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Power quality improvement of PV interfaced distribution system

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Abstract

In renewable energy, there is solar energy which is on top of the chart when it comes to the generation of electricity as it is abundantly available in India due to the geographical and climate conditions. These power quality problems and degradation of energy can be avoided by using a control mechanism. It is vital to include a reliable control mechanism in the solar energy conversion system that is connected to the system which will reduce the problem in power quality. This work includes the use of adaptive back propagation which provides an improvement in the degree of precision and accuracy over a longer period of time that the technology is capable of achieving as a consequence. With the help of adaptive back propagation which is being used as the foundation for this procedure, we can achieve accurate results which are possible. This work deals with adaptive back propagation-based control for optimal operation by providing the active power to loads and rest of the remaining power will be provided to the grid. It will help in the mitigation of harmonics in the system, balancing the loads, and improving the power factor of the system. To extract the highest amount of energy possible from the solar photovoltaic array, a process that is known as Incremental-conductance (INC) using the maximum power point tracking (MPPT) is used. The outcomes of computer simulations are used to evaluate how well the suggested system functions, which contributes to the assurance that the system is operating in the most suitable way possible.

Keywords: MPPT, NN, Delta bar, PV, INC, Power Quality

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1. Introduction

Over the last few decades, the growth of world economy and the introduction of cutting-edge technology have both grown more dependence on energy as the fundamental component. This is a major concern as we are getting more dependent and not looking for an alternate source of energy. As per the trend, it is being predicted that in a few years there will be a 1% increase in the world population. This forecast is based on information gathered from a wide variety of different sources. On the other hand, estimates put the rise in the gross domestic product (GDP) will also be increased due to the population increase. In addition to this, if one takes the GDP per capita as a measure of global energy consumption, then it is obvious that there is an increase in the need for various types of energy (Shukla and Singh, 2020). This is because the world population is growing at a faster rate and the need for the global population will also increase at an accelerating pace. Eventually fossil fuels (such as petroleum, natural gas, and coal) will start running out and it will have a gap between the generation and the demands of the customer. The focus that is now being placed on renewable types of energy is becoming ever more vital (Shiva et al, 2017). To have a substantial energy base, it is very necessary to use the full potential of the renewable energy sources which are available to us in abundance through the nature. It is possible to achieve this goal by making full use of potential which renewable sources provides us all the time. According to the study, the contribution of renewable energy sources to the overall demand for energy is around 18% all over the globe. On the other hand, International Energy Agency (IEA) has forecast that in coming years, demand for energy on a global basis would grow by a factor of 1.5 (Shah et al, 2021). This research was produced from an investigation of the historical information that was readily accessible. The support provided by government, in addition to an increase in the number of government subsidies for their straightforward installation & operation, is a key reason for the development in popularity of solar energy (Shah et al, 2017). Utilizing solar energy has numerous advantages including its ability to improve grid power while reducing pollution (Sharma, 2020; Sharma, 2022; Sharma and Bala, 2023). One of the many reasons why solar energy is becoming more popular due to its availability in nature and it is been seen as the solution of power crisis in future. The surge in popularity of solar energy may be somewhat attributed to the benefits described above.

The pace at which India consumes energy on a worldwide scale has dramatically increased as a direct result of this enormous growth in solar power, which is rapidly increasing and will soon become the significant form of renewable energy (Meena et al, 2019). Solar energy is rapidly gaining prominence as one of most important and widespread kinds of renewable-energy. The use of solar cells is closely connected with scientific research and technical advancement which is referred to as photovoltaics, abbreviated to PV for short. Solar energy is the kind of energy that is created when sunlight and UV rays from the sun are converted into electricity by solar cells (Das et al, 2018). Solar photovoltaics is the term used to describe this process. Another synonym for "solar energy" is "photovoltaic energy," and both terms relate to the same thing. The results of this study are going to immediately lead to advances in both the amount of electricity that can be produced by the photovoltaic system as well as the system's overall efficiency. In addition to this, it is of the utmost importance that the load is supplied with a consistent voltage at all times, even though the warmth of the sun and the amount of irradiance it provides may change (Heera and Mini, 2020; Shukl and Singh, 2020).

