# Design and Application of an ANN controlled Off Grid Inverter for PV Power Systems

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## Abstract

Most of conventional power systems, especially fossil fuel plants harms the environment. Their poisoning and toxic gas emission levels are dangerous for our future. In recent years, renewable energy sources are in demand for clean energy production. One of the most using renewable energy generation style is photovoltaic power systems have increasing place in renewable power plants. However, new control technics using on PV power systems for power generation are in progress to improve power quality and reliability. In this paper, one of the methods in progress, artificial neural network control system is handled for generating clean energy. An ANN (Artificial Neural Network) controlled inverter topology is designed simulated and experimented. The proposed inverter model includes a dc/dc converter stage in order to boost up and stabilize the PV panel's output voltage, and it includes a three-phase push-pull inverter stage to feed ac loads.

**Key words:** Artificial neural networks, photovoltaic, renewable energy, solar energy

## 1. Introduction

Even though they have most place in energy production, Conventional energy production systems give most damage to environment due to high toxic gas emissions of fossil fuel plants. It has seen that one of the most reliable solution for clean energy is renewable energy systems. In recent years, renewable energy systems are having important place. Especially solar energy systems are increasing their amount year by year. In 2014, global investments in renewable energy increased by 17% to $270.2 billion. This was the first increase in investment for three years. In addition, the trend was even more impressive in terms of capacity: last year a record of 95GW of wind and solar photovoltaic power was installed globally. As stated in this Global Trends in Renewable Energy Investment 2015 report, renewable energy excluding large hydro accounted for 48% of new generating capacity installed globally in 2014, and the share of renewables in global electricity generation increased to 9.1%. This is equivalent to avoided greenhouse gases emissions of some 1.3 gigatonnes annually [1]. Although, technology in electronics and panel systems is in increasing trend. PV panel efficiencies are increasing every year and optimization of PV energy systems is taking important role in designing these types of systems.

The most using optimization technic is P&O algorithm in literature. The algorithm is try to reach and stay the maximum power point for PV panels in system. The algorithm depends on an iterative method. It perturb the system to a fixed operating point and observe the system if it is working correctly or not. If the system works correct, algorithm does not change system parameters. Else,

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if the system does not work correctly, then the algorithm changes few parameters and observes the system again [2]. Abdalla et al. described an algorithm for optimal control of a PV system under partial shading. A multilevel DC-link is the essential part of the proposed system and its control engages a voltage-hold perturbation and observation (VH-P&O) method combined with a PWM algorithm with permutation of PV sources [3]. Mahmoud et al. provided an MPPT approach combining model-based and heuristic techniques has recently appeared in the literature for accelerating the tracking speed of the maximum power point (MPP) of PV systems. It combines the well-known heuristic P&O and model-based techniques [4]. Belkaid et al. investigated sliding mode control (SMC) based MPPT with two different step sizes designed for Boost-type DC/DC converter method [5]. Saravanan et al. provided a comprehensive review on various maximum power point tracking (MPPT) algorithms based on Perturb and Observe, Incremental Conductance, Soft Computing and other techniques along with the real time hardware implementation of photovoltaic (PV) system [6]. Ghaffarzadeh et al. proposed a dual surface sliding mode controller and implemented to increase robustness and speed of boost converter, its asymptotic response is proved in the presence of disturbances [7]. P&O algorithm is based on classical loop control method in control system literature. The disadvantage of classical loop control technic is takes too long time for stabilizing the system due to changing little changes in input parameters.

In this study, to avoid of this disadvantage, an ANN controller is used. ANN systems has capability of human like thinking. Therefore, system can interpret input variables for having a result. In this paper, an ANN controller sets the voltage level by determining solar cells input voltage. Then, an inverter circuit converts the dc voltage to ac voltage. The proposed system is experimented with local loads and results are discussed.

