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Optimized Control in Grid Connected Photovoltaic System based on Single-Stage Voltage Source Inverter

M. Marimuthu
M.E Scholar
Dept. of Electrical and Electronics Engg
Dr.SivanthiAditanar College of Engineering
Tiruchendur – India

***Abstract:** Renewable energy, such as solar energy, is desirable for power generation due to their unlimited existence and environmental friendly nature. Ruggedness, reliability, and one-cycle control (OCC) which does not require the service of a phase-locked loop for interfacing the inverter to the grid are increasingly being employed for such applications. This paper presents a single-phase photovoltaic system that provides grid voltage support. The design of the one-cycle controller of a single-stage inverter for photovoltaic applications is carried out by means of a sinusoidal pulse width modulation to optimize inverter performance at both high and low insulation levels. This allows the design of a maximum power point tracking perturb and observe controller that significantly improves inverter performance. However, the OCC-based schemes reported earlier require sensing of the grid voltage which somewhat offsets one of the inherent strengths of OCC-based systems. In order to overcome the limitation of prior researches, an OCC-based grid-connected single-stage PV system is proposed in this paper which does not require sensing the grid voltage. The viability of the proposed scheme is confirmed by performing simulation validation.*

***Keywords:** Maximum-power-point tracking (MPPT), one-cycle control (OCC), photovoltaic (PV) m0dule, single-phase grid-connected inverter.*

I. INTRODUCTION

Among the renewable energy sources, a noticeable growth of small PV power plants connected to low-voltage distribution networks is expected in the future. A single-stage inverter, controlled by using the one-cycle control (OCC) technique, has been presented in the literature. The theoretical analysis of such an inverter, reported in, is not in-depth. Thus, it does not allow satisfactory performance both in terms of power extracted from the PV array and quality of the current injected into the grid., wherein a significant improvement of the theoretical model has been proposed and used to increase the power extracted from the PV model and to reduce the distortion of the current injected into the single phase grid. Simulation results have demonstrated that the set of variables influencing the operation of the one-cycle controller can be optimized to get nearly maximum power at one assigned insolation level or the highest average power in a given insolation range.. Moreover, it has also been highlighted that the inverter proposed in [1] is lacking a true maximum power point tracking (MPPT) controller. After values of the parameters of the analog circuitry implementing the OCC are fixed, power extracted from the PV array is maximized at only one specific irradiation level. Therefore, under time varying atmospheric conditions, a consistent decrease in efficiency of PV power extraction is observed. To overcome such a limitation, [6] proposed the idea of matching a digital MPPT controller with analog OCC circuitry, and some preliminary simulation results have been presented. Environmentally benign technologies like solar photovoltaic (PV)-based systems are increasingly being used for electricity production in the context of global warming, climate change, and rapid exhaustion of fossil fuels. A portion of the huge gap between the expected demand and availability of the electricity produced in many parts of the world, particularly in developing countries, is expected to be met from renewable energy sources like solar PV.

Moreover, effort to reduce carbon emission from electricity sector has forced policy makers across the globe to promote electricity production from renewable energy sources based on solar PV. Further, the renewable-energy-promotion policies across different parts of the globe, like feed-in tariff, renewable portfolio standard, net metering, etc., are providing considerable incentives even to individual single-phase customers to install solar PV panels and sell the excess power generated to the utility. A reliable and low-cost single-phase grid-connected inverter which requires little maintenance has become the order of the day for interfacing such low-capacity systems to grid. A typical grid-connected PV system has more than one power-processing stages [1]. The first stage is usually a dc–dc converter which draws peak available power from the solar array by incorporating maximum-power-point tracking (MPPT) and also provides a boost in the dc-link-voltage level. The output of this stage is inverted using single- or multiple stage dc–ac inverters before feeding to the grid . The inverter control ensures that whatever amount of power is extracted from the solar array is being dumped on the grid which is achieved indirectly by maintaining the dc-link voltage at a set reference. The reliability, compactness, and cost effectiveness of the PV system can be improved by employing a single-stage dc–acinverter [3]–[7]. The.reliability of a single stage PV system operating in hard-switched mode has been objectively shown to be more than that of two-stage systems in . Unlike the two-stage systems, inverter in a single-stage system performs the following two functions: 1) extracts peak available power from the solar array by employing a proper MPPT algorithm and 2) dumps the power derived from the solar array on the grid by maintaining the power-quality discipline of the utility. Hence, the control configuration of single-stage inverter- based grid-connected systems generally consists of two current-control loops. The fast inner current controller regulates the current injected to the grid while maintaining prescribed total harmonic distortion (THD) and power factor, while a slow outer current-control loop incorporates the MPPT algorithm used. To interface the inverter with the grid, service of a phase-locked loop (PLL) is required. Designing a PLL for interfacing with a weak grid is always a difficult proposition considering the non idealities like frequency variation and harmonic distortions present in the line voltages. Moreover, the PLL routine consumes considerable computational resources of the digital signal processor (DSP) used for its realization. In order to simplify the control structure of grid-connected inverters in a PV system, schemes based on one-cycle control (OCC) have been proposed [3]. Systems based on OCC do not require the service of a PLL.

