



# Direct Power Control of PV-Grid Connected Using Artificial Neural Network

## التحكم في الخلايا الشمسية المتصلة بالشبكة عن طريق الشبكة العصبية الاصطناعية

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### KEYWORDS:

*Photovoltaic system, grid connected inverter, neural network, power flow control, robust control.*

*المخلص العربي:- في هذا البحث، تم تصميم الشبكة العصبية الصناعية (ANN) كمتحكم في أنظمة الطاقة الشمسية المتقدمة المتصلة بالشبكة الكهربائية. يستخدم المتحكم المقترح في تدريب أكثر من مجموعة ظروف تشغيل واسعة المدى. تم بحث تحقيق المحاكاة في خرج العاكس الثلاثي الأوجه المتصل بالشبكة بواسطة القدرة الفعالة عن طريق حقن قوة كهربائية نشطة تعمل على حدوث اضطراب كبير في ظروف التشغيل المختلفة. لكي نحسن أداء عملية التحكم يقترح استخدام حاكم باستخدام الشبكات العصبية الصناعية ليقتارن مع عملية التحكم التقليدية بواسطة (PI). نتائج المحاكاة تعرض غرض عملية التحكم (ANN) وقابليتها لتحسين أداء منظومة الطاقة الشمسية المتصلة بالشبكة ثلاثية الأوجه على نطاق واسع من عمليات التشغيل.*

**Abstract**—In this research, an artificial neural network (ANN) controller design for connecting photovoltaic (PV) power system to the grid is introduced. The proposed controller is trained over a wide range of operating conditions. Time domain simulations of a grid-tied three-phase inverter by an active power injection subjected to major disturbance is investigated. To improve the superiority of the proposed controller, the performances of the developed ANN is compared with a conventional PI controller. The simulated results prove the capability of the proposed ANN controller to enhance the PV system performance over a wide range of operating conditions.

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## I. INTRODUCTION

PHOTOVOLTAIC (PV) systems are important renewable energy sources because it is available in most areas around the world. Also, it is easy to get a DC power source from PV systems. By using inverters, DC power can be converted into AC power. In addition, PV power system, it is getting more value time after time. The significant advantages of photovoltaic system are the usage of abundant and free energy from the sun [1]. Photovoltaic system has a major problem: amounts of electric power have been generated using solar arrays changes continuously according to the weather condition and daytime [2]. The output voltage of an inverter in grid-connected mode is capable of feeling excess power to the grid when the power generation is more than local demand. The development of controlling system generates from output voltage and current [3]. So far, many researches were focused on inverter output power control [4]. The design of the controller's inverter is important for all PV system performance [5]. A three phase PV connected to grid inverter using the PI control is introduced in [6]. Apparently, the design of the inverter without transformer seems a favorable way to be improving the overall inverter output. Up to now, neural networks (NNs) attract more and more attention [7].

By applying the intelligent controllers such as artificial neural network (ANN), the design of the controllers in power systems does not need exact mathematical model description of the system [8].

The main advantages of the ANN intelligent controllers are the mathematical structure, which consists of interconnected artificial neurons that mimic a much smaller scale. The design of such intelligent controllers does not need an exact mathematical model description of the system [9]. Moreover, increasing the numbers of the semiconductor switches raises the overall system cost. To build up an intelligent control system, the designer needs to acquire knowledge or information about the system. The PV grid connected system is managed by controlling number of hidden layers [10]. ANN was originally conceived as an attempt to model the brain of how to operate and function. The aim of the controller has been created an artificial model by input, output and hidden layer. This encourages many researchers to develop controllers for PV systems using ANN [11].

The purpose of this paper is to design a controller for active power injection to the main grid using ANN. For this purpose, the proposed controller has been trained over a wide range of operating conditions. Also, a PI controller is developed using genetic algorithm optimizations. To improve the effectiveness of the proposed ANN controller, the results of the ANN controller is compared with optimized conventional PI controllers. The output waveform response behavior such as the inverter output currents, power and PV input voltage and current developed by the ANN control

system [12] exhibits better performance in reducing the system overshoot as compared with that of the PI controllers. The control strategy for the switching signal generation consists of several functional components such as phase-locked loop-type grid synchronization [13], abc stationary reference frame to dq coordinate transformation, current regulations, ANN controller design, PWM signal generation and signal conversion.

