Single-Stage PV grid-connected system with three level diode clamped inverter and Hysteresis current controller

RashaKamel El Tantawy,ShawkyHamedArafah, Salah Ghazy Ramadan

Abstract: Multilevel inverters are good solution for high power photovoltaic grid-connected systems with medium voltage. This paper presents a Single-stage photovoltaic grid-connected system with three level diode clamped inverter based on Hysteresis current controller technique. Besides the proposed Perturb and observe maximum power point tracking to guaranty maximum power from photovoltaic systems Compatible with Single-stage photovoltaic grid-connected system. The Hysteresis current controller with three level inverter that is to improves the dynamic performance of photovoltaic grid-connected system (decrease overshoot, settling time and steady state error) compared with two level inverter. Moreover the total harmonic distortion of the current injected to the grid is decreased andimproveing the power quality. The simulation is done using Matlab-Simulink Sim Power Systems.

Index Terms—proposed Perturb & observe, Hysteresis current controller, multilevel inverter, photovoltaic, Single-stage grid-connected.

1 INTRODUCTION

PV (Photovoltaic) power is one of the promising more renewable energy sources. The main advantages are reliability, and availability [1]. The high capacity PV power plant with medium voltage grids have found wide range of all around the globe due to ability, simple construction, low cost through the use of general-purpose components, ruggedness, high reliability, increase power density and improves system modularity while maintaining high efficiency levels[2].

Two topologies of grid-connected PV systems are namely; Single-stage and two-stage [3- 5] PV systems. The two-stage system includes boost circuit in addition to the inverter, while the Single-stage system doesn't contain any additional circuits beside the inverter. The inverter for Single-stage performs both the MPPT (maximum power point tracking) function, as well as the power transfer to the ac grid. The Single-stage inverter is commonly used in high power because more efficient and economical than it's two-stage [4].

Grid-connected PV systems are being developed very fast and systems from a few kW of a GW are now in operation. As an important source of distributed generation specification that is having a big impact on the design and performances of the PV inverter [6]. For low power PV systems, the classical two-level inverter is typically employed as the interface between DC-link and grid. The MLIs (Multilevel inverters) are good solution for the PV system with a high power and medium voltage. Because it is troublesome to connect only one power electronic semiconductors switch directly. Therefore a new family of MLIs has emerged as the solution for medium- and large-scale solar applications [2]. The MLIs have several advantages such as: 1) Generate better output waveforms with a lower dv/dt , 2) Increase the power quality due to the great number of levels of the output voltage , 3)Reduced AC side filter(decrees the cost) , 4) Can operate at low switching frequency. And 5) can be directly connected to high voltage sources without using transformers; this means a reduction of implementation and costs [12]. Also, the MLIs with one-stage for PV system grid integration have been suggested in order to improve the performance of the PV system [7]. The common MLI topologies classified into three types namely: 1) diode clamped [8, 9], 2) flying capacitor and 3) cascaded H-Bridge MLI. The DC-MLI (diode clamped multilevel inverter) is widely adopted in a transformer less PV system. This topology of can solve the problems of leakage current injected to the utility grid [10].

The relationship between the voltage and current of the PV cell is the nonlinear. Due to the variation in the environmental condition primarily the temperature and solar irradiance. Therefore MPPT is an essential part of the PV system to ensure that the power converters operate at MPP of the PV cell and to provide high conversion efficiency [11]. There are several methods of MPPT available for PV system. The following criteria have to be considered to select the method [12]:1) Category, 2) Grid interaction, 3) Implementation methodology, 4) Tracking efficiency, and 5) Stages of energy conversion. There are several Methods reported in literatures to track the MPP, some of them are very much close to other methods as to their operating principle. The commonly used methods are listed in Ref [11-20].