The generation of power cells for the use of a mixture of photovoltaic arrays that may either be in parallel or series variety of criteria, such as the temperature and the amount of irradiation from the sun, are taken into consideration to determine the approach that will be taken (Singh et al, 2020; Nagasiddalingaiah and Usha, 2022). The efficiency of solar photovoltaic modules is one of its defining characteristics. It is very essential to make sure that the load is provided with the maximum amount of power by operating the system at its peak power point. This will ensure that the load is receiving the most amount of power feasible. The impacts have arisen as a result of changes in both the temperature of the surrounding environment and the amount of solar radiation that is now accessible (Kumar et al, 2019). To improve overall efficiency of system as well as to get a precise measurement of MPP of a photovoltaic array, MPPT methods are designed to automatically locate the point of maximum voltage or maximum current where a photovoltaic array should achieve its optimal level of power production taking into account the influences of irradiation and temperature. This is done to ensure that the array generates the maximum amount of power possible given the conditions. This enables the array to function at the maximum effective level of power output that it is capable (Veramalla et al, 2017). MPP tracking, which is also often referred to as MPPT, has been the subject of a great deal of research and development, and several alternative approaches have been proposed and put into practice for the MPPT system which is an electronic device that can adjust the electrical operating point of the module. It is attached to provide the load with the maximum amount of available power. This is accomplished by tracking the power point at which the load receives the maximum amount of power (Bhargav and Antony, 2016). The term "renewable energy" refers to the generation of electricity from non-depletable sources such as the sun, the wind, rain, tides, and geothermal heat. It is also often used to refer to the energy that may be harvested from living things. Tidal energy is one example of another kind of renewable source of energy (Ambhore and Reddy, 2017). These resources are capable of regenerating at a rapid pace and can do it on their own at sporadic intervals.

In light of this, it is conceivable to see these resources as having a limitless supply. This stands in contrast to the traditional fossil fuels, which are gradually but undoubtedly running out of their supply (Xavier et al, 2016). The severe scarcity of energy that is now being experienced on a worldwide scale has offered a fresh push for the development and growth of energy sources which are renewable and do not contaminate the environment. This is a positive development. The adoption of CDMs, is becoming more widespread among businesses in every region of the world (Kannan et al, 2015). One of the major things working against fossil fuels is the pollution that is linked with the combustion and burning of fossil fuels, which is one of the main reasons for this to happen. In addition to this, the supplies of fossil fuels throughout the globe are rapidly depleting, which is another one of the forces acting against the use of fossil fuels (Nandagopal and Jasmine, 2018; Das et al, 2022). On the other hand, it is a common knowledge that conventional energy sources are detrimental to the ecosystem in which they are located. It is widely being acknowledged that renewable energy sources are a great deal more environmentally friendly and they will provide energy without the adverse effects of pollution (Singh et al, 2016). Solar power is quickly being recognized as an essential component in the process of settlement of the ever-increasing need for energy on a worldwide scale. This is mainly because solar energy is a renewable resource.

The general cost of using solar electricity has gone down. Because of this, there was a significant decrease in the overall cost of producing solar power. The modelling of a PV array has been made available thanks to the efforts of Villalva et al who have developed a method that is straight forward, fast, and accurate for the installation of a solar photovoltaic array. This information is probably included in their publication. Also, the qualities of the solar photovoltaic array give proof that there is a nonlinear link between the array's voltage and current. This evidence was provided by the array's properties (Alagu and Karpagavalli, 2015). As a result of this, it is necessary to make use of a MPPT technology to extract largest amount of power possible from the solar photovoltaic array. As a consequence of this, it is the technique of choice for this specific application, and it is also suited for deployment in professional and corporate settings due to its adaptability (Pozzebon et al, 2013). Depending on the number of stages that are put into action, solar photovoltaic systems may be classified as a single stage topology or a double stage topology,

On the other hand, single-stage topology has several advantages that distinguish it from double-stage topology and make the latter a less desirable option to go with the end. These advantages consist of a decrease in the overall complexity of the system, and a lower rate of system losses as a direct result of the absence of a boost converter. In addition, the following are some ways that these advantages might be summed up because of the combination of all of these advantages leads to an increase in the use of solar photovoltaic arrays; the option that should be prioritized is the single-stage topology (Bhatkar and Kinge, 2018). It is not possible to supply the grid with energy that is obtained from the PV array in a method that is direct. As a result, a power converter such as a VSC is required for the process of converting DC to AC. The combination of a solar photovoltaic array and a voltage source converter (VSC) at point of intersection with utility grid is something that can be used in both grid independent and grid connected power generation systems.