SPR-415E-WHT-D with 85.3V open circuit voltage model is used. This array is available in Matlab/Simulink built-in internal libraries. The parallel modules are 81 with series 10 modules per string.

The equation of output voltage from PV is

$$V_{rms} = 0.612m_a V_{dc} \quad (1)$$

Where,

$m_a$  : Modulation index

Solar cell mathematical modeling is an important step in the analysis and design of PV control systems. The PV mathematical models could be obtained by following equations

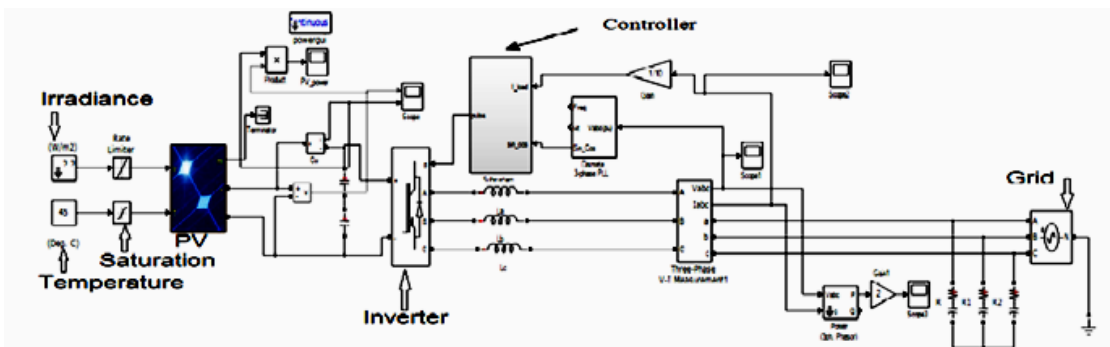


Fig. 1 Model of PV grid using SIMULINK

## II. POWER SYSTEM MODEL

Figure 1 shows the model of the PV grid connected power system. The system includes generator, inverter and controller. The inverter is connected to the grid through a filter inductor of 3mH. An image of the developed Matlab/Simulink ANN controller is shown in Fig. 2. The main grid currents is sensed and converted into dq rotating reference frame coordinate system. The direct power control is achieved by setting a reference signal to the d-axis current component. The reference tracking is achieved through the ANN controller. To maximize an active's power control, the q-axis current components are set to zero.

### A. Photovoltaic System (PV)

PV cell is the main building block of PV module, which consists of many PV cells connected in series/parallel manners for each module [14]. The non-linear output characteristics of I-V and P-V, for such PV modules, depend mainly on solar insulations and cell temperature. As a PV module has non-linear characteristics, it is important to model a PV module for the purposes of making a design, operations and discovering the causes of degradation of PV performance [15]. To get the output voltage of 380V from the PV array, the Sun Power

$$I_c = I_{ph} - I_o \left\{ e^{\left[ \frac{q}{AKT}(V_c + I_c R_s) \right]} - 1 \right\} \quad (2)$$

$$V_c \frac{AKT}{q} \ln \left( \frac{I_{ph} + I_o - I_o}{I_o} \right) - I_c R_s \quad (3)$$

$$I = I_{ph} - I_o \left\{ e^{\left[ \frac{q}{n_s AKT}(V + n_s I R_s) \right]} - 1 \right\} \quad (4)$$

