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Artificial neural network based DC-DC converter for grid connected transformerless PV system

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ABSTRACT

The transformerless photo voltaic (PV) inverter system connected to grid has created a new trend in the energy market due to its reduced space requirement, low cost and increased efficiency when compared to its counterpart i.e with transformer. Transformerless inverter system suffers from common mode leakage currents due to parasitic capacitances between PV panels and ground. However, different new inverter topologies and state of the art modulation strategies are proposed in the literature to counter it. A dc-dc converter is of more significant to maintain the constant PV output voltage at string level and extract maximum power from PV. This paper presents Artificial neural network (ANN) algorithm-based dc-dc converter to track maximum power from PV module connected to grid without transformer. It also compares the performance of ANN based algorithm with conventional perturb and observe maximum power point tracking (MPPT) technique. MATLAB/Simulink environment is used to pursue the simulation of ANN based algorithm and analyses its performance for variety of irradiance levels.

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1. INTRODUCTION

The solar photo voltaic PV system is one of the finest renewable energy resources among the family of renewables like wind, and bigas, due to its less maintenance, short time of its payback period. India is to reach 175GW renewable energy capacity by 2022 out of which it is 100 GW of solar PV is expected. It is forecasted that the solar PV capacity is raising at a rate of 16% between 2018 to 2026 [1]. The global solar market recording new trends in its installation due to the availability of advanced power conversion technologies in industry and sophisticated research. The grid connected to solar PV systems are popular, as they adopt the maximum power point tracking techniques at module level, string level or even at central level, i.e for entire PV system resulting highly efficient [2].

The transformerless grid connected PV system involves a PV array, DC-DC converter, inverter, and grid as shown in Figure 1. A general grid connected PV system include either a high frequency transformer on PV side or a power frequency transformer on grid side that provides galvanic disconnection between PV and grid, resulting in the reduction of variation in common mode voltages, that are caused by virtual capacitances between PV and ground. The variation in common mode voltage causes leakage currents which can be reduced by incorporating extra switches on AC side or DC side [3]. By eliminating the transformer in the system, the efficiency can be boosted by 1-2%. There is a considerable reduction in space and cost which made the leading manufacturers of PV systems to offer at competitive prices. However, grid connected PV systems should adhere to grid standards and protection of the system to meet safety of the system and operating personnel [4].

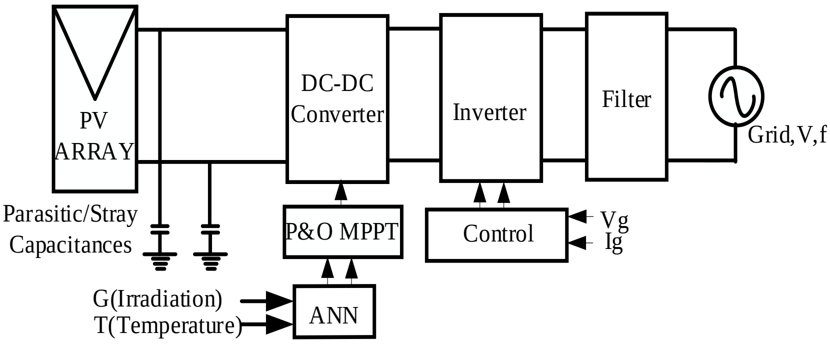


Figure 1. Transforemerless grid connected PV system using neural network

The grid connected transformerless inverter PV system has an effect of stray or parasitic capacitances formed between PV panel's aluminum beading and ground which could cause variation in common mode voltage, in turn results huge leakage currents. The Figure 1 indicates PV array connected to a DC-DC (boost) converter and the pulses to the converter is governed by Perturb and observe maximum power point tracking algorithm [5]-[7]. The input to maximum power point tracking MPPT is PV voltage and current which are inherited from the artificial neural network that is controlled by irradiance and temperature inputs. Though, there are multiple hybrid control networks to track maximum power from are in literature, this ANN based DC-DC maximum power tracking converter is having an advantage of simplified implementation [8]. An H bridge inverter with bipolar pulse width modulation is used to convert dc power into ac and subsequently feed into the grid. The control pulses to the inverter are fed from the control block, which is controlled by grid voltage, grid current. Boost converter used for raising the voltage that is required to with in the prescribed limits to avoid any tripping of the inverter [9]. This paper presents an ANN based DC-DC converter using perturb and observe technique to track maximum power from PV to grid [10].

