



Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid

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Abstract. Predictive control method has advantages such as simple structure, functional and follow the simple mathematical. In this paper, a new method is provided for controlling the open-Delta three-phase inverter. Model-based predictive control system is used for controlling the current of a open-Delta three-phase inverter, which is in the process of converting the photovoltaic energy conversion plays a three-phase network. The controller at any time, the next period current are estimated using a model system. Four switches are used to build a open-delta three-phase inverter, that Four signal switches are necessary for inverter and Signals can be done based on the cost function minimization. Open-Delta Three-phase inverter, produces four pulses required to conduct two basic switching using switching PWM. Appropriate choice of switching states and estimated future states of the phase currents, the inverter may be provided with reasonable accuracy the phase currents. In this study the effect of different parameters such as: inductance coupling inductors, capacitors and reference current is evaluated on the performance of the proposed controller. A sample of inverters, with nominal power 3300 VA is simulated by SIMULINK MATLAB software. At the simulation section of paper, An example of the current predictive controller is designed for Open-Delta three-phase inverter, and is implemented in SIMULINK MATLAB software. The current predictive controller for the six-switch three-phase inverter is designed and implemented in SIMULINK MATLAB software and simulation results have been compared both three-phase inverter topology.

Keywords: PV systems, Open-Delta three phase inverters, Estimated load, Model-based predictive control method

1. INTRODUCTION

In recent years, due to the limitations of renewable energies and environmental pollution, human attention has been directed towards the use of renewable energies. Solar energy as a clean and renewable energy source that has attracted a lot of attention to. Pv system, solar energy is directly converted to electrical energy. With growing semiconductor industry in recent years and reduce production costs semiconductor devices, today's solar arrays have found wide applications in the grid-connected Pv systems can be pointed out. Pv system have various fields. Depending on the type of user to delete some parts there. Pv system in perfect condition, including solar cell, regulatory point of maximum power, voltage regulators, controlling the rate of charge and discharge the battery, energy storage unit and the inverter voltage. The proposed components according to the requirements and needs of consumers and to reduce costs can be reduced, thus the use of the inverter voltage or voltage storage unit for all Pv system generate electricity does not use [1].

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One of the most important parts of solar cells for energy exchange with the grid converters is DC / AC inverter. Open-Delta are the type of connection used in this article. Characteristics of converters, high efficiency and power factor inputs can be cited. Considering the loads fed by the converter must have high reliability. Reduce the number of switches used in disguised as one of the most expensive components used in the converter structure has been considered. Articles and studies on the use of this topology is reported [2-9].

The control method is one of the most important issues in the use of inverters, The different control methods in this context is provided, Such as Multi-loop feedback control method [1, 10-11], the controller is Deadbeat [12-14], adaptive controller based on resonant filter banks [15-16], controller-based replication [17-18]. Predictive control method is one of the other control methods, different algorithms have been proposed as predictive control. Current control can be used in various applications such as active power filters [19-20], Preset power factor [21], inverters [19, 22], rectifiers [22] and non-interrupted power supply [14, 23]. In recent years, various studies have been done to improve the control method [24-27].

In this paper, the open-delta three-phase inverter with nominal power 3300VA is designed by the predictive controller. And simulation in the SIMULINK MATLAB.

2. STRUCTURE of the OPEN-DELTA THREE-PHASE INVERTER

In conventional inverters can reduce the number of switches from six to four inverters can be found Open-Delta three phase inverter. In this type of inverter replacement capacitor instead of two switches located on the base and reduced number of switches.

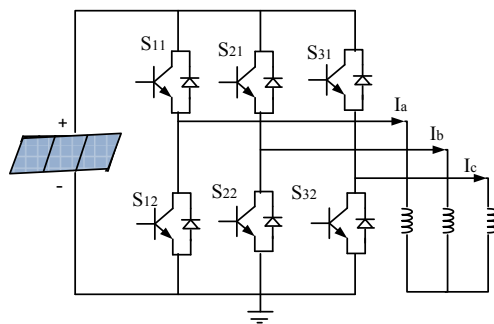


Figure 1. The six-switch three-phase inverter voltage source.

Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid

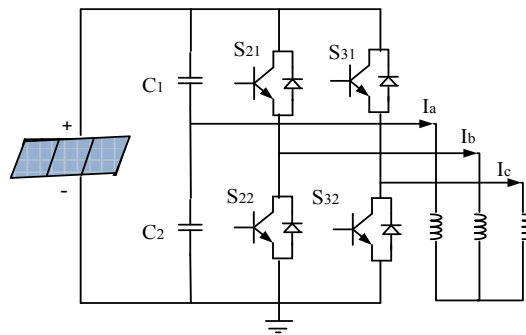


Figure 2. Open-Delta three phase inverter voltage source.

Six switch inverters are the most common form of three phase inverters, the topology of the converter in Figure 1 is shown. In this inverter, the six-switch inverter is used as a bridge inverter. In this figure if the capacitor is used instead of switches (S11 and S12), there will be open delta three-phase inverter that In Figure (2) is shown. Open-Delta three-phase inverter, compared to six switch three-phase inverter has advantages such as: Reduce the number of facilities including a reduction in the number of semiconductor (switches and diodes), Reduce the cost of inverters, Reduced switching losses, Reduce the complexity of the control circuit, Increased reliability and Reduce the space occupied Converter. The only limit to four switch inverter, is DC link capacitor voltage unbalance, which this problem can be reduced by appropriate control. Various methods have been proposed for balance voltage that can be minimized ripple voltage by using different performs.

3. MODEL-BASED PREDICTIVE CONTROL

Today, the control of industrial processes and the selection of a suitable method for this purpose is very important. Control algorithm used in industry should be desired capabilities, including its ease of use by the operator and simple setting , In fact, it will be your baseline for the development of industrial applications. Although the PID controller is common in the industry, but industrial processes involving the dynamic range of different behaviors that are limiting the use of such a controller. Thus, the predictive control method is a method of control suitable for industrial applications[8]. Block diagram of the model-based predictive control for controlling the three-phase inverter connected to the PV system in Figure 3 is displayed.

MPC design approach is based on three main themes:

- 1- Model: Use the model to predict the process output signals.
- 2- cost function: Compute a set of control signals on minimizing an cost function specified.
- 3- Process Optimization: Commonly used strategy of limiting the distant horizon. This means that the cost function of the optimal control sequence, only the first control command

string to apply the process and the next steps to optimize the operation of repeated again.

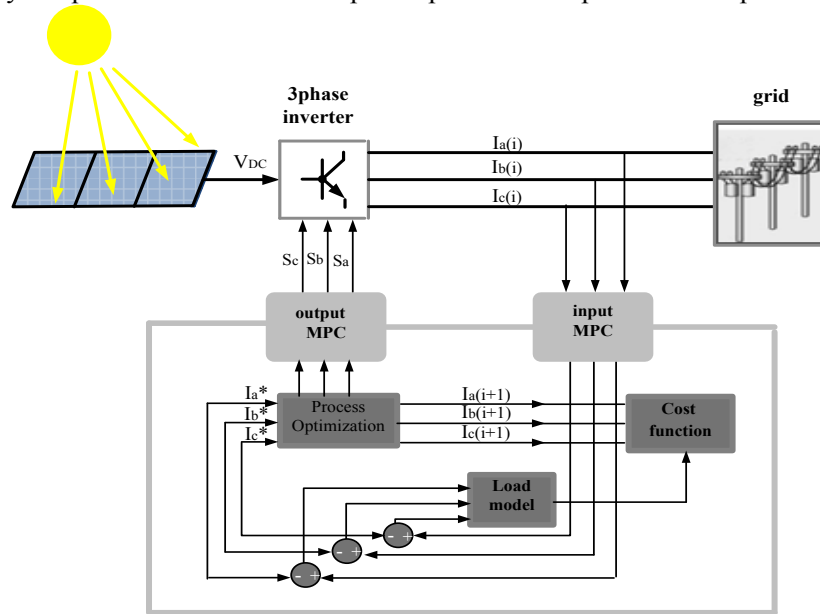


Figure 3. Diagram of a grid-connected Pv system by using predictive control

3.1. Inverter system model

Three-phase inverter has the currents and sinusoidal voltages with a phase difference of 120 degrees from each other. Inverter output current and voltage space vector is shown as follows:

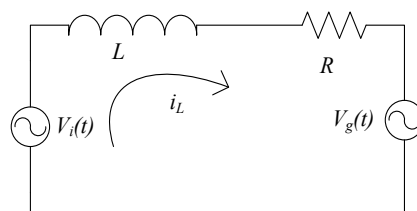
$$i = \frac{2}{3} (i_a + \alpha i_b + \alpha^2 i_c) \quad (1)$$

$$V = \frac{2}{3} (V_a + \alpha V_b + \alpha^2 V_c) \quad (2)$$

$\alpha = e^{\frac{j2\pi}{3}}$ is different phase, Three-phase voltage vector.