## 2. Materials and Method

For a voltage controlled inverter circuit, firstly, dc PV panel voltage is need to be boost up to a suitable value for inverter stage. For this purpose, a boost converter circuit topology is used for application. Figure 1 shows the boost converter circuit topology. There, an inductor stores magnetic energy and with a switching device stored energy transferred to a huge value capacitor. According to the increasing the period of this application, voltage level in the capacitor rises.

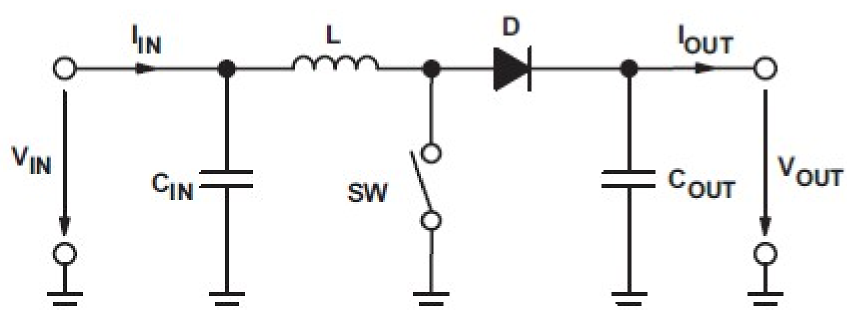


**Figure 1.** Boost converter circuit topology.

Boost converter output voltage is given by Equation I.

$$V_{out} = \frac{V_{in}}{1-D} \qquad \text{(Equation I)}$$

$V_{in}: Input\ Voltage\ (V)$
$V_{out}: Output\ Voltage\ (V)$
$D: Duty\ Cycle\ (\%)$

As it is shown in Equation I, duty cycle is the most important parameter for defining output voltage level. For practical use of this type of converter topology, duty cycle changes between 0.1 to 0.95.The importance is that point is what type of controller is decide this working point. Classical loop controller strategies like P&O algorithm can result in instability of power network. Because, in classical loop control technics, system needs a feedback value for correction of output signal in each iteration. It results of waving on output signal. Therefore, these types of systems is need to a constant duty cycle value for constant input voltages. If input voltage changes suddenly, system has to update the duty cycle value instantly due to stabilize the system. So, in this study an ANN controller used to control boost converter circuit.

In desired system, boost converter circuit has a 1mH inductor and 600uF capacitor. 1kHz frequency is used for duty cycle application. Minimum DC input voltage is calculated as 60V and maximum input voltage is considered as 275V. Boost converter tries to boost voltage up to 550V level.

After boost converter, a push-pull inverter circuit topology is used for dc/ac conversion. Desired push-pull inverter circuit is shown figure 2 below. Inverter output voltage is 3-phase 220Vrms and 50Hz.