2. ARTIFICIAL NEURAL NETWORK

Artificial neural network is also referred as neural network is the mathematical equivalent that mimics the human/animal brain cells or neurons. A set of neurons artificial in nature are employed to learn from the set of input-output relation and estimate the output for any change in future inputs by adapting variations by learning [11]. A simple neural network is a feed forward network that involves a input layer acquires the external data, hidden layer and output layer that gives the result of the problem, as shown in Figure 2. Interconnection between the layers of neurons is achieved by numerical weights and biases. A neuron in a neural network is a node having a mathematical equivalent that can acquire and classify the data using a curve fitting mechanism [12], [13].

In the following neural network shown in Figure 2, every arrowed line indicates connection between any two nodes or neurons input layer to hidden layer or hidden layer to output layer, signifying the flow of information. The network containing three layers, to get the required output it is needed to adjust the weights to get the desired output [14]. The major applications of neural networks are in medical, aerospace, finance, military, digital signal processing technology. Artificial neural networks are trained using an algorithm that learns from the exiting data and draw out some relationship between input and output such that it readjusts the weights to reduce the error between actual output and target output. Back propagation is such an algorithm that is used to tarin the network based on the input data sets. The performance of any neural network containing nonlinear complex relations, can be improved by training the network over a larger data set. ANN can handle multi dimensional problems for which exclusive mathematical model is not available. In this paper ANN based DC-DC converter using a perturb and observe technique is presented to track the maximum power from the PV maintain the output voltage constant [15].

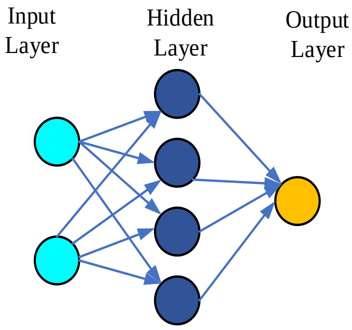


Figure 2. Basic neural network

3. PV MODULE CHARACTERISTICS

Solar irradiation is not constant over the day and varies from season to season. The voltage, power also depends on the temperature of the module. Solar I-V, P-V characteristics shown in Figure 3, on x axis PV voltage is indicated, on y axis PV current and power are as shown. Isc represents short circuit current, voc is open circuit voltage of PV cell and MPP is maximum power point [16]. It is the point where the maximum voltage and maximum current of PV will occur. It is required to operate the solar PV at MPP point to get the maximum power from it. In spite of variation in solar irradiation and temperature, PV will not deliver maximum power to the load. In order to counter this various MPPT techniques are found in literature [17]. Standard test conditions are of irradiation level 1000W/m^2, temperature 25^{0}C is used to test the solar PV so that the maximum power can be received [7].

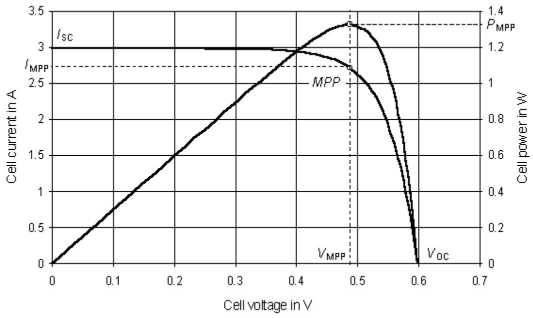


Figure 3. Typical PV cell characteristics

3.1. Maximum power point tracking

The power generated by solar PV is highly dependent on solar insolation and temperature. However, the solar insolation is not constant over a day, so that it is required to track maximum power from existing solar insolation and temperature of the panel. Many of the techniques are available in literature for tracking the maximum power from PV [3]. The most used, efficient algorithm to track maximum power from PV is perturbation and observation as it is simple to implement. It is also analogous to hill climbing technique. Some of the other techniques include incremental conductance method, sliding mode based MPPT technique, parasitic capacitance technique [7].

3.2. Perturb and observe algorithm

In this technique voltage, current and power measured at regular intervals and compared with previous intervals. As per the p-v characteristics, if the power output measured is in increasing mode, then perturbation (small change in voltage) followed is positive otherwise, if the power measured is decreasing perturbation value will be negative, so that, voltage is reduced to reach maximum power point. This process will be repeated through out the PV is feeding the load or grid. The flow chart shown in Figure 4 indicates the power measured at instant is same as power at the preceding instant, that is maximum power point has been achieved and it bypasses the flow [4]. If the variation of power with respect to variation of voltage is greater than zero, then voltage will be altered accordingly. For a positive slope in PV curve the operating point is on left of MPPT and if the slope is negative, the operating point is right of MPP.