The main objective of the system for grid MLI with PV system is to convert DC power from the PV panel to AC power feeding to the grid. In grid-connected PV systems, a key consideration in the design and operation of inverters is how to achieve high efficiency with power output for different power configurations. The requirements for Single-stage inverter connection include: MPPT, high efficiency, control of DC-link voltage, control power injected into the grid, synchronizes the

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generated power with the grid, power factor, and low total harmonic distortion of the currents injected into the grid (increase power quality). Consequently, the performance of the inverters connected to the grid depends largely on the control strategy applied [4, 16]. There are three main types to Control Strategies for Grid Inverter; VOF (Voltage oriented control) [6, 17], DPC (direct power control) [6] and HCC (Hysteresis current control) [5, 18, 20].

VOC is based on synchronously rotating frame control method. This control method consists of an outer dc link voltage control loop and an inner current control loop to achieve fast dynamic response. This technique is complex and increases THD (total harmonic distortion) for line voltage, has a low dynamic response and stability of this system depend on grid parameters [6].

DPC is based on the instantaneous power and operation by directly controlling its instantaneous active and reactive power [21]. This Control Strategy has become more widely used over the last few years due to the advantages of fast dynamic performance and simple control implementation when compared with the other methods. On the other hand, the disadvantage of the DPC is the variable switching frequency and increase THD in the case of line voltage distortion [6].

The HCC is most strategy common use. This method ease of implementation, robust, unconditional stable system, no sub harmonic oscillation, fast response and inherent peak current limiting capability [10].

In this paper, three phase DC-MLI for Single-stage PV grid-connected systems. MPPT technique has been done using a proposed P&O (Perturb and observe). Also HCC with three phase two level inverter and three level diode clamped inverter for one-stage PV grid connected systems. Comparison between classical two-level inverter and three level diode clamped inverter are done to measure the performance improvements due to the use of MLI under changes in irradiance.

2 Non ideal Equivalent Circuit of PV array

The equivalent circuit of a Non ideal model PV cell consists of a diode and a current source connected in parallel with Series and Shunt resistance. The PV Arrays are made up of some combination of series and parallel modules to increase power. The PV array can be considered to be composed from a number of series cells, NS, connected in parallel with a number of parallel cells, Np as shown in Figure (1). If all the cells are identical and are operating under the same conditions (same irradiance and temperature), then the single diode model can be used to represent the array. In this case, the models the mathematical model of PV arrays is expressed by [22]:

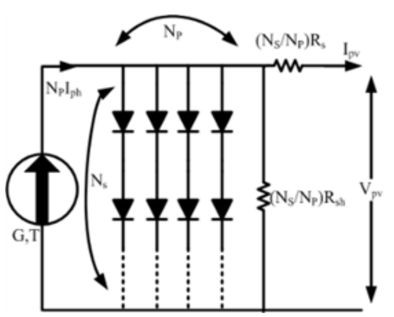


Figure 1 equivalent circuit of PV array

$$I_{PV\text{-}array} = N_p I_{ph} - N_p I_o \left(\exp\left(\frac{q}{nkT} \left(\frac{V_{pv}}{N_s} + \frac{I_{pv} R_s}{N_p} \right) \right) - 1 \right) - \frac{N_p}{N_s R_{sh}} \left(V_{pv} + I_{pv} \frac{N_s}{N_p} R_s \right) \quad (1)$$

3 Diode-Clamped Multilevel Inverter

The DC-MLI proposed by Nabae, Takahashi, and Akagi in 1981 was essentially a three-level diode-clamped inverter [16]. The total number of capacitors required for N-level is typically (N-1). The number of clamped diodes and power electronic switches required for each phase will be (N-1)*2 and 2(N-2) respectively [3]. Three phase of a three-level diode clamped inerter is shown in Figure (2) the remaining three legs have the same switch diode configuration and share the same DC-link source.