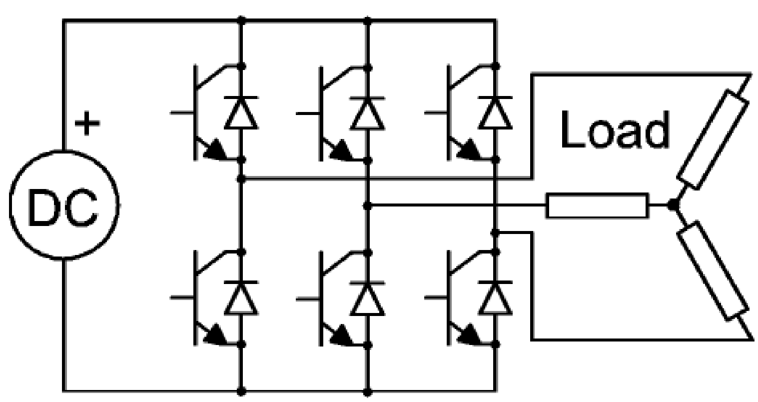


**Figure 2.** Three-phase inverter schematic

### *2.1. ANN system design*

Different artificial intelligence technics are used for controlling pv power systems. Especially, MPPT technics have important place when off-grid photovoltaic systems are discussed. Seyedmahmoudian et al. proposed a fast and efficient technique based on Radial Movement Optimization (RMO) for detecting the GMPP under partial shading conditions [8]. Enany et al. presented a novel artificial intelligence technique based on Adaptive Neuro-Fuzzy Inference System (ANFIS) [9]. Jena et al. made a classification of modeling techniques for both uniform and non-uniform irradiance conditions. Modeling of PV systems under uniform irradiance is classified into non-iterative methods, iterative methods, artificial intelligence based methods and dynamic models [10]. Makhloufi presented a method for sizing remote PV systems based on genetic algorithms has been compared with two classical methods, worst month method and loss of power supply probability (LPSP) method [11].

In many applications, ANN structures are used for their human like interpreting capability to make robust controller. Although, ANN has many simulation and application examples in renewable energy systems. In these examples, PV modelling and control applications are coming forward. Karabacak et al. presented artificial neural network applications of PV, WECS and hybrid renewable energy systems which consist of PV and WECS (Wind Energy Conversion System) [12]. Also, Elobaid et al. presented a detailed survey for ANN based PV MPPT techniques. The authors propose new categorization for ANN PV MPPT techniques based on controller structure and input variables. In addition, a detailed comparison between those techniques from several points of view, such as ANN structure, experimental verification and transient/steady-state performance is presented [13]. Mutlag et al. presented artificial intelligent-based maximum power point tracking (AI-MPPT) by considering three artificial intelligent techniques, namely, artificial neural network (ANN), adaptive neuro fuzzy inference system with seven triangular fuzzy sets (7-tri), and adaptive neuro fuzzy inference system with seven gbell fuzzy sets [14]. Khanaki et al. presented a two-stage maximum power point tracking (MPPT) controller using artificial neural network (ANN) for photovoltaic (PV) standalone system, under varying weather conditions of solar irradiation and module temperature [15].

In this study, boost converter system, which is expressed in section 2, is designed as a black box modelling methodology [16]. In designed black box model of boost converter, model inputs are PV panel Voltage and Duty Cycle. Model output is boost converter output voltage. Then, an ANN controller modeled for controlling output voltage of boost converter. ANN controller structure is created in Matlab/NNtool (http://www.mathworks.com/help/nnet/ref/nntool.html). For our case, the ANN controller changes and stabilizes the output voltage of boost converter. Boost converter output voltage is related with input voltage of boost converter and duty cycle. Input voltage of the boost converter is based on PV panel voltage. PV panel voltage is based on solar irradiance. So, boost converter input voltage is not controllable. Therefore, boost converter output voltage can only controlled by duty cycle. So, for the output data of ANN, duty cycle is used. PV panel voltage is chosen for ANN input data. Figure 3 shows the black box modelling of the boost converter circuit and the ANN controller

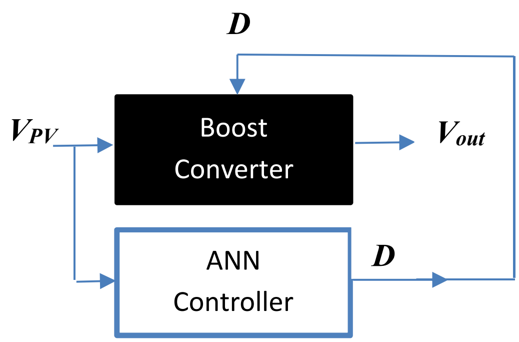


**Figure 3.** ANN controller and boost converter black box model.

ANN controller is trained with a data set of PV panel output voltage and duty cycle data. The data is obtained from a real time working prototype of study. For obtaining the data set, many experiments are made with prototype circuit. After experiments, a working space is determined by a 3d graphic. Figure 4 gives the determined working space of prototype circuit. Some useful data is chosen for training the ANN from working space. For Europe, many electrical loads' nominal working voltage is 220Vrms. However, our system has a 3-phase push-pull inverter outer side. So, for 3 phase inverters, dc input voltage is should be approximately 550V.