T as detailed in the following equations [18].

$$\frac{dp}{dv} = 0, \text{at Maximum power point} \quad (1)$$

$$\frac{dp}{dv} > 0 \text{ left side of Maximum power point} \quad (2)$$

$$\frac{dp}{dv} < 0 \text{ right side of Maximum power point} \quad (3)$$

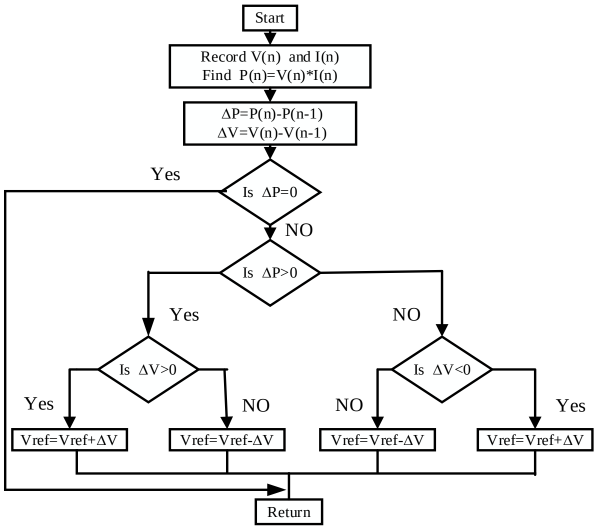


Figure 4. Perturb and observe MPPT technique

3.3. DC-DC converter

A DC-DC converter is used to vary the voltage according to the perturbation is positive or negative, such that it will boost the voltage or decrease the voltage to reach maximum power point. A boost converter shown in figure is considered for the operation [19]-[20]. The output voltage of a boost converter will be raised, and the output voltage of the converters governed by duty cycle (D) which is controlled by the MPPT algorithm [21].

$$V_{out} = \frac{V_{in}}{(1-D)} \quad (4)$$

Tuning the duty cycle is done to match the impedance of load and PV. The value of duty ratio is in between 0 and 1 making the output voltage if most converter is greater than input voltage. The parameters of boost converter are the value of inductance and capacitance mentioned in Figure 5. are determined by the amount of ripple allowed as mentioned in (5) and (6).

$$L = \frac{V_{in}(V_{out}-V_{in})}{f_{sw} \times \Delta I * V_{out}} \quad (5)$$

Where f_{sw}represents switching frequency, ΔI is the ripple current in the output.

$$C = \frac{I_{out}(V_{out}-V_{in})}{f_{sw} \times \Delta V * V_{out}} \quad (6)$$

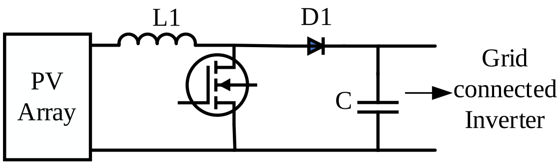


Figure 5. Boost converter

3.4. Second harmonic currents

The effect of second harmonic currents is more prevalent due to the use of two stage converters. This is due to the momentary power output will oscillates at double the frequency of output voltage. This second harmonic current will also be injected back into DC converter further to DC input [19], [20]-[22]. One of the descent ways of reducing the second harmonic current is to increase the DC capacitor. In this paper is the problem of second harmonic currents is solved by using high value of capacitance.

4. TRANSFORMERLESS INVERTERS

With the increased research on grid connected converter systems, grid connected inverters using with transformers are replaced by transformerless inverters, as it takes less space, and the efficiency can be increased. There are various inverter topologies that are published in the literature that describes reduction of leakage currents are basic H bridge inverter using bipolar pulse width modulation [23]. Transformerless inverters are broadly categorized as the following: Providing isolation either on DC side or grid side. H5 inverter topology i.e full bridge inverter with added switch provides dc side disconnection to avoid leakage currents. Inverter is highly efficient reliable concept HERIC, inverter that uses two extra switches on ac or grid side switches will be incorporated either dc side or ac side to isolate PV from grid [24] as shown in Figure 6.