$$I_{ph} = \frac{G}{1000} [I_{sc} + k_i(T - T_r)] \quad (5a)$$

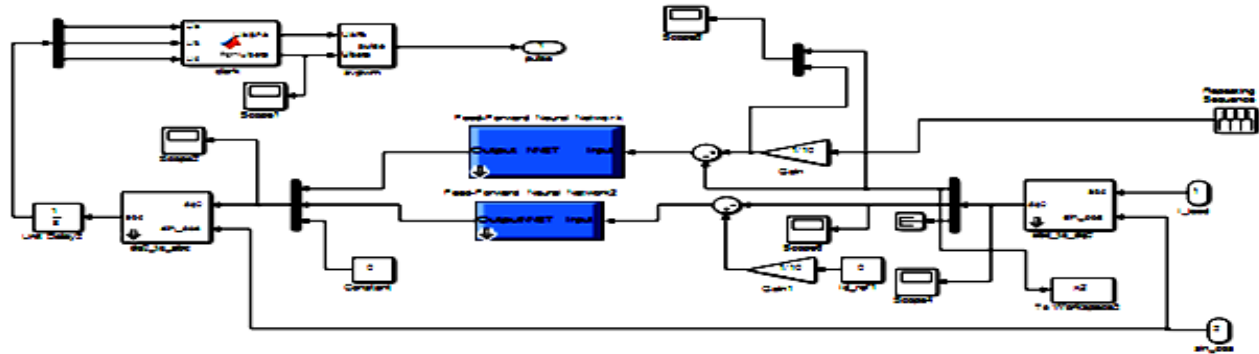


Fig. 2 ANN deign in PV grid system

$$I_o = I_{or} \left( \frac{T}{T_r} \right)^3 e^{\left[ \frac{qE_g}{AK} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right]} \quad (5b)$$

The module output power can be determined simply from

$$P = VI \quad (6)$$

Where

- $I_o$ : The reverse saturation current,
- $I_{ph}$ : The light generation current,
- $I$  : The photoelectric output current,
- $I_{sc}$ : The short circuit current,
- $A$  : The ideality factor,
- $V$  : The photoelectric voltage,
- $R_s$ : The module series resistance,
- $n_s$ : The number of series connected solar cells
- $k$  : The Boltzmann's constant,
- $q$  : The magnitude of the electron charge,
- $T$  : The absolute temperature,
- $G$  : The isolation value.

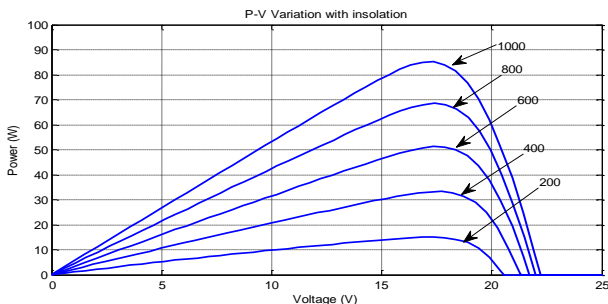


Fig.3. P-V with variation of insolation

Figure 3 depicts the PV characteristics with varying the insolation. Also, the I-V relation of the PV cell with the variation of insolation is showing in Fig.4.

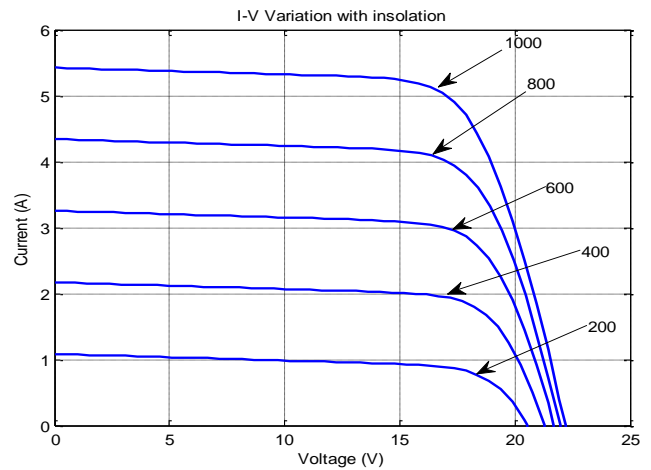


Fig.4. I-V with variation of insolation

### B. Inverter

The three phases inverter is shown in the Fig. 5. It consists of a DC link power stage capacitor and insulated gate bipolar transistor (IGBT) and filter inductors. The DC-link consists of capacitance ( $C_{dc}$ ), which is calculated according to equation (7).

$$C_{dc} = \frac{3 P_n}{f_n V_{dc,n}^2} \quad (7)$$

Where:

- $P_n$ : Nominal power of the inverter,
- $f_n$ : the grid nominal power,

$V_{dc,n}$ :nominal open circuit voltage of the PV generator.