In addition to this, they offer fast dynamic response due to the presence of the current-control loop. A single-stage single-phase OCC-based inverter for grid connected PV system which can operate at a maximum-power point is reported in [3]. The performance of this scheme in tracking the maximum power from the solar array is very sensitive to the set of design parameters chosen for the realization of the controller. Hence, maximum-power-point operation is not guaranteed if there are changes in operating conditions and/or drift in the values of control and system parameters due to ageing. In order to overcome the aforementioned limitation, the values of the control parameters are obtained in [6] by using a multi objective optimization procedure which extracts the highest average power for a given insolation range. However, the scheme reported in [6] makes the system operate closer but not at the point of maximum-power operating point (MPOP) for the designed range of insolation. In order to address the aforementioned problem, a customized perturb and observe (P&O) method for tracking the maximum-power point is applied to an OCC-based scheme so that the system operates at MPOP even if there is a variation in the insolation level and parameter values. The controller of the scheme presented in needs to sense grid voltage, grid current, dc-link voltage, and PV current to realize the MPPT algorithm. The sensing of the grid voltage somewhat reduces the basic strength of the OCC-based strategy in a sense that harmonic distortions present in the grid voltage would affect the control performance of the system. Moreover, the presence of a number of sensors increases the complexity and thereby reduces the reliability of the system. In an effort to overcome the aforementioned limitations, an OCC-based single-stage PV system is proposed in this paper which does not require sensing of the grid voltage. The scheme proposed in this paper estimates information regarding grid voltage from a fundamental component of the inverter output voltage. The fundamental component of the inverter output voltage is derived by processing the inverter switching function and the dc-link voltage through an analog filter and a saturator. The idea of estimating the grid voltage or virtual flux, utilizing the switching function of the inverter, grid currents, and dc-link voltage, has been earlier applied in case of three-phase converters using direct power control and direct torque control and, less commonly, for single-phase rectifiers . Although, philosophically, the method presented in this paper is similar to the aforementioned schemes, the method proposed in this paper is different in the following respects. In the proposed scheme, the implementation of the inverter-output-voltage estimator is quite simple and has been realized by involving simple analog circuits.

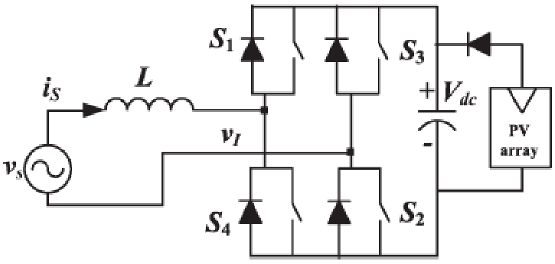


Fig. 1.Single-stage single-phase grid-connected PV system

While the proposed scheme estimates the fundamental component of the inverter output voltage, all the earlier methods estimate the grid voltage. Hence, those schemes require the value of the filter inductor used and the grid current to carry out estimation. Therefore, a mismatch in the inductor value affects the operation of those schemes. The proposed scheme is not affected by this problem. Further, the proposed controller requires less number of sensors (two) as compared to that required (four) in for the implementation of the core controller comprising of OCC and MPPT blocks. In addition to this, the core controller used in the proposed scheme is realized through a simple analog controller. The operating principle of the scheme is discussed in detail in Section II. The issues pertaining to the realization of the MPPT routine is presented in Section III. Detailed simulation studies are carried out to verify the effectiveness of the proposed scheme, while the viability of the scheme has been ascertained by performing experimental studies on a laboratory prototype developed for the purpose.