For the optimal operation of grid interfaced solar photovoltaic (PV) system, a neural network-based adaptive back propagation algorithm is presented in this study. The solar PV array supplies maximum power by utilising the proposed technique based maximum power point tracking to the grid and the load. The keypoints of this article are as follows:

- To implement on MATLAB Simulink Solar PV Interfaced Distribution System using Deltabar NN control.
- To implement on MATLAB Simulink Solar PV Interfaced Distribution System using Adaptive Back-propagation.
- To compare both algorithms on basis of output graphs.

2. System Configuration

Fig.1 shows are presentation of the system in its configured state. It is made up of a PV array, and it is applied in the conventional testing environment. In addition, MPPT which is themed on the INC approach used to extract greatest amount of power from solar photovoltaic array which is being utilized. Interfacing a single stage photovoltaic energy conversion system with grid linked system & non-linear loads at point of intersection requires the employment of a voltage source converter at POI.

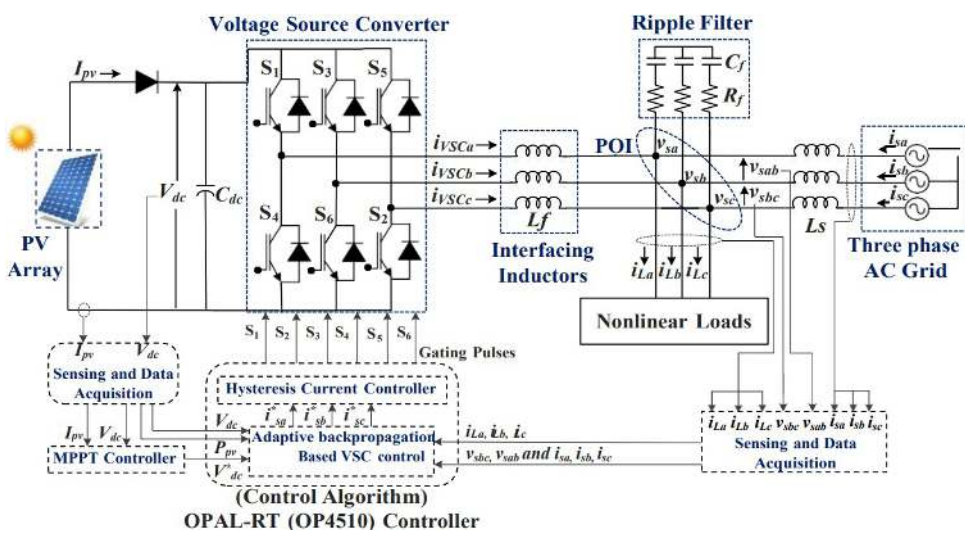

Fig 1. Proposed System Configuration

To reduce or nullify the impact of the current-harmonics that are already a part of the system which is being suggested, it is interfaced via an inductor (L_f). Here a ripple\filter is used which made up of R_f & C_f which is coupled with shunt at POI to reduce switching-ripples is being installed at this point. VSC is made up with switches that are based on IGBT. These switches are numbered S1 through S6, and switching-pulses were determined by generate reference-currents through effective implementation of NN control algorithm. An accurate estimate of the active-power component of the grid-current may be accomplished with assistance of NN control. Following that, put to use in the process of generating switching-pulse's for VSC In light of this, the implementation of an adaptive control algorithm is an absolute need if one wants to improve the performance of the VSC.

4. Proposed Algorithm

Adaptive back-propagation control method as presented in the Fig.2. For the estimate of reference-grid currents which is carried out by control-technique through proper-switching of VSC hence, suggested system does not make use of harmonics.