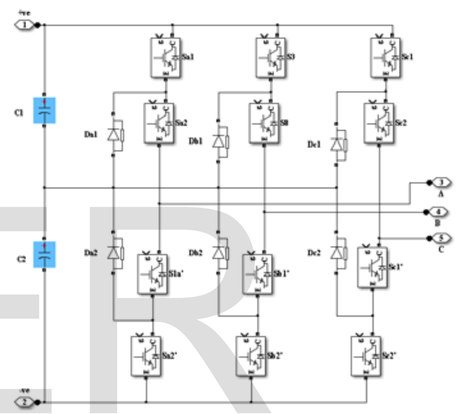
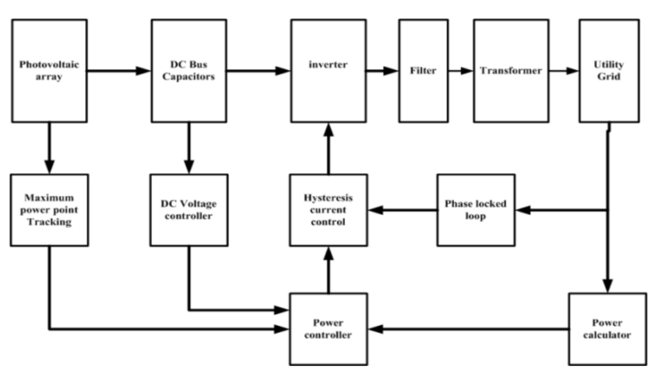


Figure2.A three-level diode clamped inverter

4 The Proposed strategy for Control of Grid-Inverter with PVsystem

The Grid-Inverter system consists of many parts, namely the PV panels, DC bus capacitor, inverter, filter, MPPT control, the power control, the PLL (phase locked loop), power calculation, DC controller and the HCC system. Figure (3) shows the proposed block diagram of grid–inverter control system.

Figure. 3 proposed block diagram of grid–inverter control with PV system



4.1 Proposed Perturb and observe

The Proposed P&O method with Single-stage inverter topology is used to produce reference output power. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. As can be seen in Figure (4), on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP. A flowchart of this method is shown in figure. (5).

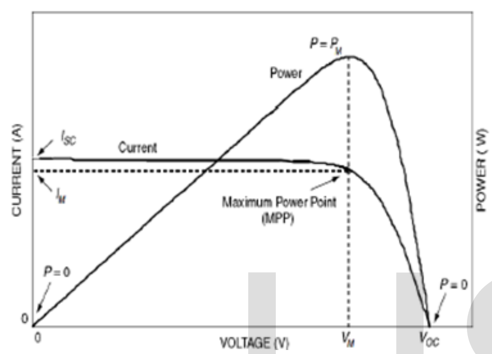


Figure4 the I-V curve and P-V curve of PV cell

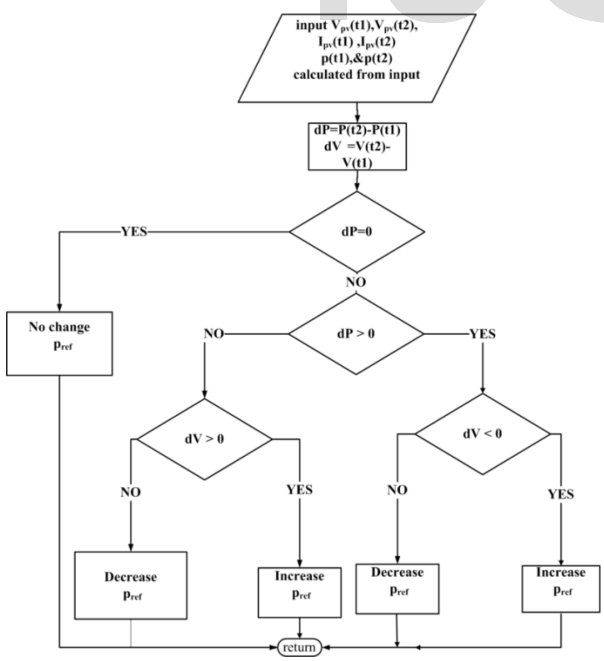


Figure5 Flowchart of the Proposed P&O methods.