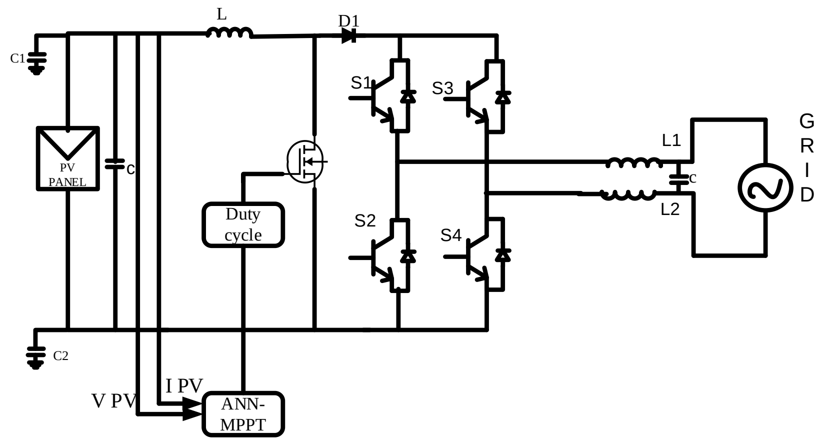


Figure 6. GRID connected Inverter controlled by ANN based MPPT

5. CONTROL TECHNIQUE

The pulse width modulated output from MPPT controller will manipulate the resistance at the input terminals of boost converter to match with the resistance at the output terminals of PV. In addition to the perturb and observe technique driven by Vpv, Ipv used in MPPT controller, artificial neural network generates a pulse-width modulation PWM reference to boost converter using PV voltage and current. The maximum power point for a particular PV curve is calculated by ANN and a reference voltage signal is generated and fed to classic perturb and observe technique [25].

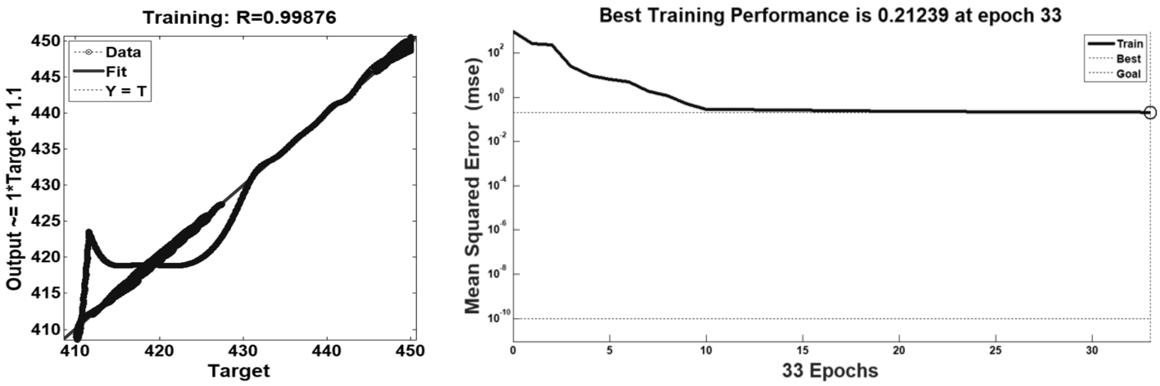
The conventional maximum power track technique is replaced by an artificial neural network whose input are controlled by PV current and voltage. The an algorithm is trained for various parameters like as number of nodes, number of layers. Regression plots are compared with these variations to achieve best tuned model. The model developed and used for the purpose is using three (3) layers, each of 25 nodes is used for the best performance as shown in the Figure 7. Levenberg-Marquardt [7] function is used to train the model. The model with Levenberg-Marquardt implementation is compared with gradient descent with momentum & adaptive LR indicating that the mean square error is observed to be minimum using Levenberg-Marquardt training function. MATLAB Simulink windows for various parameters can be observed in Figure 7. Regression plots for models tuned can indicate that the model with three layers and 25 nodes with each layer shows good performance of the model during training. Mean square error of 0.212 is found to be minimum out of all trainings [17]-[20].

6. SIMULATION AND RESULTS

Simulation of transformerless inverter using bipolar pulse width modulation and unipolar pulse width modulation is used to develop grid connected PV system. The following parameters shown in Table 1 are maintained for simulation. Training of the neural network is analyzed using regression plot is shown in Figure 7(a) indicates regression plot indicating regression coefficient is near to unity (b) Performance plot indicates best training performance using mean square error is achieved at epoch =33. The number of layers considered 3 and the number of nodes in each layer are 25 for which model is trained and validated. Figure 8 is indicating radiance varying in range of 500-1000 Watts/m^2 at the respective intervals, DC link voltage is proportionally increased as shown in Figure 9. The PV voltage follows the curve of irradiance.