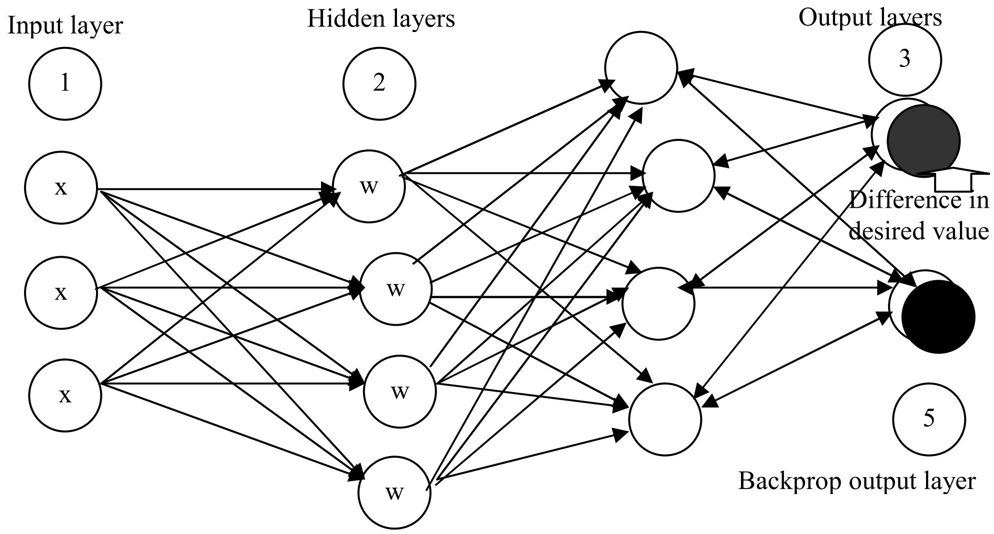

Fig 2. Adaptive Back Propagation

The detailed control structure consists of the following elements:
(a) an incremental-conductance-based MPPT controller PV array; (b) a calculation of the load's active power current component; (c) the application of an adaptive backpropagation learning technique; and (d) an evaluation of the active power components of the grid current. The following section deconstructs these elements in more detail:

A. Utilizing Incremental-Conductance MPPT for Solar PV Array

The system implements the MPPT technique based on incremental conductance INC method at a specific amount of insolation. The INC algorithm is used to determine the real operating point because it stops perturbing once the MPPT has been reached. Due to an INC technique's strong steady state performance, simple implementation, quick dynamic responses, and high convergence rate. The following equations control how the INC based MPPT functions.

$$\frac{dP_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}}.\frac{dP_{pv}}{dV_{pv}} = 0, \text{therefore } V_{MPPnew} = V_{MPPold} \quad (1)$$

$$\frac{dP_{pv}}{dV_{pv}} > -\frac{I_{pv}}{V_{pv}},\frac{dP_{pv}}{dV_{pv}} > 0, \text{therefore } V_{MPPnew} = V_{MPPold} + \Delta V_{MPP} \quad (2)$$

$$\frac{dP_{pv}}{dV_{pv}} < -\frac{I_{pv}}{V_{pv}},\frac{dP_{pv}}{dV_{pv}} < 0, \text{therefore } V_{MPPnew} = V_{MPPold} - \Delta V_{MPP} \quad (3)$$

Where exactly do the current and previous references DC-link voltages are represented by the symbols V_{MPP} (new) and V_{MPP} (Pold), and the previous sample values are applied to further iterations. The results of these iterations are saved as V_{pv} and I_{pv}.

B. Active Component of Load Current Calculation

The active power components of the load (as, bs, and cs) are detected using adaptive back propagation from the polluted load currents and the supervised and feed-forward principle. Here, the three phases of the system's input layer are expressed.