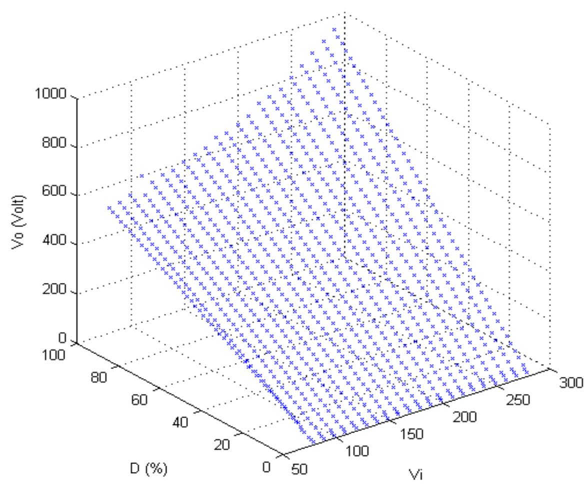


**Figure 4.** Results of experiments to obtain a dataset for ANN training, 3d dataset graph. (Axes: Vo: Boost converter output voltage, Vi: PV panel voltage, D:Duty Cycle)

Thus, the data, which corresponds with 550V output voltage, is chosen for training data. ANN trained with Levenberg Marquad – back propagation. ANN structure is designed as one input layer, one hidden layer and one output layer. 5 neuros are placed in hidden layer. Figure 5 shows ANN structure.

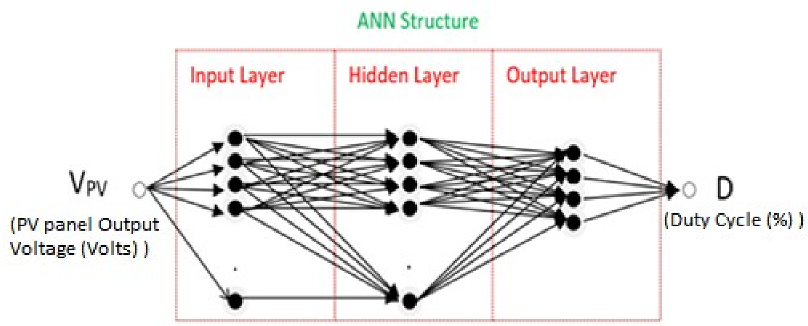


**Figure 5.** ANN structure for boost converter controller.
(ANN input: $V_{PV}$ (PV panel output Voltage (Volts)) ANN output: D (Duty Cycle(%))

Training Mean Square Error (MSE) graphic for designed ANN structure is shown in Figure 6. In graphic, best validation performance is reached at 622$^{nd}$ approach.