The function of the DC link capacitor is to link, the dc power to the inverter system, help to stabilize the input voltage for the inverter [16].The inverter is connected to the grid through a filter inductor of 3mH in each phase which reduces the high-frequency harmonic components were injected into the grid system. The output current of inverter is controlled by rotating d-q reference frame. Phase locked loop (PLL) is used to synchronize grid with PV [17].

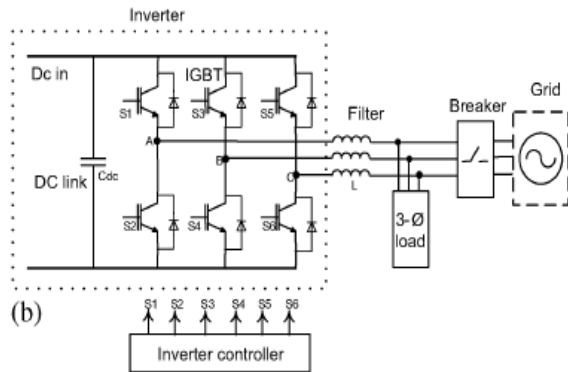


Fig.5. Universal 3-leg inverter

C. Phase Locked Loop

The correct phase angle is very important information in grid-connected systems such as UPS, controlled rectifiers, active filters, dynamic voltage restorers and also in the emerging distributed generation systems such as photo-voltaic [18].

The most widely accepted synchronization solution to a time-varying signal is described by the basic structure shown in Fig. 6. The difference between phase angle of the input and that of the output signal is measured by the phase detection and passed through the loop filter. The loop filter output signal drives the voltage-controlled oscillator (VCO) to generate the output signal, to follow the input signal [19].

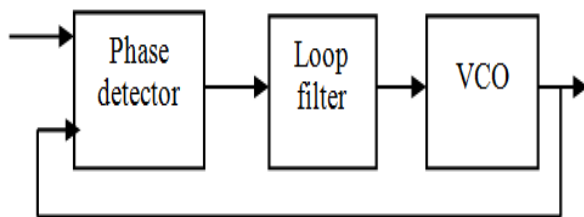


Fig.6. Close loop synchronization structure

Synchronous frame PLL (SF-PLL) is widely used in three-phase systems. The block diagram of the SF-PLL is illustrated

in Fig. 7, where the instantaneous phase angles is detected by synchronizing the PLL rotating reference frame to the utility voltage vector. The PI controller sets the director quadrature axis reference voltage  $V_d$  or  $V_q$  to zero, which results in the reference being locked to the utility voltage vector phase angle. In addition, the voltage, frequency  $f$  and amplitude  $V_m$  are obtained as the byproducts [20].

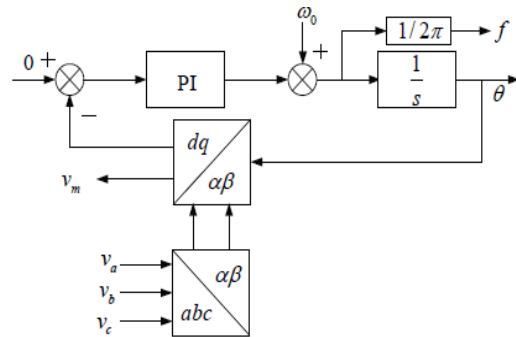


Fig.7. Block diagram of synchronous frame PLL

III. CONTROLLER DESIGN

A. PI Control

There is no doubt that the PID controller is one of the most used controller type in control loops [21]. PI control is a conventional method of controlling, it is used here to control the 3- phase PV grid connected system. In this system, the feedback currents from the grid are used in order to control the grid system. The transfer function of the conventional PI controller is:

$$G_s(s) = K_p + K_I / s \tag{8}$$

If  $e(t)$  is the input to the PID controller, the output PID from the controller is given by:

$$PID = K_p e(t) + K_I \int e(t) dt \tag{9}$$

The integral term corresponds to the accumulated area of error versus time. The proportion gain can increase the response output controller and control accuracy of the system [22]. The integration gain is used to eliminate the steady-state error of the system.