3.2. The model of Load stream Converter

One of the things that the control method is required, the domestic system is suitable circuit model to determine the cost function may occur. As shown in Figure(4) is shown; Load model, as a function of load current and input voltage source inverter circuit can be obtained.



Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid

Figure 4. Inverter Load Model.

Using the inverter load model can easily flow into the Load model to determine the cost function is achieved. Dynamic load Converter can be defined as follows:

$$\frac{d}{dt} i(t) = \frac{1}{L} (V_i(t) - \varepsilon(t)) - \frac{R}{L} i(t) \quad (3)$$

Which can be related (3) to form discrete wrote as follows:

$$i_L^p[k+1] = \left(1 - \frac{RT_s}{L}\right) i_L[k] + \frac{T_s}{L} (V_i[k] - \varepsilon[k]) \quad (4)$$

T_s :during the sampling period

k :k-th sample is selected

$i_L^p[k+1]$: To estimate current future state, with $k+1$

$i_L[k]$: k-th sample is output current inverter

$V_g[k], V_i[k]$: k-th sample is grid voltage and output voltage inverter

3.3. Predicting the cost function

The cost function is one of the most important parts of the predictive control. The switching signals for the next interval is determined based on the cost function, This function is defined as follows:

$$g = |i_L^* - i_L| \quad (5)$$

i_L^* is Current reference values. Using the previous section, we can obtain the three-phase inverter costs. In the case where $k = k+1$ we have:

$$i_L^p[k+2] = A \times i_L[k+1] + B \times (V_i[k+1] - V_g[k+1]) \quad (6)$$

That:

$$A = 1 - \frac{R \times T_s}{L} \quad (7)$$

$$B = \frac{T_s}{L} \quad (8)$$

Assuming a forecast horizon of one step, Usually, the future values of the load current and the evaluation of the cost function for each voltage vector that can be used in a period And in order to be selected. Voltage vector that minimizes the cost function is to select the next sampling period. The red part of Figure 5 represents the output signals MPC is applied, which provides commands for controlling the phase inverter. As in part (a) of Figure (5) is used to control the six-switch three-phase inverter, three phase control signal is needed and the MPC

will produce six pulses to guide the transistor is needed. Part (b) of Figure (5) represents control of two-phase switching of Open-Delta inverter, by MPC, and reduce a phase control section, is visible, which clearly show the simplicity of the controls.