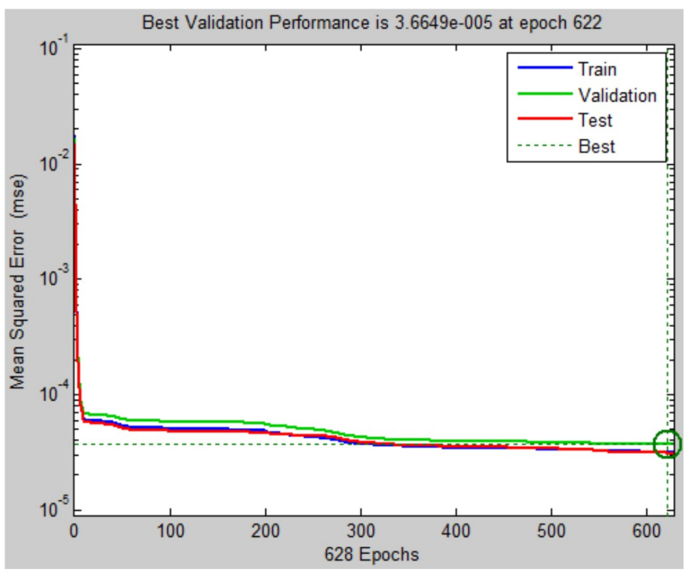


**Figure 6.** Training MSE graphic for designed ANN structure.

## 3. Results

Desired ANN controlled boost converter and push-pull inverter combination worked very well together. Series of experiments are made for measuring the performance of the designed system. First, boost converter topology experimented on various duty cycle values and output voltage level observed. Then, a working space is determined by the observed values. After, a training space is defined by selecting data points from working space. Then, prototype system is experimented with various input voltage starting 12V up to 275V. Then, system is tested off-load and on-load. Figure 7 shows the inverter's phase A voltage when dc input of the boost converter is 12V on no boost effect condition.

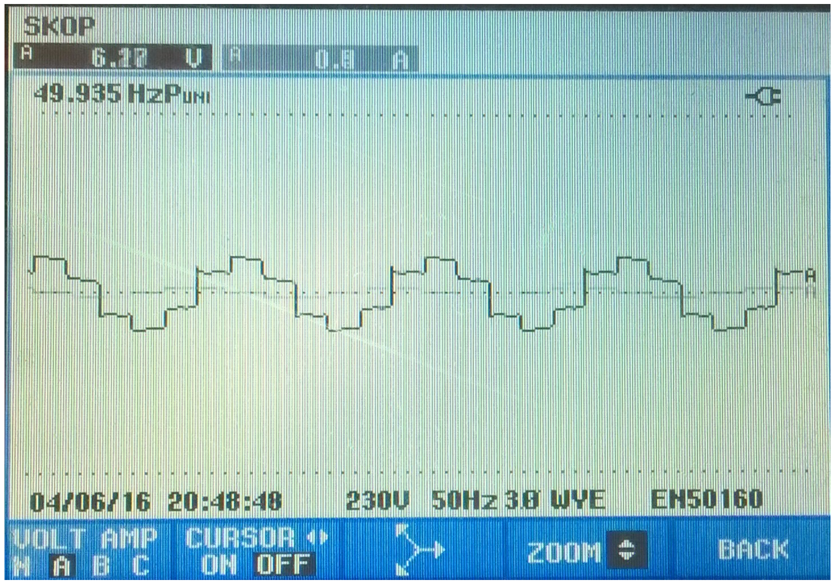


**Figure 7.** Inverter Phase A voltage when no boost effect

Figure 8 shows phase A, B,C of the inverter when dc input voltage is 12V and maximum boos effect applied by the ANN controller. In this condition, inverter output rms voltage is 230V 50Hz.

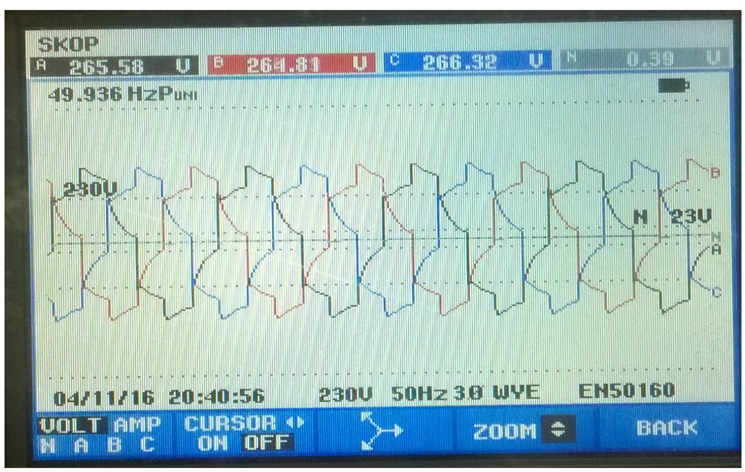


**Figure 8.** Three-phase inverter output voltage when dc input voltage is 12V and boost converter worked on %95 duty cycle.(Maximum boost effect by the ANN controller)

A three phase delta connected load test is given Figure 9. For loads, 3 halogen-free white heat lamps are used. Again, dc input voltage is 12V and boost converter duty cycle is %95. In phasor diagram, 0.1 Ampere per phase is observed. Figure 10 gives lamps connected in delta to the prototype system.