B. ANN Control

Intelligent control achieves automation via the emulation of intelligence. ANN is one of advanced control. It is used to control the three phase PV-grid connected system. NNs have been successfully used in optimization, to pattern recognition, associative memories and many other fields [23]. ANN is used

in this system because it has many advantages such as: NN synthetic varieties of artificial intelligence is one of the of advanced control types and also there is no need to the power system description, NNs include input layer, output layer and a number of hidden layers as shown in Fig. 8. The input layer depends on control in the current, which is composed of two axes (d-axis and q- axis). The output layer represented by the control signal axis.

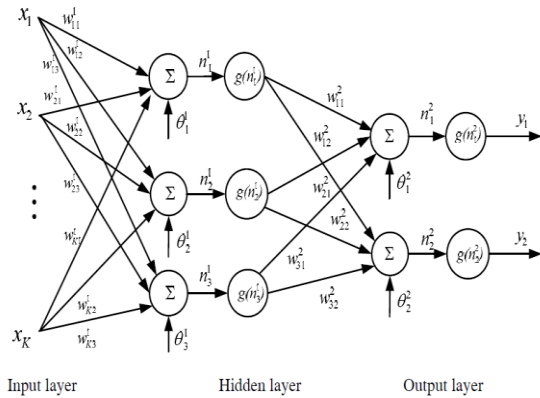


Fig.8. Neural network internal structure

The hidden layer in ANN architecture consists of many neurons organized in layers. Each neuron in a layer is connected to all the neurons of the next layer. Figure 9 shows a block of the developed feed-forward neural network. It consists of 10 hidden layers and one output layer. The input layer to this network is the rotating reference frame current error in the d-axis component. The output layer in Fig. 9 represents the control signal. The results of training are given in Fig. 10. The correlation coefficient of 0.8 or higher shows a good training of the ANN controller [24]. This is also highlighted from the mean squared error as shown in Fig. 11.

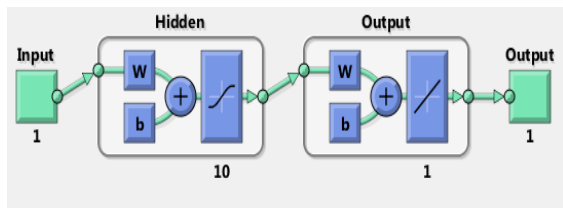


Fig. 9. Developed feed forward NN

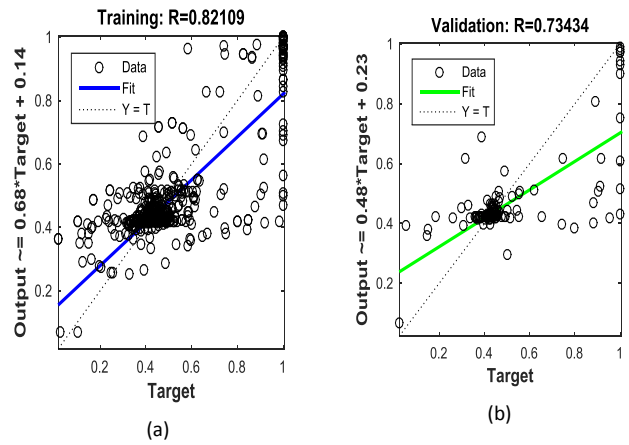


Fig.10.(a), (b) Neural network training regression.

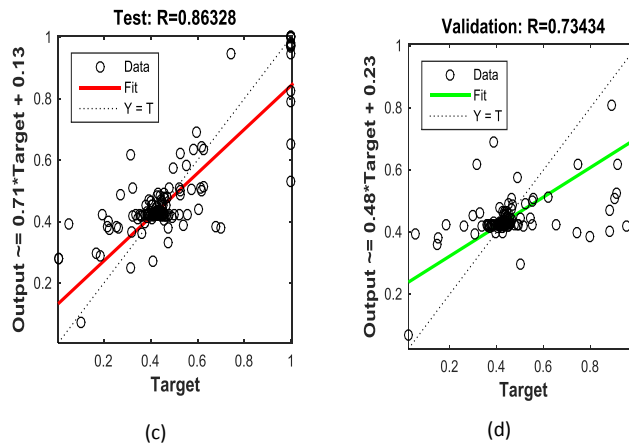


Fig.10. (c), (d) Neural network training regression.