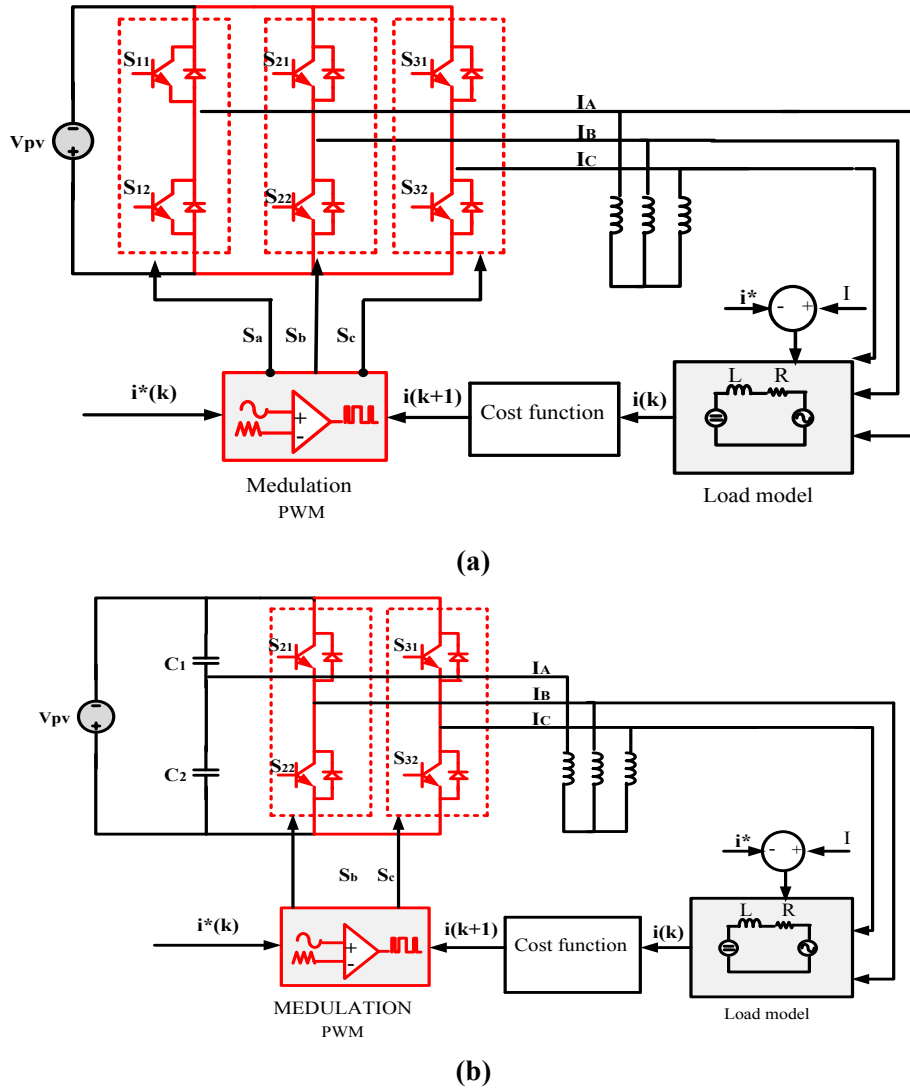


Figure 5. Block diagram of predictive control Model to current control of three-phase inverter: (a) six-switch three-phase inverter. (b) open-delta three-phase inverter.

4. THE SIMULATION RESULTS

To evaluate the performance of the proposed controller, A typical photovoltaic system can be connected to the grid by power rating 3300 VA using predictive control for control of open-delta and six-switch three-phase inverters are designed and simulated by SIMULINK MATLAB software. Inverter circuit parameters in Table (1) are presented.

Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid

$$I_A = a. \sin(\omega t) \quad (9)$$

$$I_B = b. \sin\left(\omega t - \frac{2\pi}{3}\right) \quad (10)$$

$$I_C = c. \sin\left(\omega t + \frac{2\pi}{3}\right) \quad (11)$$

Table (1): Parameters of inverter circuit.

value	parameter
2000 V	V_{dc}
5 mH	L
3300 VA	S_n
1 μ sec	T
50 Hz	F
10 mF	C_1
10 mF	C_2
5000	K

The input voltage source inverter is provided by Pv system. DC voltage of the photovoltaic sector, by the boost converter has reached the desired level. Voltage inverter is required, 2,000 volts, which The DC voltage is achieved with the help of DC-DC converter. Solar cells, is Converter solar energy into DC energy, which, with energy capture, allowing energy production is about 0/8 volts. Depending on the type of application, with series and parallel solar cells, current and voltage can be increased, and the voltage is 80 volts.

Predictive control is a closed loop control method, the sampling instant of the three-phase inverter phase currents , verify system performance, and to improve current and estimates of future value, the desired output is achieved.

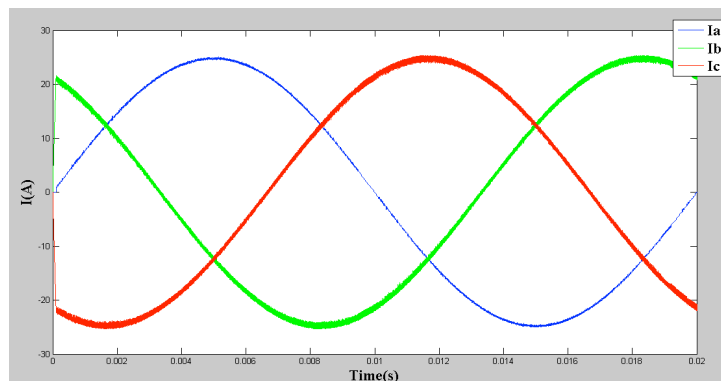


Figure 6. Open-Delta three-phase inverter phase currents.

in the design and simulation of Open-Delta three-phase inverter, enters two-phase-switching for

the control. In Figure (6) I_a and I_c currents in Open-Delta inverter shown. Optional values are compared with the reference waveform, that waveforms are sinusoidal, Differences between the two waveforms is optimized, and as the output value will be applied to the inverter.