Table 1. Parameters

Parameter	Value
Irradiance	750-1000 Watts/m^2
Temperature	25-45^{0}C
DC link Voltage	450 volts
Grid voltage; Frequency	230V;50Hz
Switching Frequency	3780Hz
Power rating of PV array	3500W
Filter inductance	2.18mH
Filter Capacitor	330uF
Parasitic Capacitance	100 uF



(a) (b)

Figure 7. ANN training performance (a) regression plot and (b) Performance of the ANN training

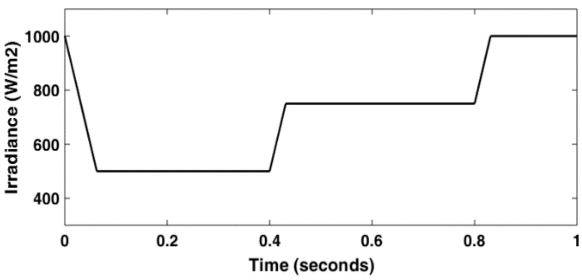


Figure 8. Irradiance

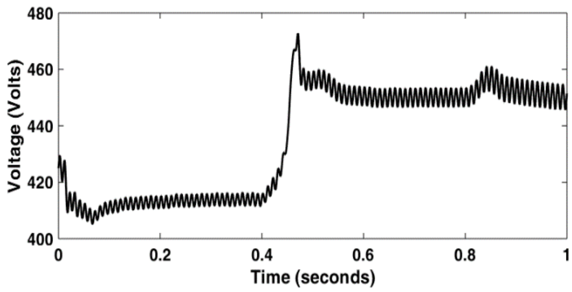


Figure 9. DC link voltage

Power at the DC side is shown in Figure 10 peak power reaches 3500 Watts. Direct axis current i.e only active component of current as shown in Figure 11 is injected into grid by making q axis component zero. Figure 12 indicates grid voltage and the grid current indicated by Figure 13. The grid current is varying with respect to the irradiance level. Figure 14 shows inverter current and is injected to grid as per the requirement. It depends on voltage value and phase angle. Inverter supplying the required current governed by the reference current. Figure 15 indicating the leakage current is found to be zero. The trained neural network model used for the purpose of generating a reference wave for PWM to operate DC-DC converter and the common mode leakage current is zero. Figure 16 represents the solar irradiation data obtained for 8 weeks. The duty cycle value is being achieved with respect to the trained model and the best duty cycle value is achieved and it is shown in Figure 17. Leakage current is found to be zero and for the Irradiation variation shown in the Figure 18. The value of the leakage current in the figure is zoomed in the range of power of 10^{-7} to show that the current is found to be zero.