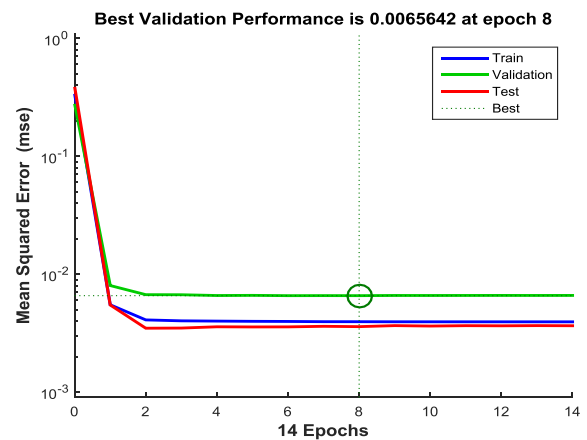


Fig.11. Neural network training performance

**IV. DIGITAL SIMULATION RESULT AND DISCUSSION**

The grid voltage profile is shown in Fig. 12. Figures 13 and 14 show the three phase inverter injected currents using PI and ANN controllers respectively. The corresponding current profile in dq reference rotating in frame is illustrated in Fig. 15. It is clear that the response to the conventional PI controller is suffering from high oscillations. The developed ANN controller is more powerful in improving the damping characteristics of the power system currents compared with the conventional PI controller. Thus, the ANN controller gives better results.

The output active power injected to grid is shown in Figs. 16 and 17 respectively. The results show that ANN control is better than PI control. The PV generator output power is shown in Fig. 18. The value of DC power is slightly low in ANN control. The PV generator current and voltage profiles are given in Figs. 19 and 20 respectively. From this result, ANN control shows smooth transitions for the voltage, current and power of the PV generator at the disturbance points.

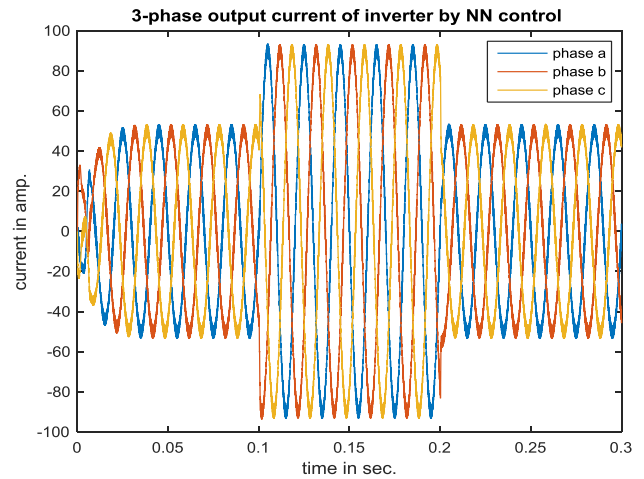


Fig.14. Inverter injected current profile using ANN controller.

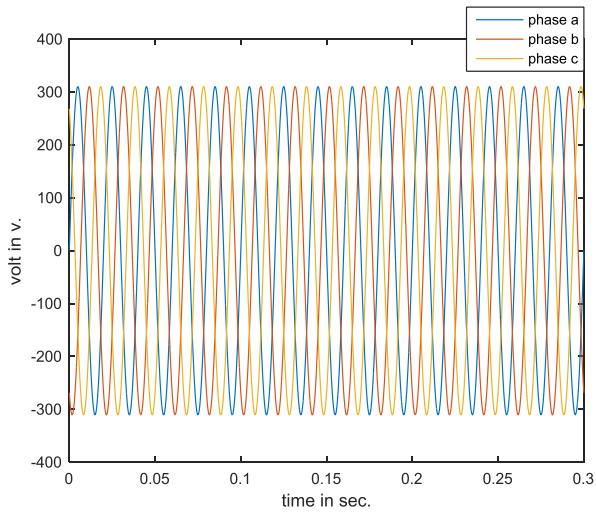


Fig.12. Grid voltage profile.