II. OCC-BASED INVERTERS FOR PV SYSTEM

A single-stage grid-connected PV system having a single phase full-bridge voltage source inverter is shown in Fig. 1. The inverter switches are controlled to generate an output voltage from the inverter whose fundamental component is *VI*1. By controlling the magnitude and phase of *VI*1 through a proper pulse width-modulation strategy, the power flow from the solar array to the grid can be controlled while maintaining a high power factor and low harmonic distortion. The inverter, however, cannot be controlled with the basic OCC-based control technique as basic OCC-based schemes exhibit instability in operation when the converter involved is operated in an inverting mode of operation. In order to overcome this problem, a modified OCC (M-OCC)- based scheme has been reported.

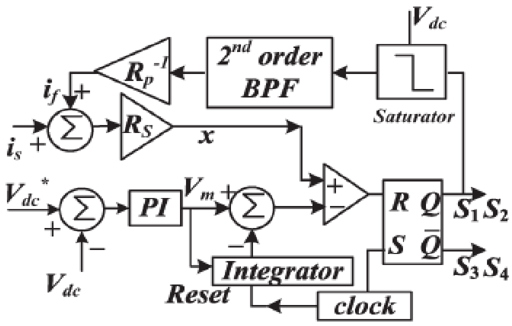


Fig. 2. Control block diagram of the proposed voltage-sensorless scheme

In the scheme reported in [7], the sensed grid voltage is multiplied by a constant gain to generate a fictitious current signal *if* in phase with the grid voltage. This fictitious current signal is then added to the actual current drawn by the inverter. The sum of these two signals is then used by the OCC core controller to generate gating pulses for the inverter switches. The scheme proposed in this paper does not sense the grid voltage to generate the fictitious current signal required to circumvent the issue of instability in OCC-based inverter. It synthesizes the fictitious current signal required by multiplying the fundamental component of the inverter output voltage with a constant gain. Information regarding the inverter output voltage is obtained from the switching function used to trigger the inverter switches and not by sensing the inverter output voltage. The schematic control block diagram of the proposed scheme is shown in Fig. 2. The dc-link capacitor voltage is sensed and compared with a set reference, and the error so generated is fed to a proportional and integral regulator to produce a signal *Vm*. A saw tooth waveform of constant frequency having a peak-to-peak value of 2*Vm* is generated using a resettable integrator. A free-running clock having a time period *Ts*is used to reset the integrator, and hence, the frequency of the clock *Fs* decides the frequency of the saw tooth waveform as well asthe switching frequency of the devices. The time constant of the integrator *Ti* is chosen to be half of *Ts*as explained. A fictitious current signal proportional to the fundamental component of the output voltage of the inverter (*if* = *VI*1/*Rp*) is added with the source current and properly scaled to obtain the modulating signal *x*, where

$$x = i_s + i_f = i_s + \frac{V_{I1}}{R_P}$$

In order to obtain *VI*1 and hence *if* , inverter switching pulses are passed through a saturator. The output of the saturator pulsates between the scaled dc-link voltage (*V*dc) and zero in tandem with the pulsation of the switching sequence between the states one and zero. The signal proportional to *VI*1 is obtained by filtering the output of the saturator. The harmonic spectrum of the saturator output has: 1) a fundamental frequency component (50 Hz); 2) a dc component; and 3) higher frequency components centeredaround multiples of switching frequency. Hence, a band pass filter (BPF) is required to retrieve the fundamental component of this signal and filter out the dcand higher order components. A second-order BPF having a central frequency equal to the power frequency (50 Hz) is used for the purpose. The circuit diagram of the second-order filter is shown in Fig. 4. The modulating signal is multiplied by a gain *Rs*and is then compared with the saw tooth waveform to generate the switching pulses. At every rising edge of the clock pulse, *S*3 and *S*4 are turned on which leads to the increment in source current *is*. When the modulating signal becomes equal to the saw tooth waveform, *S*3 and *S*4 are turned off and *S*1 and *S*2 are turned on so that the modulating signal and hence *is* decrease. The rising and falling slopes of *are* given by $ (*vs*+ *V*dc)/*L* and (*vs* − *V*dc)/*L*, respectively, where *vs*is utility voltage, *V*dc is the dc-link capacitor voltage, and *L* is themagnitude of the boost inductor.