I_{las} ϕ_0 U_{as} U_{bs} U_{cs} i_{La} i_{Lb} i_{Lc}

$[I_{lbs}]=[\phi_0] +$ $[U_{bs}$ U_{cs} $U_{cs}]$ $[i_{Lb}$ i_{Lc} $i_{La}]$

I_{lcs} ϕ_0 U_{cs} U_{cs} i_{Lc} i_{La} i_{Lb}

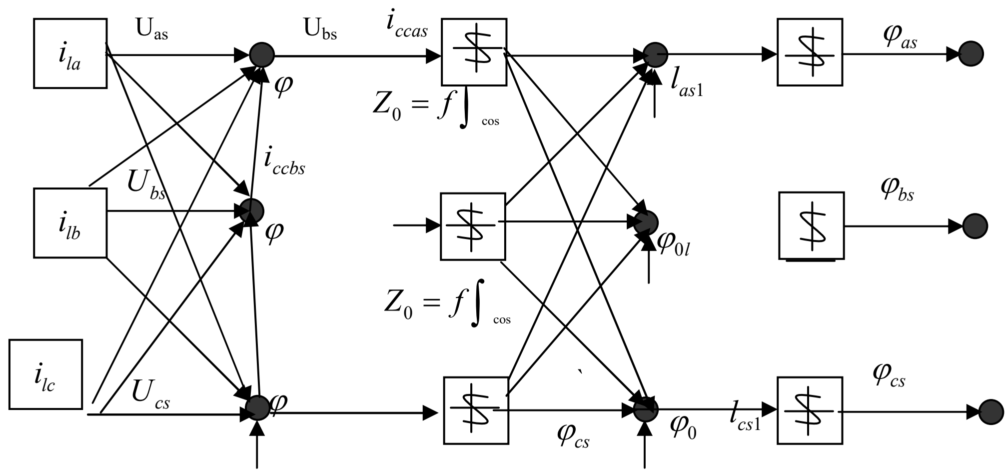

Fig 3. Weight Model of Active load current

Here, o is the bias weight and u_{as}, u_{bs} & u_{cs} are the unit templates in phase with the POI phase voltages. Therefore, the line voltages (v_{sab}, v_{sbc}) are measured and used for calculating in phase templates. These line voltages are utilized to determine the phase voltages; v_{sa}, v_{sb} and v_{sc}.

$$v_{sa} = (2v_{sab} + v_{sbc})/3 \tag{4}$$

$$v_{sb} = (-v_{sab} + vsbc)/3 \tag{5}$$

$$v_{sc} = (-v_{sab} - 2v_{sbc})/3 \tag{6}$$

Here, the updated weights for the three phases and the hidden layer's bias weights, respectively.

C. Adaptive Back-Propagation Learning Technique Implementation

It is a technique for adjusting the weights of a neural network in accordance with the error rate recorded in the previous epoch. In neural networks, the term "backward propagation of errors" is abbreviated to "backpropagation". This method is frequently used to develop artificial neural networks. This method helps to compute the gradient of a loss function for each weight in the network.

Error (b) = Actual Output – Desired Output.

Four steps of backpropagation training algorithm are −

Initializing weights: It involves assigning some modest random values.

Feed-forward (FF): Each concealed unit Z1, Z2 - Zn gets a signal from a unit X & sends it to all exposed units X. Each hidden unit computes the activation function while sending its signal Z1 to each output unit. In order to create response for specified input pattern, output unit computes for activation function.

Backpropagation of errors: Each output unit determines error for that unit by comparing activation Y(k) with goal value T(k). In order to disperse error at output unit Y(k) back to all units in the preceding layer, the factor k (K = 1..., m) is determined depending on error. For each hidden unit Z(j) its factor j (j = 1..., p) is also compared.

Its weights and biases can be updated.

D. Evaluation of Grid Currents, Active-Power Elements, and Switching Pulses Producing VSC

For calculating the DC link voltage error in the system, subtract the reference voltage and senses voltage results as follows,

$$V_{dce} = V^*(m) - V_{dc}(m) \tag{7}$$

The maximum power point tracking of solar PV array is used to determine the reference voltage level (V^*_{dc}). The DC links voltage (V_{dc}) is determined by a voltage sensor. Moreover, the proportional- integral (PI) controller receives the voltage error (V_{dce}) and uses it to calculate the DC loss component.

$$(m) = (m-1) - \{V(m)\} + \{V_{dc}(m) - V_{dce}(m-1)\} \tag{8}$$

K_i and K_p are PI controller gains (proportional gain).Incorporation of a PV power feed forward term (wpv), improves the dynamic behavior of a PV system.

$$w_{pv} = (2)/(3Vt) \tag{9}$$

where w_{pv} and V_t stand for the power and terminal voltage of a PV array, respectively. The grid active power component is calculated using the average active power load current component (L_{sa}), PV feed-forward term (w_{pv}), and loss component (I_{loss}).

4. Simulation Results

With the use of adaptive backpropagation, the following simulation results are observed which have low THD of less than1%.
(a) Response under unbalanced nonlinear-load which is connected with grid from solar-PV system.
In Fig. 4, when nonlinear load is unbalanced, in phase 'a' load is disconnected after 0.5 seconds, & phase 'a' load current is equal to zero. As net power provided to grid improves after a load is removed, an increase in the grid current is observed. At even to fan unbalanced load, grid currents are maintained sinusoidally. Moreover, a change in waveform of VSC current is seen at phase "a," where it turns sinusoidal after load has been removed. With help of PI controller's output, as illustrated in Fig. 6, DC link voltage has kept constant during this imbalance. Due to imbalanced load state in Fig.8, there has been no change in solar insolation PV power and PV current.