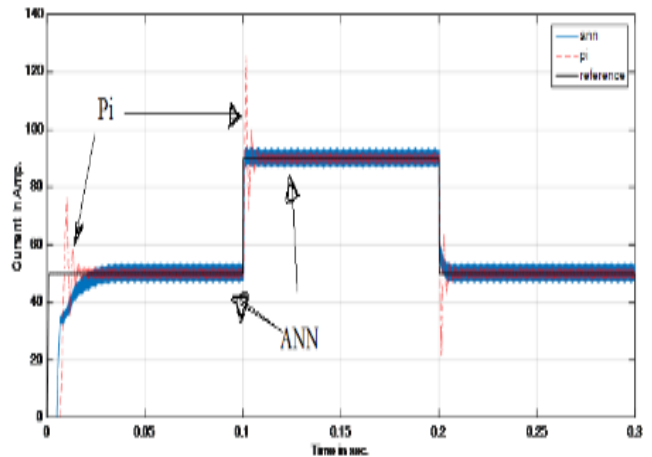


Fig.15. Inverter injected currents in dq rotating reference frame

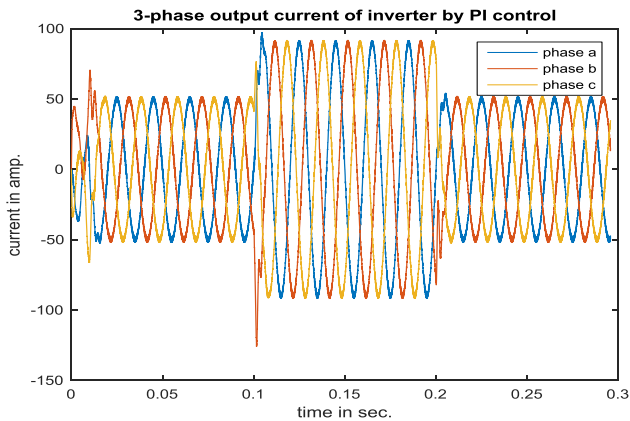


Fig.13. Inverter injected current profile using PI controller

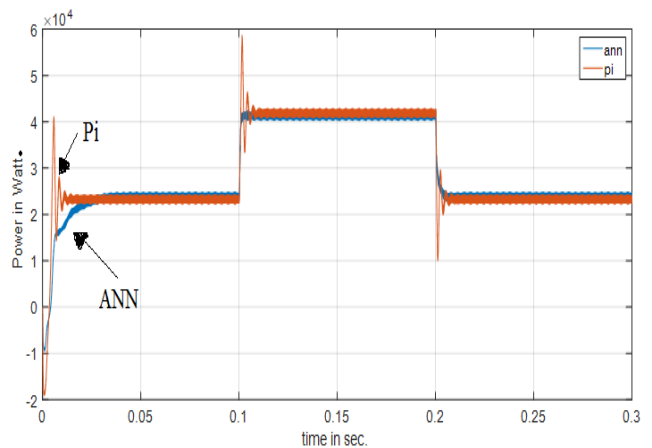


Fig.16. Injected active power.

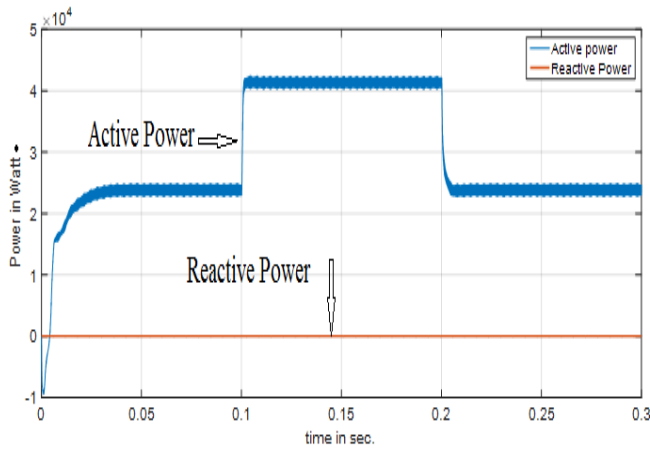
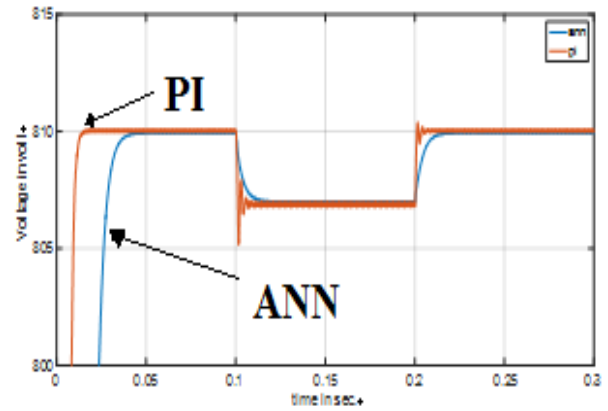