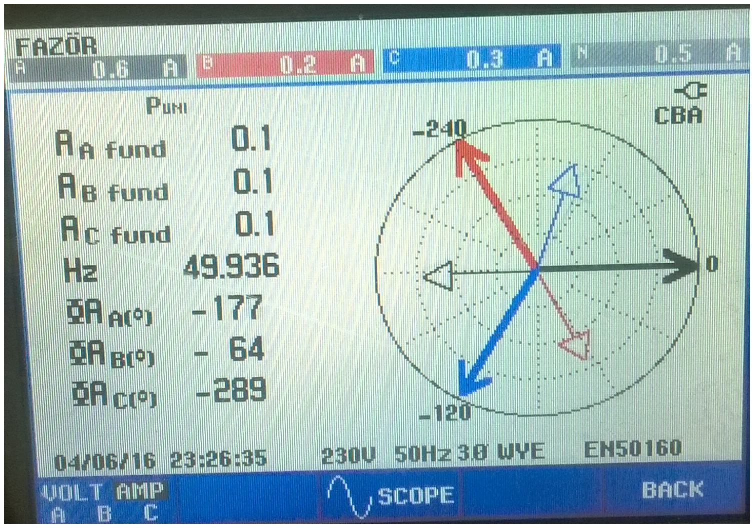


**Figure 9.** 3 phase inverter output currents when 3 phase delta connected load is connected to output of the system. (Duty cyle=%95)

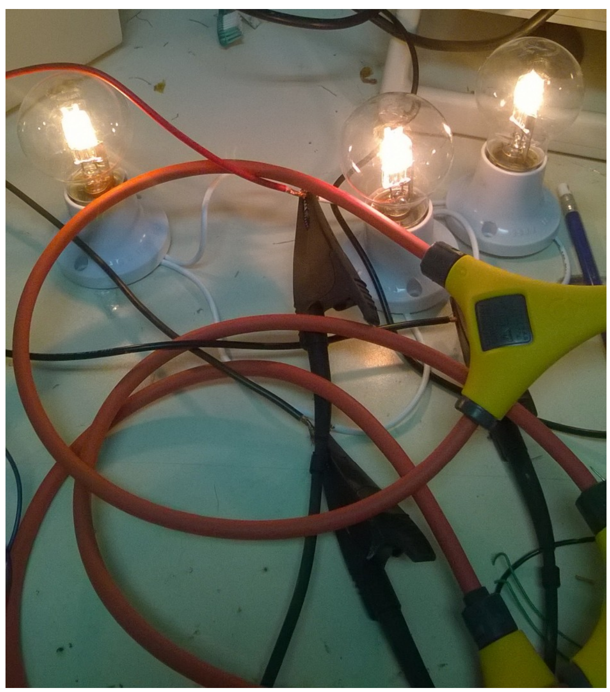

**Figure 10.** Lamps connected to the prototype off-grid ANN controlled PV system.

## Conclusions

For clean energy, dependence of fossil fuels must be reduced. For this purpose, renewable energy sources are in the limelight. For power generation of rural areas, photo voltaic power system applications are growing in whole world. Photovoltaic power system's worst disadvantage is voltage drops or waves due to environmental conditions. This issue effects power quality. For this reason, many control technics are using for stabilizing output voltage of PV panels to gain maximum power from PV panels. In this study, an ANN controlled off-grid type photovoltaic power inverter is designed and experimented. The inverter consists of two stages. The first stage is boost converter for rising the input voltage up to desired value. The second stage is push-pull inverter circuit for dc/ac conversion for feeding ac off-grid loads. The system has 5kW power capacity. In result of the study, it's shown that the proposed ANN controller has better performance then conventional controllers when changing environment conditions such as cloudy weathers on PV panels.

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