control is accomplished in SIMULINK. For concept validation, the simulation of both the proposed and conventional P&O is performed under steady as well as under dynamic weather conditions. Furthermore, it is pertinent to mention that the sampling delay as well as the step change in duty cycle are kept equal for the proposed and conventional P&O MPPT.

A. Steady weather condition

Standard testing condition of 1000 W/m² at 25°C is used to simulate steady weather condition. Figure 9 shows the performance of proposed method. It can be seen that under steady weather condition there is only one time measurement of $I_{sc}$. The power curve of the PV panel has very little oscillations as an obvious result of very small step size (0.005). However, with this step size the conventional P&O required much longer time to track the MPP and hence resulted in low tracking efficiency as shown in Fig.10.

B. Dynamic weather condition

A dynamic weather condition is simulated for the proposed and conventional P&O method such that the irradiation is decreased suddenly from 1000 W/m² at 25°C to 650 W/m² at 25°C and then increased to 1000 W/m² at 25°C. Figure 11 depicts the results of the proposed method with dynamic weather condition. While Fig.12 shows the performance of conventional P&O under dynamic weather condition.
V. DISCUSSION

As seen in simulation results, the proposed MPPT has much better performance in terms of energy harvesting. The steady state results show that the short circuit current measurement happens only at the beginning that resulted in a temporary loss of power. However, the advantage is much rapid tracking of peak power available as evident from the comparison of Fig.9 and 10. The dynamic weather condition applied to the test circuit highlights the intelligent mechanism of the current limit within the stage II of the proposed algorithm. It can be seen from Fig.12 that under rapidly changing environmental constraints, the performance of P&O is greatly compromised. The proposed MPPT however, performs the tracking of MPP with speed and accuracy as illustrated in Fig.11. Moreover, the flyback inverter injects the current into the grid with unity power factor as seen from the AC power graphs shown in Fig.9,10,11 and 12. The AC power graph is a rectified sine wave with frequency twice that of a grid. The amplitude of the current injected into the grid rises slowly in case of conventional P&O however, in case of proposed MPPT method, right from the start maximum possible current is injected into the grid. The performance enhancement in flyback inverter is verified using the energy harvesting comparison that is based on eq.9 and 10 and is summarized in Table III.

\[ Efficiency = \frac{E_{hyb}}{E_{ideal}} \times 100\% \quad (9) \]

\[ Efficiency = \frac{E_{pp}}{E_{ideal}} \times 100\% \quad (10) \]

VI. CONCLUSION

This paper discusses the use of a hybrid MPPT method to enhance the energy efficiency of a conventional flyback inverter operating in DCM mode. The performance enhancement is accomplished with the help of FSCC MPPT. The concept validation is accomplished using the co-simulation performed between PSIM and simulink. The simulation results have confirmed the following advantages when compared with the conventional P&O method.

- With the use of FSCC, the MPP is tracked much more swiftly.
- Use of very small perturbation size makes it possible to have very small power oscillations around MPP. Therefore, power harvesting is better than the conventional P&O MPPT.
- In case of dynamic weather conditions, the proposed MPPT is intelligent enough to choose the right moment to measure the \( I_{sc} \). Hence, it can be concluded that proposed MPPT detects the weather change automatically.
- The proposed MPPT is more efficient than conventional P&O in terms of energy harvesting.

REFERENCES


TABLE III

<table>
<thead>
<tr>
<th>MPPT method</th>
<th>Environmental condition</th>
<th>Efficiency</th>
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</thead>
<tbody>
<tr>
<td>Proposed hybrid MPPT</td>
<td>Steady weather</td>
<td>98.51%</td>
</tr>
<tr>
<td>P&amp;O</td>
<td>Steady weather</td>
<td>79.2%</td>
</tr>
<tr>
<td>Proposed hybrid MPPT</td>
<td>Dynamic weather</td>
<td>95.77%</td>
</tr>
<tr>
<td>P&amp;O</td>
<td>Dynamic weather</td>
<td>72.12%</td>
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