Fig.17. Injected active and reactive powers with ANN control.



(b) Zoomed in image

Fig. 19. PV generator output voltage. [(a) , (b) ].

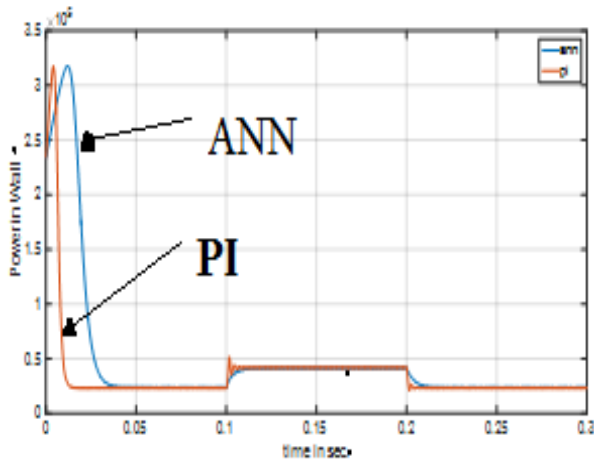


Fig. 18. PV generator output power

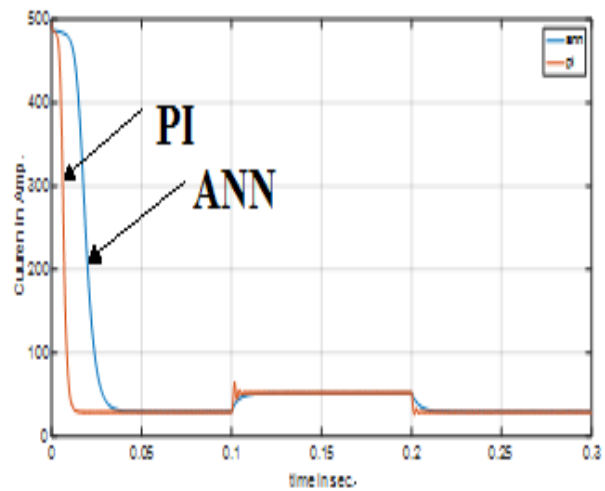
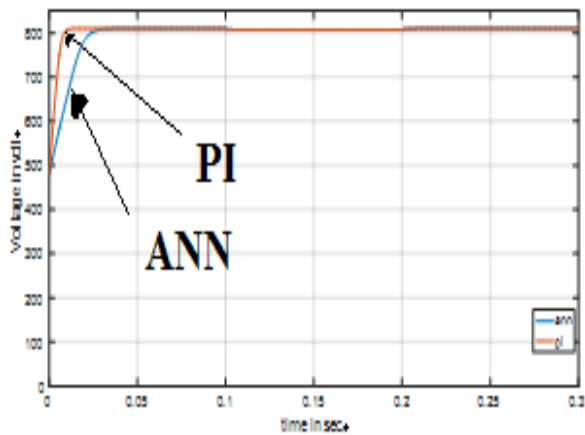


Fig. 20. PV generator output current.



(a) Voltage profile

### V. CONCLUSION

In this work, the difference between PI and ANN control for high-performance controller in connecting three-phase PV inverter to the utility grid has been presented. The obtained results showed that the inverter control system employing ANN control is better in producing stable and nearly sinusoidal waveforms of both voltage and current. The superiority of ANN compared to PI controller can be summarized as follows. It is capable to generate PV power with high quality. In addition, the developed ANN shows better response in terms of eliminating the over/under shoots and enhancing the settling time compared PI control.

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