Regulation of the Output Voltage of an Inverter in Case of Load Variation

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Abstract. In a DC/AC photovoltaic application, the stability of the output voltage of the inverter plays a very important role in the electrical systems. Such a photovoltaic system is constituted by an inverter, which makes it possible to convert the continuous energy to the alternative energy used in systems which operate under a voltage of 230V. The output of this inverter can be connected to a single load or more, at which time a second load is added in parallel with the first load. In this case, it proves a voltage drop at the output of the inverter. This problem influences the proper functioning of the electrical loads. Therefore, our contribution is to give a solution to this by compensating this voltage drop using a boost converter at the input of the inverter. This boost converter will play the role of the compensator that will provide the necessary voltage to the inverter in order to increase the voltage across the loads. But the use of this boost without controlling it is not enough because it generates a voltage that depends on the duty cycle of the control signal. To stabilize the output voltage of the inverter, we used a Proportional, Integral, and Derivative control (PID), which makes it possible to generate the necessary control signal for the voltage boost in order to have a good regulation of the output voltage of the inverter. Finally, we have solved the problem of the voltage drop even though there is loads variation.

1. Introduction
The rising energy demand and the negative effect of fossil fuel require the increase of electricity generation via renewable energy sources [1]. Wind energy, fuel cells and solar PV are used in order to meet the necessary demands of loads and inject this green electricity into the grid. This can be named a microgrid [2]. In PV applications, there are many structures used to interface with the loads or the grid. To realize this interface, power electronics like a DC/DC converter and a DC/AC inverter are used. In literature, many topologies of power electronic systems are used in order to increase the efficiency by minimizing the number of switches, reducing the Total Harmonic Distortion (THD) and regulating the voltage and current to be injected in the grid [3]. On the other hand, the control of these converters offers an efficient tool in regulating some parameters or adjusting the power injection [4]. The majority of research focuses on how to extract the maximum power using “Perturb and Observe” algorithm [5] and fuzzy logic control [6]. It also focuses on determining the state of charge of the battery using a Kalman filter [7] and Neural Networks [8]. However, some applications require an output voltage of 230V in the inverter control. In case of load variation, the DC voltage of the boost converter should be kept near the desired value and the voltage drop phenomenon must be avoided. Therefore, it is necessary to use a control scheme in order to regulate the AC output voltage of the system in a way that guarantees stability. DC/DC boost converter uses the proportional integral (PI) controllers to regulate a DC bus voltage [4-9]. However, the
identification of PID gains depends on the whole system parameters, the input voltage and the load variations. In this paper, we assume that there is no variation of input voltage and we implement a PID control regarding load variations at AC output inverter. The paper is organized as follows: in section 2 we describe our system with determine the parameters of each block. After that, in section 3, we give simulation results of two different circuits for this system, the first circuit is the inverter without boost converter in order to show the influence of the load variation on the inverter output voltage, the second circuit is the boost converter connected to the inverter using PID control for regulating and solving the problem of voltage drop in the output in case of load variation. The Last section is conclusion.

2. System Description

2.1. DC Voltage Source
The PV panel produces direct DC current from sunlight. This current can be used in electrical equipment or to recharge a battery. However, this green electricity generated depends on solar irradiation and temperature, which is reflected in a variation of the voltage and power in general. In order to study only the variation effect of the loads on the stability of voltage, we replaced the PV panel with a DC Voltage source to fix the input voltage of the converter stage. In a first step, without Boost converter, the value of the DC Voltage source used is 326V to get 230V which is the Root Mean Square (RMS) value of the voltage. In the second step, with Boost converter, the value of the DC Voltage source is 100V. It is less than the previous step because we added a Boost converter to the system in order to increase the input voltage of the inverter in case of a voltage drop.

2.2. Boost Converter
In literature, there are different types of DC/DC converters that can transform a certain level of voltage to another. They can be voltage boosters or step down converters. In this work, we used a DC/DC Boost converter as shown in Figure 1. This model requires finding the appropriate value of the inductor and the capacitor to have the desired voltage at the output of this boost converter.

![Figure 1. Model circuit of DC/DC Boost converter](image)

To determine the value of the inductor and capacitor, the following equations must be used [5].

\[ V_0 = \frac{V_i}{1 - \alpha} \]  
\[ I_0 = I_L (1 - \alpha) \]

Where, \( \alpha \) is the duty cycle, \( V_0 \) and \( I_0 \) are the output voltage and output current respectively, \( V_i \) and \( I_L \) are the input voltage and input current respectively.

The value of inductor and capacitor is given by equations (3) and (4) respectively.

\[ L = \frac{\alpha V_i}{F \Delta I_L} \]  
\[ C = \frac{\alpha I_i}{F \Delta V_0} \]
F is the switching frequency, $\Delta V_0$ is the ripple of output voltage, $\Delta I_L$ is the ripple of inductor current.