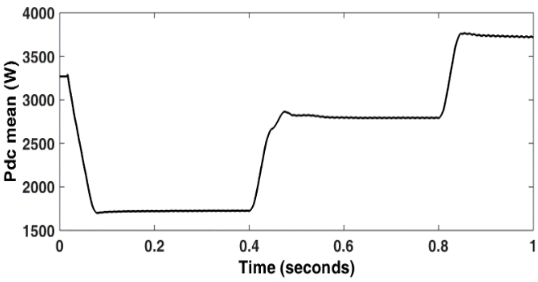


Figure 10. DC mean power

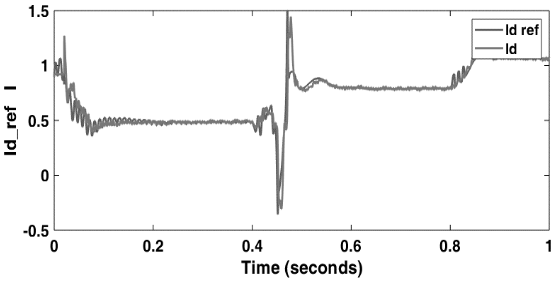


Figure 11. d axis current Id

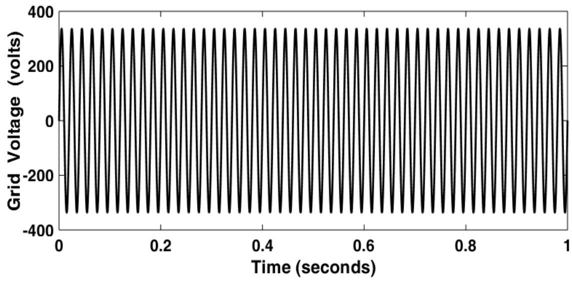


Figure 12. Grid voltage

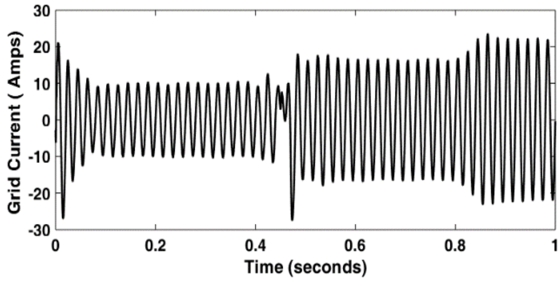


Figure 13. Grid current

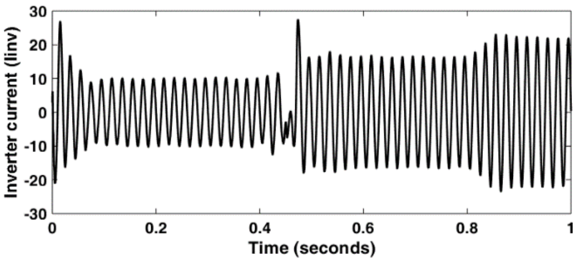


Figure 14. Inverter current

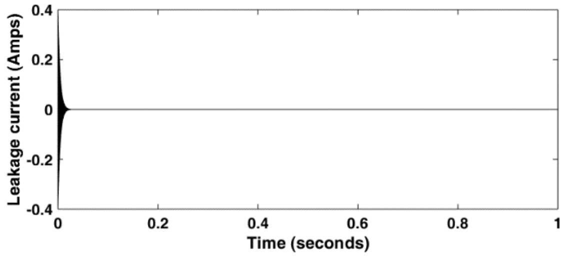


Figure 15. Leakage current

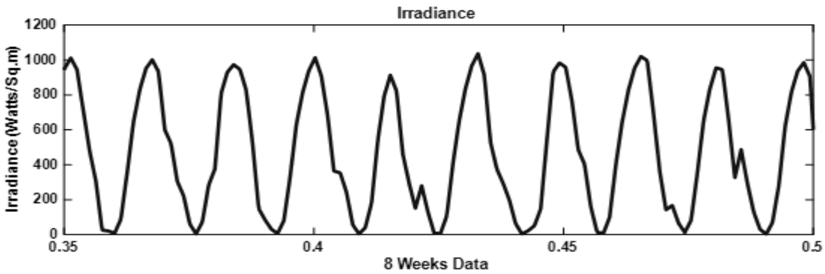


Figure 16. Irradiance variance of 8 weeks data

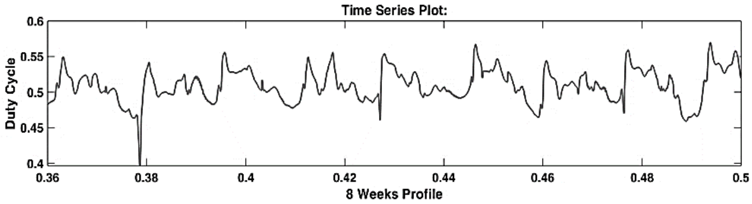


Figure 17. Duty cycle variation for the variation of irradiance

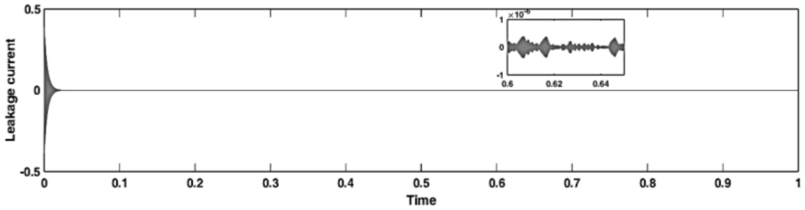


Figure 18. Leakage current

7. CONCLUSION

Grid connected transformerless inverters are more into practice due to their high efficiency, less space requirement. Due to absence of galvanic isolation the transforemerless inverters suffers leakage currents which can be avoided by different inverter topologies and pulse width modulation techniques. Artificial neural network with three layers and 25 nodes each is developed and trained to operate DC-DC converter for grid connected PV system, and the common mode leakage current using bipolar pulse width modulation technique fed to H bridge inverter. Best performance is achieved at epoch 33. The inputs artificial neural network derived from PV voltage, current. Maximum power is tracked based on switching dc converter with respect to the inputs.

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