4.2 Power calculation

In this method measure the three-phase voltage Vabcg and Iabcg of the grid and converted to synchronous rotating d-q reference frame using equation (2). From V_{gd}, V_{gq}, I_{gd} and I_{gq} calculate the active and reactive power of the energy conversion system is calculated using Equations (3) and (4) [19].

$$\begin{pmatrix} f_d \\ f_q \\ f_0 \end{pmatrix} = \frac{2}{3}\begin{pmatrix} \cos(wt) & \cos(wt-\frac{2\pi}{3}) & \cos(wt+\frac{2\pi}{3}) \\ -\sin(wt) & -\sin(wt-\frac{2\pi}{3}) & -\sin(wt+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix}\begin{pmatrix} f_a \\ f_b \\ f_c \end{pmatrix} \quad (2)$$

Where, denotes to voltages, currents

$$P_g = \frac{3}{2}\left(v_{gd}\, i_{gd} + v_{gq}\, i_{gq}\right) \quad (3)$$

$$q_g = \frac{3}{2}\left(v_{gq}\, i_{gd} - v_{gd}\, i_{gq}\right) \quad (4)$$

4.3 Three phase PLL structure

The PLL used to the synchronization between the inverter outputs and the grid voltage. Nowadays, the PLL is the most suitable method to extract the phase angle of the grid voltages in the case of PV systems due to its simplicity, robustness, and effectiveness. The grid voltage is measured, transformed into the d–q reference frame, and its q component is forced to zero through a PI controller. The PLL block also provides a measure of V_d and the grid phase angle [20].

4.4 DC voltage controllers

The DC voltage control is achieved through the control of the power exchanged by the converter with the grid. The decrease or increase of the DC voltage level is obtained by injecting more or less power to the grid with respect to that produced by the PV. Figure (6) Show the block diagram of the DC link controller. The DC voltage controller is used to produce directly on the P_{dc}[31].

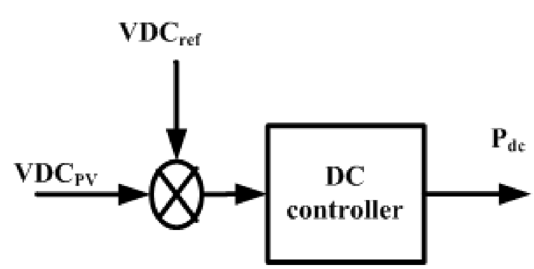


Figure6 the block diagram of the DC link controller.

4.5 Power Controller

The power controller compares the calculated active power P_g with the reference active power P^*_{MPPT} computed from MPPT algorithm. This power represents the amount of active power produced by the photovoltaic generator. The error between active power P_g and P^*_{MPPT} though PI controller and compare with output of DC voltage controller P_{DC}. The errors between them reference direct axis component current $I_d{}^*{}_{g\text{-}ref}$. The reference quadrature axis component current $I_q{}^*{}_{g\text{-}ref}$ can be competed from the equation (5) if the system operating with unity power factor. In this case the inverter is operating at unity power factor ($q^*_{g\text{-}ref}$ = 0, $I_q{}^*{}_{g\text{-}ref}$ = 0) therefore no reactive power is exchanged and the total power extracted from the PV generator is injected to the grid. Figure (7) shows the power controller.

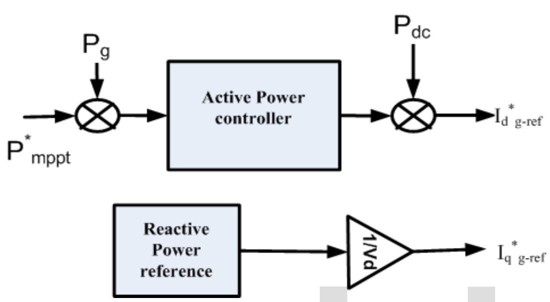


Figure 7 power controller

4.6 Hysteresis Current Controller

The HCC is a technique which can be used to control inverter where the reference current and the actual current are compared on an instantaneous basis to produce switching pulses for the inverter. A configuration of HCC is presented in Figure (8). The error signal, e is the difference between the referent and actual current. Lower and upper limits associated with the minimum and maximum values of error signal are e_{min} and e_{max} respectively. The range of error signal (e_{min} - e_{max}) where the output current of the inverter is controlled is called the hysteresis band. The advantages of this technique are simplicity, unconditioned-stability, and independent of grid parameters, robust and good transient response [5].