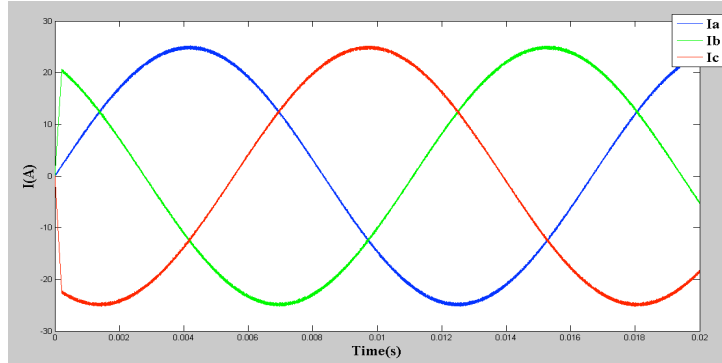


Figure 7. Six-switch three-phase inverter phase currents.

To evaluate the performance of the proposed controller. Presented controller is used to control the current inverter. The results in Figure (7) is shown. the reference values is introduced, waveform currents produced I_a , I_b and I_c In the six-switch three-phase inverter is displayed, which represents three sine wave with difference phase is 120 degrees.

4.1. The different parameters on the performance of the controller

The controller performance by changing various parameters is studied.

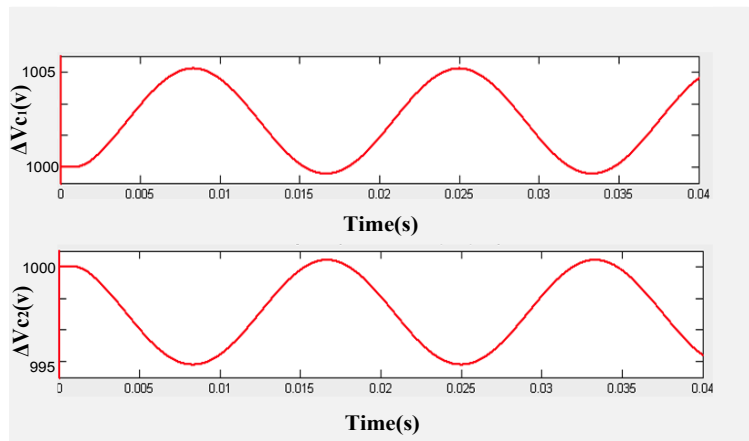
- The coupling inductance
- Value Replace capacitor
- Change the reference current

Who continue to investigate each of them will be discussed.

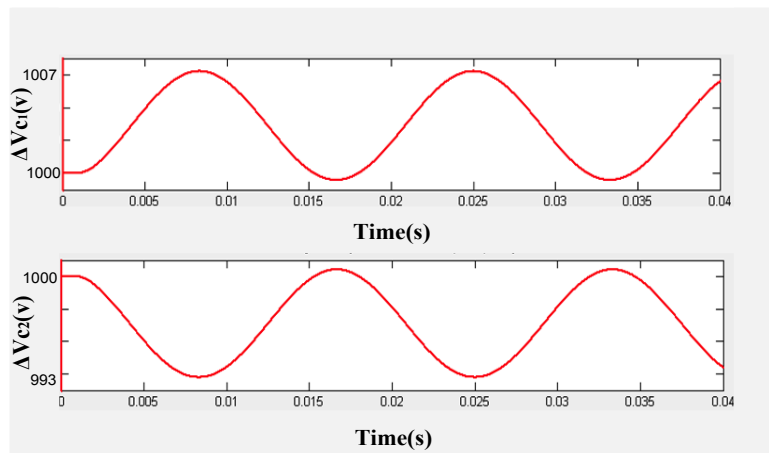
- Replace the switch capacity

Due to the current time in some time supplied by the capacitor, So if it is not symmetrical can cause unbalance voltage. On the other hand, If the capacitor is small, causes the ripple voltage will increase. Hence, one of the most important topics in the Open-Delta three-phase inverter is reducing the ripple voltage. Figure (8) displays amount voltage ripple capacitors C_1 and C_2 using the controls. ripple voltage of two 5 V Capacitors, is In the range 1000 V. Capacitor voltage ripple is 0/05%, that is an insignificant amount, and can be used regardless of its impact on the performance of the Open-Delta three-phase inverter. A 30 percent reduction in capacitance, the capacitor voltage waveform in Figure (8-B) is shown. As expected, the reduction of capacitance, the ripple of 5 V to 7 V is increased.

Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid



(a)



(b)

Figure 8. (a) Ripple voltage of capacitor c_1 and c_2 in the Open-Delta three-phase inverter. (b) Ripple voltage of capacitor c_1 and c_2 in the Open-Delta three-phase inverter with a 30% reduction in capacitance.

- Changes in the inductance coupling

The coupling inductor, one of the parameters that influence the performance of the proposed controller. According to relations (6) to (8), this parameter has a significant influence on the precision of the estimates. Therefore, we should consider changing this parameter in the controller. In this section, by reducing the amount of inductance in 50 mH, 25 mH phase currents in the figure (9) is shown. It shows that Reduce the inductance of the inductor will cause the ripple current and this reduces the accuracy of the current.

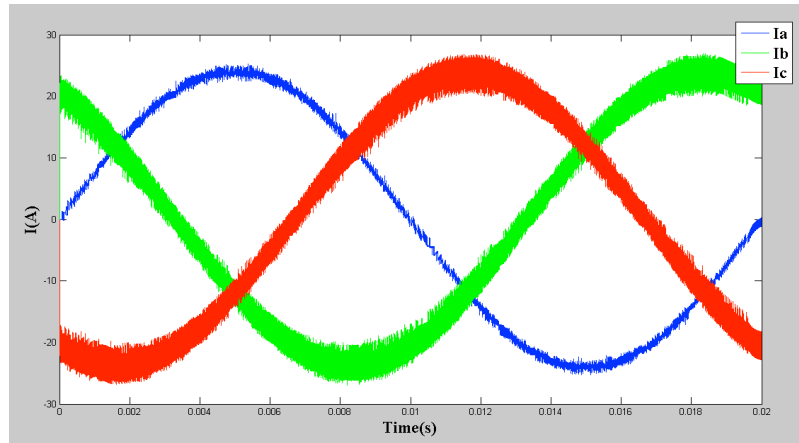


Figure 9. Current open-delta inverter :L=1mH

- Change the reference current

Change the reference current, One another of the parameters that influence the performance of the proposed controller. In some cases, it may produce a certain desired current waveforms for example, Inverters are used as a compensator harmonics generated by nonlinear loads. The harmonics of power systems, often times there are individual harmonics $h = 6k \pm 1$, $k = 1, 2, \dots, \infty$ that can be used to control the inverter by using the method proposed to eliminate harmonics.

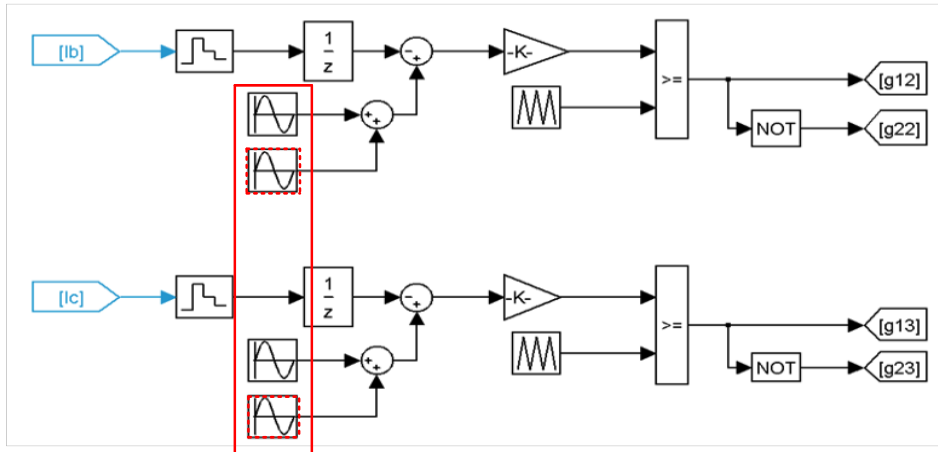


Figure 10. Block diagram of the control section open-delta to harmonic actions.

Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System Connected To The Grid

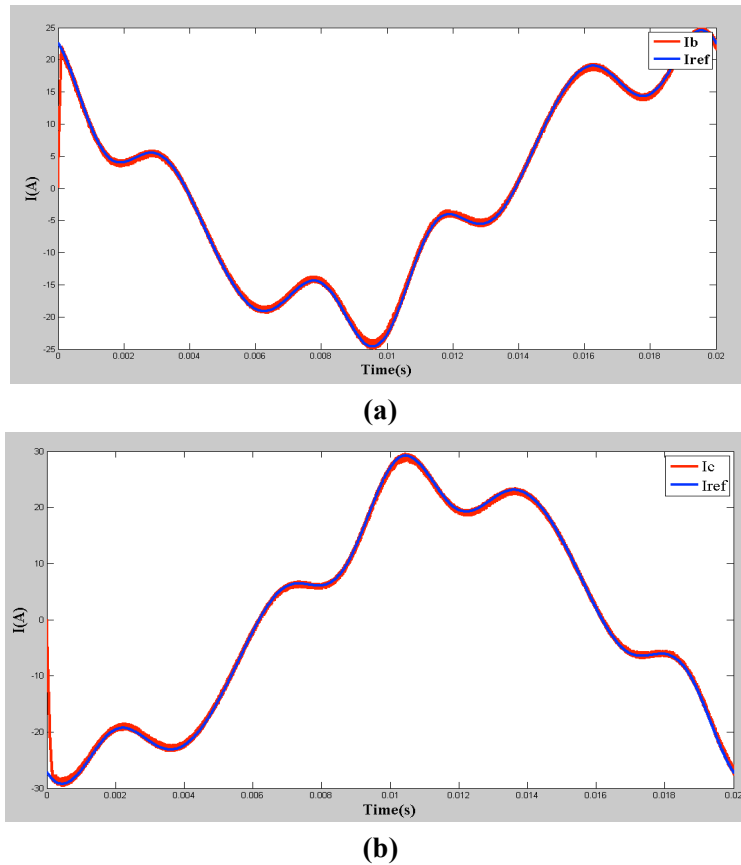


Figure 11. Effect of harmonics (third, fifth, seventh and ninth) on the performance of Open-Delta three-phase Inverter: (a) i_b (b) i_c .

Performance of model predictive control for controlling the switching currents Open-Delta inverter represents the good performance of predictive control in harmonic terms And the system controller on the system performance is not impaired in these circumstances. Flows anticipated shows full compliance with the reference waveform, ,in Figure (10) is fully visible.

Reference current considered in the simulation are as follows:

$$i_b = 25 \times \sin\left(\omega t - \frac{2\pi}{3}\right) + \frac{25}{5} \times \sin\left(5\omega t - \frac{2\pi}{3}\right) + \frac{25}{7} \times \sin\left(7\omega t - \frac{2\pi}{3}\right) \quad (12)$$

$$i_c = 25 \times \sin\left(\omega t + \frac{2\pi}{3}\right) + \frac{25}{5} \times \sin\left(5\omega t + \frac{2\pi}{3}\right) + \frac{25}{7} \times \sin\left(7\omega t + \frac{2\pi}{3}\right) \quad (13)$$

In Figure (11) To check the performance of the controller for reference current and output current b and c.

5. RESULTS

In this paper, a controller for controlling the current of the open-delta and six-switch three-phase inverter presented that is connected to the network. It was shown that In this controller, circuit parameters and flow rate in the current period specifies the output current. For this purpose uses a cost function. It is also used to optimize, switching vector selection that leads to the greatest reduction in the cost function and applies for the next period. Output current using the proposed method was demonstrated for different phases and It was concluded. Using the switching vectors, As well as the proposed controller can follow the reference current.

In another part, controller performance was evaluated by changing various parameters, such as the capacitors replacing the switch, inductor inductance coupling and change the reference current. In all the cases, evaluated the performance of the proposed controller. One important result of the proposed controller is balancing voltage replacing capacitors. It was shown that by changing the reference current of the inverter can be used as filters in harmonic compensation.

Recommendation:

1. Maximum Power Point Tracke(MPPT)
2. Hystersis Band Current Control
3. Space Vector Modulation(SVM)
4. Pulse Width Modulation(PWM)
5. Model Predictive Control(MPC)
6. SIX-Switch Three-Phase(6STPI)
7. photovoltaic (PV)

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Open-Delta Three-Phase Inverter Current Control Using Predictive Control For PV System
Connected To The Grid

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