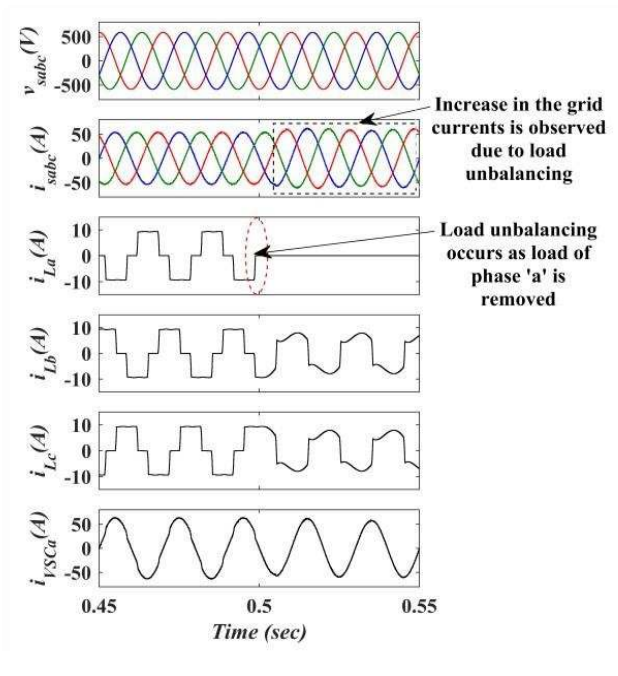

Fig 4. V_{sabc} (V), I_{sabc} (A), Load-Current (A), I_{vsc} (A) for 3-phase

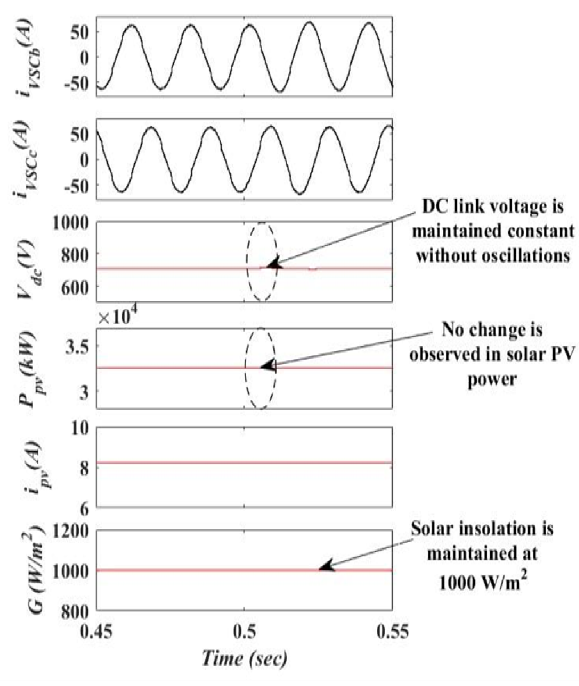

Fig 5. DC link voltage (V), Solar Power (kW), Solar current (A), and Solar irradiance (G)

(b) Response under variable solar irradiance conditions of grid connected at nonlinear load.
As shown in Figs. 6-7, nonlinear loads are coupled at POI with variable solar insolation at POI. Solar insolation levels decrease from 1000 (W/m^2) to 800 (W/m^2) in 1.3 seconds. In Fig.6, grid currents are reduced due to a fall in solar array current, which also causes a decrease in solar array power while maintaining load power consumption constant. As demonstrated in Fig.7, decreases in solar insolation results a subsequent decrease in VSC currents. As shown, PV power and PV current both decrease while the DC link voltage is kept constant using the reference value derived from MPPT & other adjustment in system settings.