The modulating signal x is being compared with the saw tooth waveform to generate the switching pulses. When x is less than the saw tooth waveform, S3 andS4 are on, and the output voltage of the inverter is −Vdc. When x is greater than the saw tooth waveform, S1 and S2 are turned on, and the output voltage of the inverter is +Vdc.

III. MPPT IMPLEMENTATION USING P&O METHOD

The P&O method is one of the popular methods to track the maximum-power point. Implementation of MPPT by P&O method is generally done by using DSP or microcomputer, but discrete analog and digital circuitry can also be used for the purpose. The controller consists of an analog multiplier, a free-running clock, a sample and- hold circuit, a toggle switch, and an integrator. The P&O controller receives the signal *Vm* from the OCC controller of Fig. 2.

The output of the P&O controller is *V*dc∗which sets dc-link voltage reference required by the OCC controller of Fig. 2. An integrator connected to the output of a toggle flip-flop generates the voltage reference *V*dc∗. The period of the P&O cycle is decided by a free-running clock which sets sampling instants for the sample-and-hold circuit and toggling instants for the toggle flip-flop. In order to understand the working of the MPPT Depending on the output level of the toggle flip-flop, *V*dc∗can have either a rising or a falling slope. The rate of change in *V*dc∗is kept much smaller than the control bandwidth of the OCC controller. An analog multiplier of low bandwidth is used to perform the division *Vm*/*V*dc. The signal *Vm*/*V*dcis sampled at the beginning of a period of a P&O cycle using the sample-and-hold circuit.

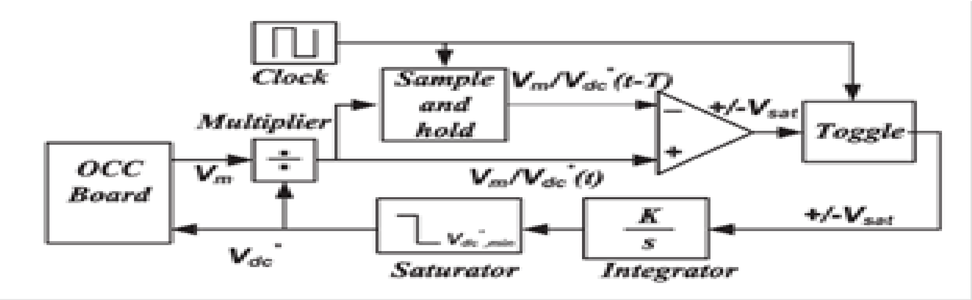


Fig. 3. Block diagram of the MPPT realization.

A comparator compares the current value of *Vm/V*dcwith that of its previous value stored in the sample-and-hold circuit. A positive comparator output implies that in the current cycle, the power delivered by the inverter has decreased, while a negative comparator output indicates an increment in power in the current P&O cycle. Therefore, when the output of the comparator is positive, the slope of *V*dc∗is reversed to that followed in the previous P&O cycle. Furthermore, if the comparator output is negative, the slope of *V*dc∗is maintained the same as that of the previous cycle. The reference dc-link voltage *V*dc∗ so generated sets the operating voltage of the solar array.

IV. SIMULATION RESULTS

In order to predict the performance of the proposed one cycle- controlled voltage-sensorless grid-connected system, detailed simulation studies are carried out on MATLAB–Simulink platform. In order to objectively show that the proposed voltage-sensorless scheme does not have the problem of current instability while operating in the inverting mode of operation, a model of the system shown in Fig. 1 is simulated. As the grid voltage and source current are almost 180°out of phase, the scheme is supplying power to the grid at a very high power factor. From this simulated behavior, it can be inferred that the dynamic response of the proposed OCC based voltage-sensorless system is quite fast and no instability in current controllability is observed during the inverting mode of operation.