2.3. **Inverter**

The main objective of an inverter is to convert DC current to AC current [3]. As shown in figure 2, the inverter used in this paper is composed of four switches that are MOSFET transistors to obtain an H-Bridge inverter. The main objective of this part is the conversion of voltage from DC to AC.

![Figure 2. Model circuit of DC/AC Inverter](image)

2.4. **Low-pass Filter**

In this paper we used a passive low-pass filter LC which is composed of an inductor and capacitor. It is placed between the inverter and the loads. This filter allows us to obtain a purely sinusoidal voltage, in order to use it by different loads.

![Figure 3. LC filter](image)

The value of inductor and capacitor is calculated by equations (5) and (6) as follow:

$$L < \frac{0.3U_{inv}}{2\pi f I_{L_{max}}}, \quad (5)$$

$$C < \frac{1}{(2\pi f_c)^2 L}, \quad (6)$$

Where, $U_{inv}$ is the maximum value of the inverter output voltage, $I_{L_{max}}$ is the maximum value of the inductor current, $f$ is the frequency which is 50Hz and finally $f_c$ is the cutoff frequency.

2.5. **Loads**

The final part is loads that consume the electrical power. In this work, we used different values of simple resistive loads to examine the inverter output voltage in case of load variation. At first, we used a single charge fed directly to the output of the inverter. After a while, we added a second load in parallel in order to have a growth of the electrical consumption. After that, there is also the addition of a third load in parallel.

3. **Simulation results and discussions**
We simulated this work in two parts. The first is the variation loads at the output of inverter without using a boost converter which means without regulation. The second is made by adding a stage of boost converter at the input of the inverter to ensure a stable voltage. Simulation is done using Simulink.

3.1. The effect of the load variation on the inverter output voltage

The simulation circuit is illustrated in the figure 4.

**Figure 4.** Simulation of the output voltage inverter with different value of load, without regulation

We obtained directly at the output voltage of the inverter (Scope1), an alternative voltage as shown in figure 5. After filtering this voltage by the LC filter and making some variation of load at different times, the phenomenon observed is the voltage drop at the output of the inverter (Scope2) as shown in figure 6(a). In figure 6(b), a zoom at the moment t = 1s shows the effect of the addition of a second load. Figure 7 illustrates the RMS value of the output voltage at different times with load variation.

**Figure 5.** Output voltage inverter before filter

**Figure 6a.** Output voltage of inverter with load variation without regulation

**Figure 6b.** Zoom at t=1s on the output voltage of inverter
3.2. Regulation of the output voltage in case of variation load

The simulation circuit is illustrated in the figure 8.

Figure 8. Simulation of the output voltage inverter with different value of load, with PID Control

The problem of voltage drop in case of load variation is solved by using the PID control for a boost converter in order to regulate the output voltage of the inverter if there is a phenomenon of voltage drop. As shown in figure 8, the reference RMS voltage is 230V and it is compared with the RMS value of the output voltage inverter. In case of voltage drop following the addition of a new load, the PID controller plays a very important role in adapting the duty cycle in order to regulate the voltage at the output of the inverter.

To simulate this circuit, we used the following parameters as illustrated in table 1.

Table 1. Parameters of circuit elements.

| Parameter | Value   | Parameter | Value   | Parameter | Value   |
|-----------|---------|-----------|---------|-----------|---------|
| VDC       | 100 V   | f         | 50 Hz   | Kp        | 0.0013  |
| Vref (RMS)| 230 V   |           |         | Ki        | 0.0318  |
| L1 (Boost)| 9.90e-4 H | L (filter) | 2.97e-3 H | Kd       | 3.0479e-15 |
| C1 (Boost)| 3.33e-5 F | C (filter) | 1.18e-6 F | Load1    | 50 W    |
| Load2    | 100 W   | Load3    | 150 W   |           |         |

As shown in figure 9a and figure 9b, we solved the problem of the voltage drop following an addition of different loads. At t = 1s, the addition of a second load causes a decrease in voltage. The PID controller can generate the appropriate duty cycle to provide the voltage needed to obtain an RMS value of 230V.
Figure 9a. Output voltage of inverter with load variation with regulation

Figure 9b. Zoom at t=1s on the output voltage of inverter

Figure 10. RMS value of output voltage with regulation

Figure 10 illustrates the RMS value of the output voltage with PID control. As shown, despite the response time that exceeds 600 ms, the PID controller achieves our goal, which is the stability of the voltage on a value of 230V.

4. Conclusion
The model of the inverter with load variation is simulated and tested using Simulink platform. The PID control is used as a corrector of voltage drop in the output voltage of the inverter. To meet international requirements and standards, the voltage must be 230V for the electrical devices. This has pushed us to realize a solution that is efficient and simple to have stability in the voltage of the inverter even if there is a change of loads. To improve the system, we plan to study our system in the case of inductive loads.

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