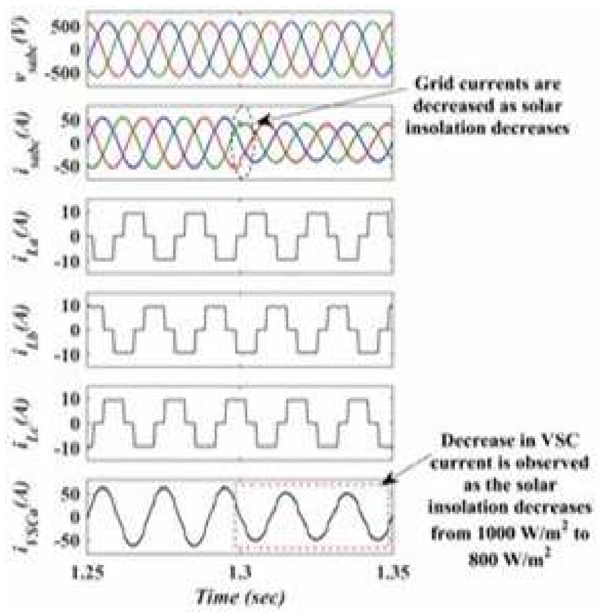

Fig 6. V_{sabc} (V), I_{sabc} (A), Load-Current (A), I_{vsc} (a) for 3-phase

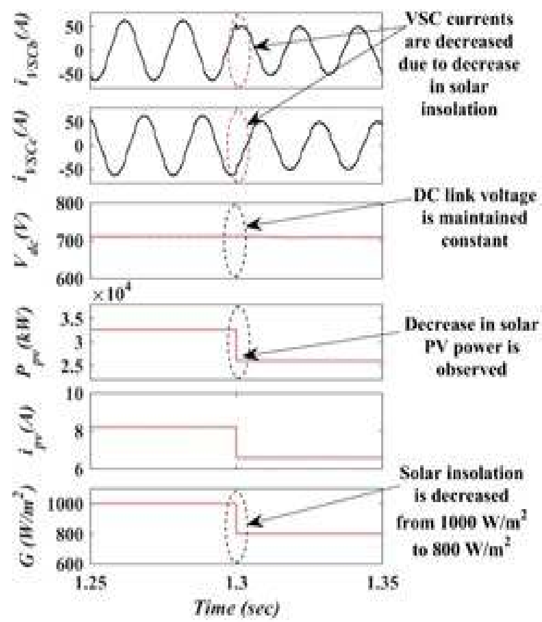

Fig 7. DC link voltage (V), Solar Power (kW), Solar current (A), and Solar irradiance (G)

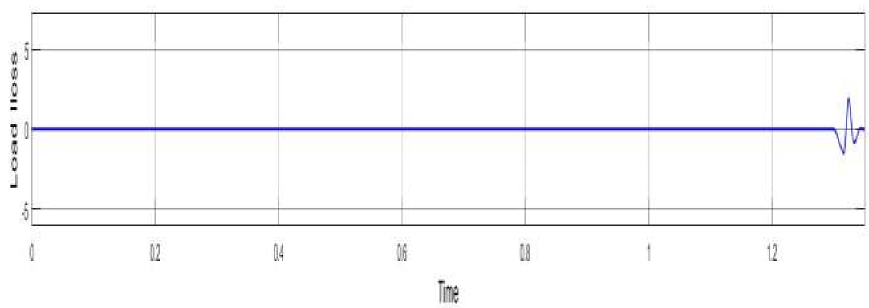

Fig 8. Load Current loss (I_{loss})

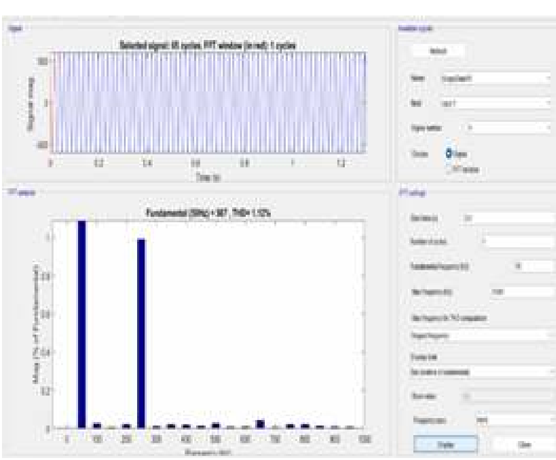

Fig 9. THD of V_{sabc} (NN)

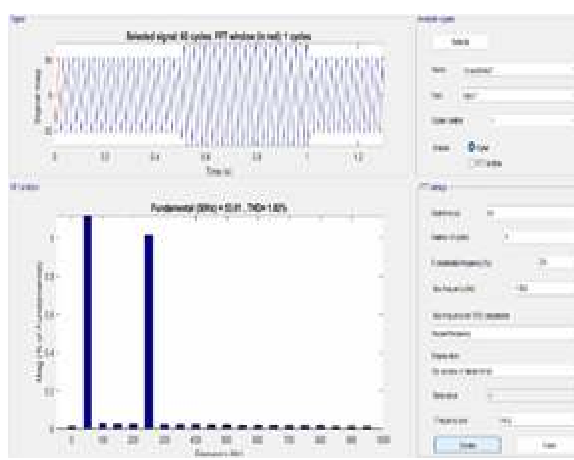

Fig 10. THD of I_{sabc} (NN)