The parameters of the inverter chosen for the purpose of simulation and the controller are as follows:

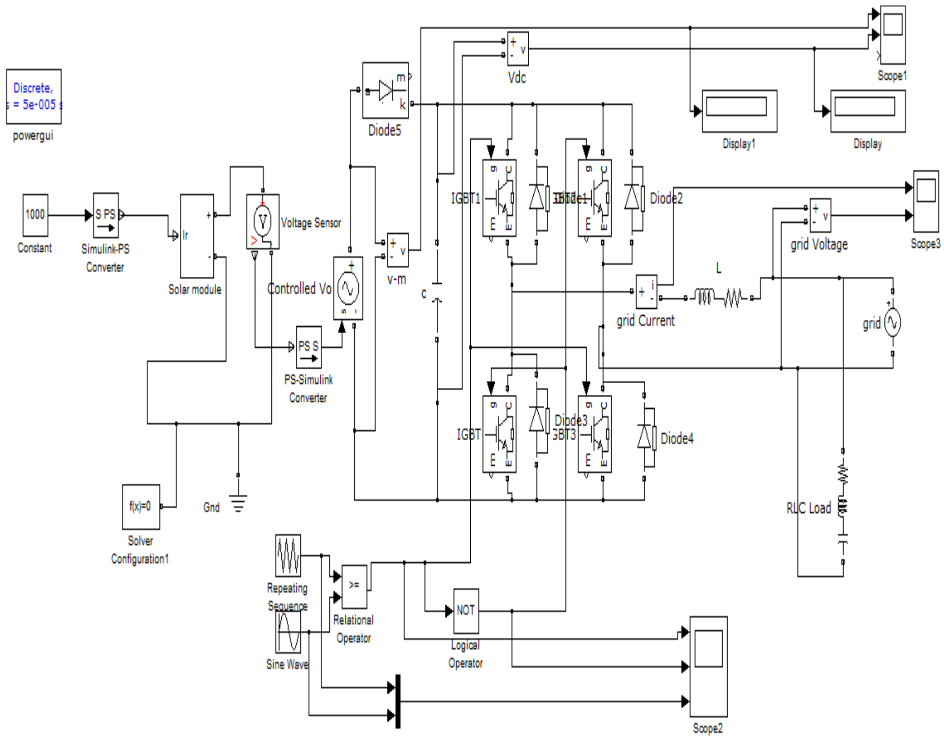


Fig. 4.Simulink model for grid connected inverter.

1) Switching frequency: 20 kHz;

2) Dc-link capacitor: 2200 μF;

3) Series inductor: 2 mH;

4) *Rp*: 1.5 Ω;

5) *RS*: 0.16 Ω;

6) Quality factor of BPF (*Q*): 2;

7) Central frequency of BPF: 49.8 Hz.

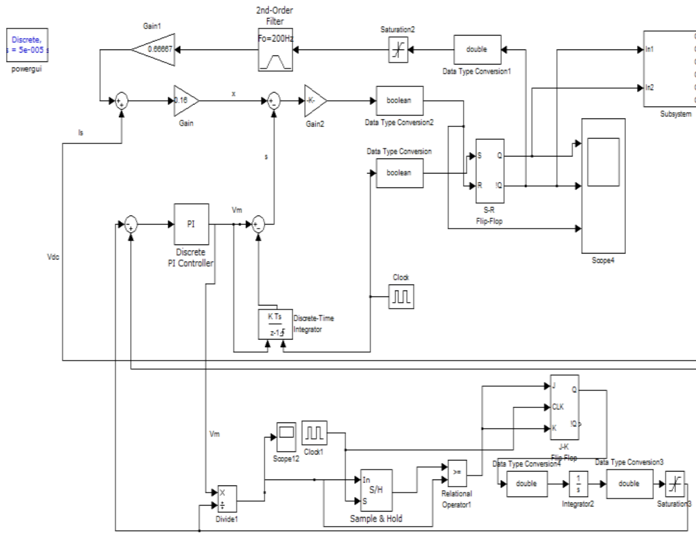


Fig.5. Simulink model for OCC.