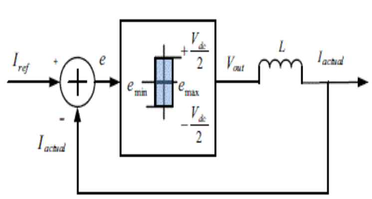


Figure 8.Configuration of hysteresis current controller

4.6.1 Hysteresis Current Controller with Multilevel Inverter

One possible technique that can be used to assist the current regulator in selecting the "correct" voltage level is the use of multilevel hysteresis bands. For an *N*-level inverter, *N* band are required with each band representing the switching between two adjacent voltage levels [10, 18].

The HCC with MLI based on the magnitude error for an "N" level inverter can be associated with a number of bands around the reference current, in such a manner that each band belongs to a specific voltage level. The tolerance bands for an "N" level inverter are of two different natures. The first band consists of a main zone and the load current always has to be inside the main zone to minimize the harmonic distortion. The second set of switching bands has different zones surrounding the main zone in order to provide a reliable and a robust control for an "N" level inverter [18].

In The HCC with diode clamped three-level inverter the current error of each phase processed during three levels hysteresis band controller as shown in Figure.(9) This hysteresis controller has three digital outputs to operation inverter swathe according to the following relations.

If e_i> HB than upper switch S_{a2} and S_{a1} is on.
If e_i<- HB than lower switch S_{a2}' and S_{a1}' is on.
If -HB>e_i< -HB than lower switch S_{a2} and S_{a1}' is on.

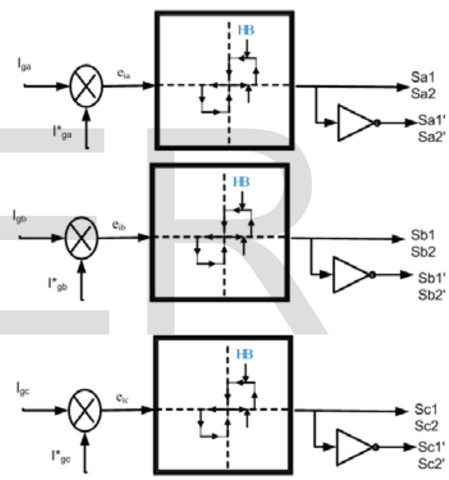


Figure 9 hysteresis current controllers with three-level inverter.

5 Simulation and Analysis of Results

The Control of Grid Connected Photovoltaic using the hysteresis current control strategy, these results take whether using change in irradiance of PV with The main simulation parameters are listed in appendix [A].

5.1 The simulation results of Photovoltaic Array

Figure (10) shows I-V and P-V curve with change irradiance G from 250 W/m2 to 1000 W/m2 in steps of 250. From These figure the changes in irradiance have effect on the output power of array.

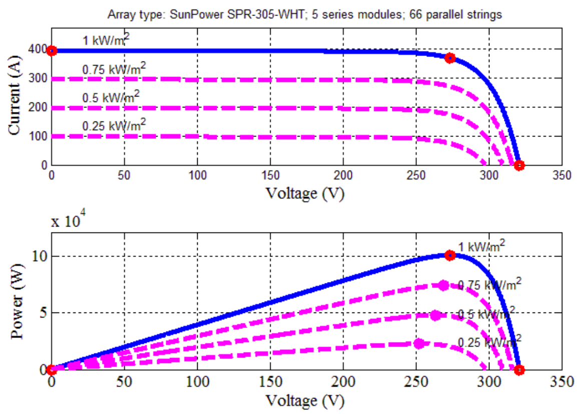


Figure 10 the simulation results of PV array (a) I–V characteristics (b) P–V characteristics

5.2 The complete system simulation Results

The complete system simulation for a PV generation system is done using Matlab /Simulation. The simulation results are divided into two status (depending on inverter topology) state (a) two levels inverter and state (b) three-level inverter. To verify the proposed technique with two cases studies are implemented.