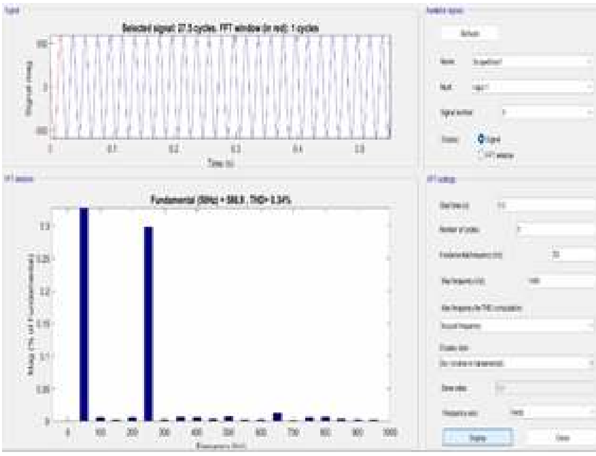

Fig 11.THD of V_{sabc} (A_{bp})

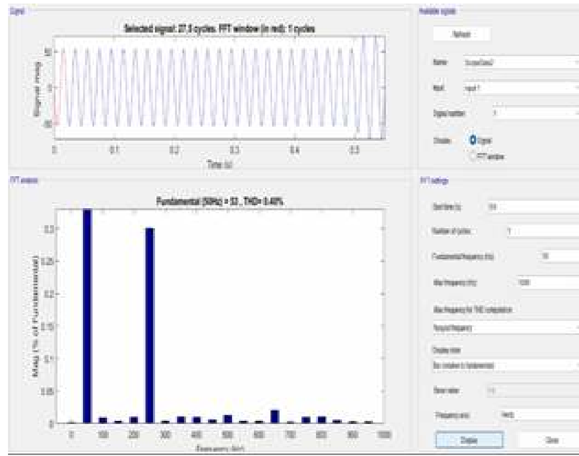

Fig 12.THD of I_{sabc} (a_{bp})

A THD comparison of Delta bar Delta Neural network and Adaptive Backpropagation is being in Table 1. See parameters of the system (Table A).

Table 1. Comparison between Delta bar delta and adaptive backpropagation THD outputs

Description	Delta NN (THD)	Adaptive Backpropagation (THD)
V_{sabc}	1.12	0.34
I_{sabc}	1.02	0.40

5. Conclusion

An adaptive back-propagation control technique for solar systems that are interfaced with 3-phase grid systems is being performed and described in this paper. This strategy makes use of back propagation as its primary method of control. To extract the greatest amount of power which can be generated in PV array, an incremental conductance based MPPT has been put into operation. This has been done to maximize the amount of energy that can be obtained. The control strategy can carry out a broad range of duties, such as balancing the load and eliminating harmonics from the system. One of its other capabilities is the ability to do these tasks. It has been shown that grid-connected photovoltaic systems may function well under nonlinear loads even when subjected to anomalous conditions on the power grid, such as load unbalancing, blocking solar insolation & voltages ag situations. These criteria consist of the following: When there is an unequal distribution of the load, circumstances like these have the potential to occur. The reference currents that are obtained by the control structure are used to generate switching pulses that are used by the VSC. The switching pulses that are used by the VSC are produced as a consequence of this operation. The control method that has been suggested simplifies the system as a whole and is straightforward to apply inside the system itself. This results in a reduction in level of overall complexity. THD of grid current was measured and analysed in line with the standard; the results showed that it had a value that was lower than1%.

Appendix

Table A. Parameters of the system

Symbol	Parameter	Value for Adaptive BP
Vsab	Voltage of three-phase grid	415 V
fs	Frequency of system	50 Hz
Rs	Resistance of grid impedance	0.01 Ω
Ls	Inductance of grid impedance	0.1 mH
Vdcref	Reference DC link voltage	700 V
Cdc	Capacitance of DC link	6.5 mF
RL	Resistance of load	70 Ω
LL	Inductance of load	300 mH

Table A (cont'd). Parameters of the system

Symbol	Parameter	Value for Adaptive BP
Lf	Interfacing inductance	4 mH
Rf	Resistance of ripple filter	5 Ω
Cf	Capacitance of ripple filter	10µF
Kp	Proportional gain	20
KI	Integral gain	2
φo	Bias weight of input layer	0.4
φo 1	Bias weight of hidden layer	0.2
ξ	Momentum	0.6
Ppv	Solar PV power	30 kW
Voc	Open circuit voltage	32.9 V
Isc	Short circuit current	8.21 A
Vmp	MPP voltage	26.3 V
Mp	MPP current	7.61 A
Ts	Processing time	$10e^{-6}$

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