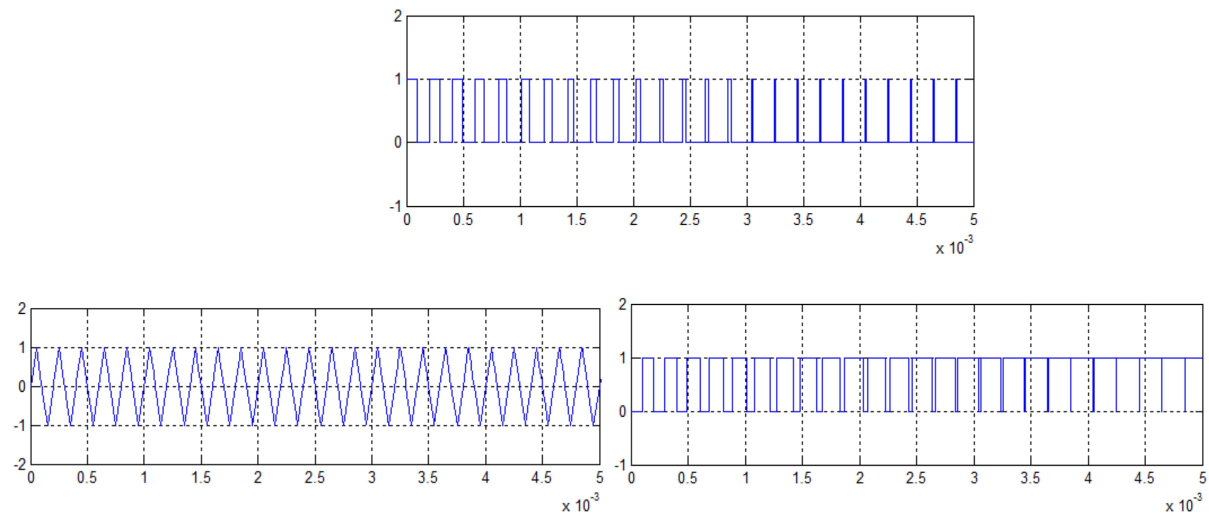
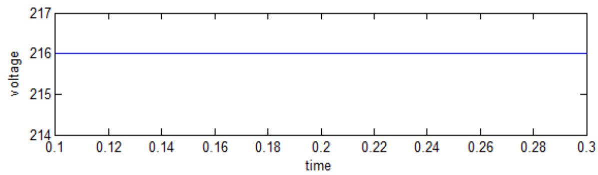
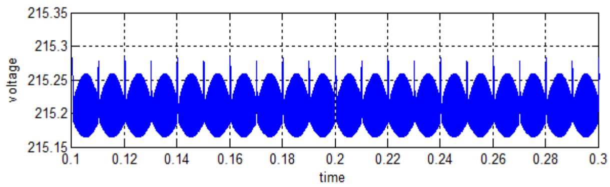


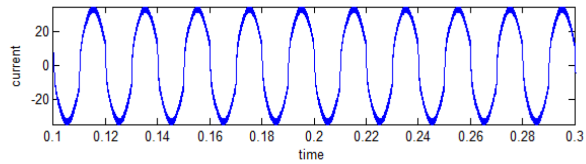
Fig. 6. Simulated performance of SPWM signal



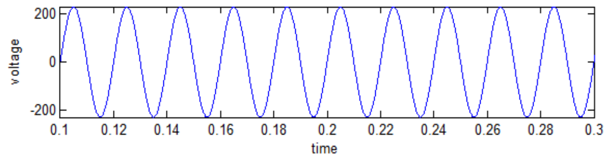
(a)



(b)



(c)



(d)

Fig. 7.Simulated performance depicting the stable operation of the proposed scheme. (a) PV voltage. (b) DC-link voltage (c) Grid current . (d) Grid voltage.

A detailed simulation study of the proposed OCC-based single-stage single-phase- grid-connected PV system of Fig. 1 has been carried out, and the simulated performance is shown in Fig. 7.

V. CONCLUSION

In this paper, the optimal design of single stage inverter for PV applications has been done and it is controlled by means of Sinusoidal pulse width modulation. In conventional system, sensors have been used to track the grid voltage in order to tackle the instability problems. But in the proposed technique no sensors have been used to track the grid voltage which is one of the advantage and one-cycle control (OCC) which do not require the service of a phase-locked loop for interfacing the inverter to the grid so it increases the efficiency. If One Cycle Controller based Maximum Power Point Tracker is connected to this system which tracks the maximum power of the solar panel will improve the efficiency of the system will be done in future.

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