Figure (11) presents irradiance variation. Simulation is done for irradiance change first from 1000 to 600 W/m2 ramp from time 1to 1.1 Sec. second from 600 to 1000 W/m2 ramp from time 2to 2.1 Sec., third from 1000 to 800 W/m2 at time 3 Sec. and fourth change from 800 to 1000 W/m2 from at time 4 Sec.

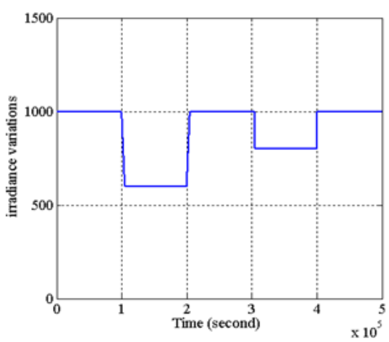


Figure 11 irradiance variations.

Figure (12) show results Output of P&O MPPT algorithm Power and Actual Output Power of PV array

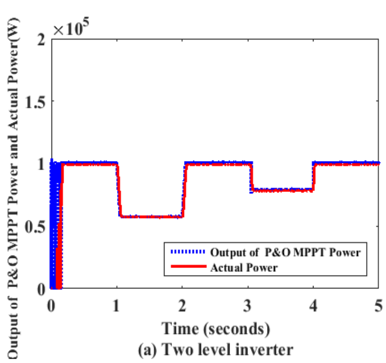
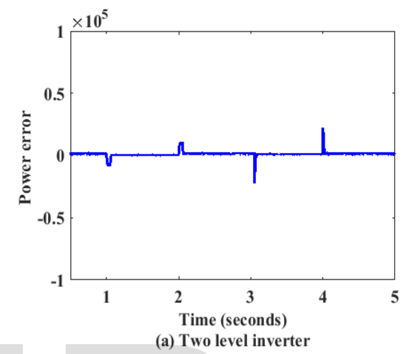


Figure 12 the P&O MPPT algorithm output Power and Actual Output Power of PV arrays.

Figure (13) shows the error between the output of P&O MPPT algorithm and Actual Power of the PV array.



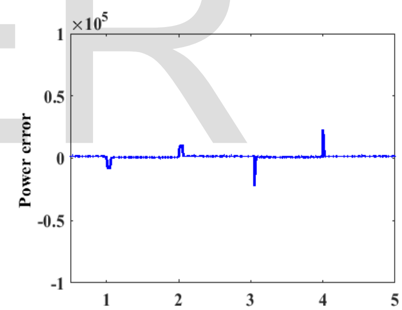
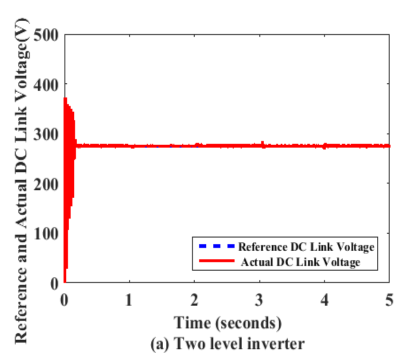
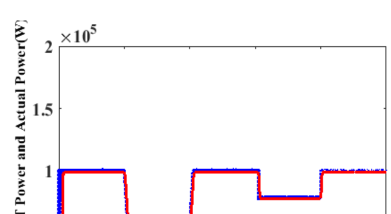


Figure 13 the power error between the Output of P&O MPPT algorithm and Actual Power of the PV array.

Figure (14) presents the performance between the actual and references the DC link voltages.





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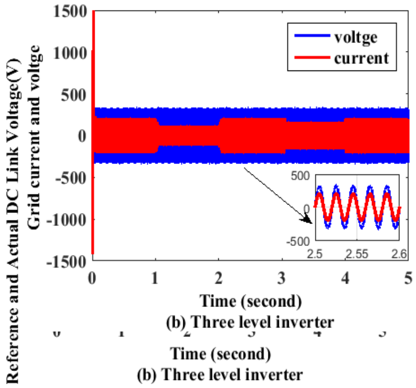


Figure 14 simulation results of dynamic responses of the reference and actual DC link voltage.

Figure (15) shows the three phase utility-grid current

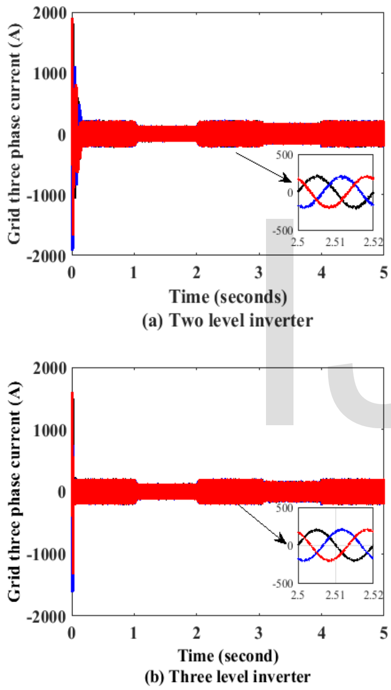
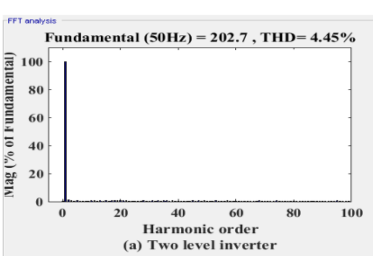


Figure 15 performances of the three phase utility-grid current.

Figure (16) shows the performances of THD for the three phase current.



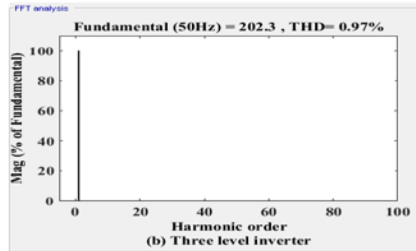


Figure 16 simulation results performances of THD for three phase current

Figure (17) presents the active and reactive power injected to the grid

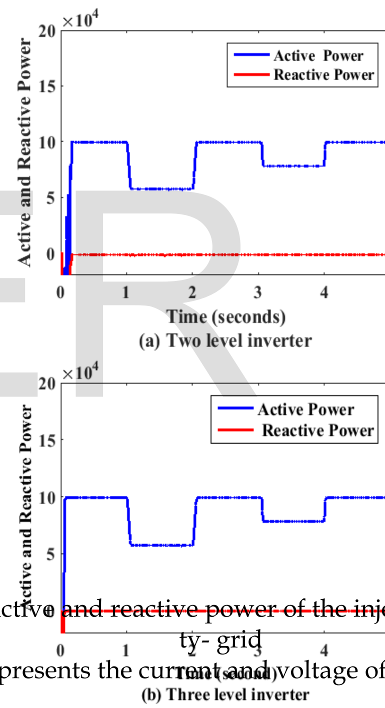


Figure 17 Active and reactive power of the injected to the utility- grid

Figure (18) presents the current and voltage of the utility- grid

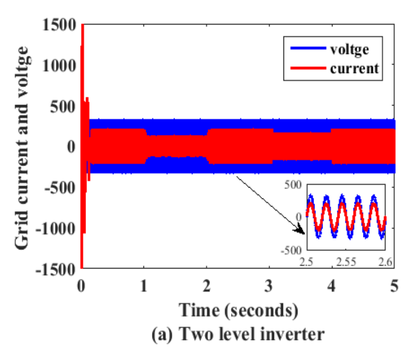


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Figure 18 the performances of grid current and voltage.

5.3 Dissection of the Results

A previous result of the proposed system shows that. The peak overshoot decreases during the irradiance variation also steady- state time decreases with Three- level inverter. The time needed to reach the steady-state in this research decreases compared with Ref [14, 24- 26]. As will the higher level inverter gives lower steady state error in power. Moreover ref [14, 15, 25 -27] gives a power error much higher than ours'. The DC link voltage is almost constant for three-level inverter with the change in irradiance. The DC link voltage ripples are reduced using three-level inverter, the time needed to reach the steady state and the dc link voltage ripples in this work are less compared with Ref [17, 24, 26, and 27].

The starting current decrees with three-level inverter, besides the time needed to reach the steady state are also decrees. The proposed system (three-level inverter) gives current with less distortion which improves the utility-grid power quality. The THD decreases and the current become more sinusoidal with the increase of the inverter levels. Moreover ref [8, 11, 24, and 28] gives THD higher than ours'

The reactive power almost zero (unity power factor) with change of irradiance, the system operation with unity power factor with change of irradiance. The angel between current and voltage equal zero.

Table 1 Comparison between the proposed schemes

Comparison Performance	Two levels	Three levels
Peak overshot of starting for DC link voltage	37.5%	27.3%
steady state time for DC link voltage	0.12Sec	0.07 Sec
Steady State Error Range for DC link voltage	0.73%	0.05%
first cycle Starting current	763%	652%
Peak overshot of the active power with changes in irradiance	exist	No exist
Steady State Error Range for active power with changes in irradiance	3%	2%
Total harmonic distortion	4.45%	0.97%

6 Conclusions

The design of HCC with two-level and diode-clamped three level inverter for Single-stage PV grid-connected system is done. Besides the tracking method of the maximum power point is implemented using proposed P&O algorithm. A comparison between the performance of two-level inverter and diodeclamped three level inverter are depicted and their performance is collected in Table 1. A comparison between our results and other references result is done. The results show that the diode-clamped three level inverter is Fast , robust ,reduce DC voltage ripples, decrees peak overshoot, steady-state time and steady- state error for the performance of power injected to the utility grid. As will as the THD in the current injected to the utility grid decreased with diodeclampedthree-level inverter. Matlab/Simulink SimPowerSystems is used to verify the obtained results.

Appendix A the used grid and PV array parameters

Grid Parameter	Value	Unit	PV array parameters	Value	Unit
Dc-bus voltage	275	V	I_{MPP}	5.58	A
Dc-bus capacitor	1000	uF	V_{MPP}	54.7	V
Grid Filter resistance	0.1	Ω	$V_{O.C}$	64.2	V
Grid Filter inductance	1.2	mH	$I_{S.C}$	5.96	A
line to line voltage	380	V	N_P	66	
Frequency	50	HZ	N_S	5	
			R_S	993	
			R_{Sh}	0.037	

Symbols and abbreviations

P_g	Active power injected to the grid
G_o	ambient irradiance
T_o	ambient temperature
k	Boltzmann's constant
DC-MLI	diode clamped multilevel inverter
i_{dg}, i_{qg}	Direct and quadrature grid current space vector components in two phase rotating d-q reference frame
v_{dg}, v_{q}	Direct and quadrature grid voltage space vector components in two phase rotating d-q reference frame
DPC	direct power control
HCC	Hysteresis current control
n	ideality factor of the cell which is a measure of the junction quality and the type of recombination (n = 1 - 2)
G	irradiance
MPP	maximum power point
MPPT	maximum power point tracking
MLI	Multilevel inverter
N_P	number of parallel cells
N_s	number of Series cells
$I_{PV-ARRAY}$	Output current of the PV array
I_{pv}	Output current of the PV cell
V_{pv}	Output voltage of the PV cell
I_{Ph}	photocurrent
PV	photovoltaic
P_{dc}	Power Produce By Pv Array

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q_g	reactive power injected to the grid
R_s	Series resistance
R_{SH}	shunt resistance
a_{sc}	temperature coefficient of short-current
q	the electron charge
T	the junction temperature
$I_{Ph-ARRAY}$	The short-circuit of array measuredunderirradianceG_O=1000W/m^2 andT_O=25°C
VOC	Voltage oriented control

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