IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 1, August 2022

Delta-Bar-Delta Neural Network (NN) Based Control Approach for Power Quality Improvement of Solar PV Interfaced Distribution System

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Abstract: *A serious concern regarding deterioration in power quality, has emerged with the increasing integration of solar photovoltaic (PV) energy sources to the utility primarily in the scenario of weak distribution grid. Therefore, power quality improvement of the grid tied solar energy conversion system is paramount by implementation of a robust control technique. This work deals with a delta-bar-delta neural network (NN) control for operating optimally by feeding active power to the loads and remaining power to the grid as a function of distribution static compensator (DSTATCOM) capabilities such as mitigating harmonics, balancing of load and improving power factor. The control algorithm provides the ability to adjust weights adaptively in an independent manner and hence it offers alleviation in model complexity predominant during abnormal grid conditions along with reduction in computational time. Moreover, the neural network based control technique offers enhanced accuracy due to the combinational neural structure in the estimation process. In addition, the system performance according to the IEEE-519 standard, has been verified hence, it is proficient in maintaining the power quality. The solar PV array efficient utilization is accomplished through an incremental conductance (INC) based maximum power point tracking (MPPT) technique. For validating the behavior of proposed system, its performance is studied using simulation results. Moreover, a prototype is developed for validation and experimental results corroborate reliable operation under non-ideal grid conditions comprising of wide range of load variations, voltage sag and varying solar insolation conditions.*

Keywords: Incremental conductance (INC) maximum power point tracking (MPPT) algorithm,neural network (NN) etc.

I. INTRODUCTION

The energy has emerged as the backbone of the economic and technological development of the world during the past few years. In accordance with the reports, the population of the world is estimated to grow by 1% in the coming years. However, the gross domestic product (gdp) rise is estimated to be around 3%. Moreover, considering gdp per capita as the global energy demand indicator, the escalating requirement of energy sources, is prevalent [1].

Therefore, with an increase in the energy requirement of the world and the exhaust of fossil fuels (like coal, natural gas and petroleum), the emphasis on renewable energy sources is predominant [2]. In addition, the increasing pollution levels due to an increase in the carbon footprint, is one of the main factors for the inclination towards utilization of renewable energy sources. In order to build a large energy base, there is a need to fully exploit the available renewable energy resources. Currently, the contribution by the renewable energy sources, is around 18% of the world energy demand.

However, according to an estimate by the international energy agency (iea), the overall energy requirement of the world, is expected to increase by 50% in the near future [3]. With the reduction in pollution and an increase in grid parity as the major benefits, solar energy is gaining popularity due to the encouragement given by the government, with an increase in government subsidies for their easy installation and operation [4].

The contribution of solar power in terms of meeting the global energy demand is increasing rapidly.

During recent years, the major factors include a sharp fall in the cost of silicon, which is the primary resource in the solar power production [5] and an upsurge in technical skill thereby leading to a decrease in the overall solar photovoltaic (pv) cost. Villalva et al. [6] have presented the modelling of pv array, where a simple, fast and accurate method is given for realizing the solar pv array.

On the other hand, the solar pv array characteristics depict the nonlinear behaviour between its voltage and current. As a result, it is necessary to extract maximum power from the solar pv array by utilizing a maximum power point tracking (mppt) mechanism in order to ensure that the interfaced power converter is capable of self-adjusting its parameters during run time based on the varying current/voltage levels of the pv source.

The realization of mppt controllers [7] can be based on different methods and algorithms. However, the prevalent techniques include perturb and observe (p&o) [8] and incremental conductance (inc) techniques. Due to the reduced oscillations in inc method while determining the maximum power point (mpp), it is preferred here and it is also suitable for commercial purposes. The utilization of solar photovoltaic systems, can be grouped into single stage or double stage topologies. However, the benefits of single stage topology, include reduction in cost as the required number of component are less, decrease in losses of the system due to absence of a boost converter and reduction in the overall complexity of the system thereby enhancing the utilization of solar pv array, which makes it a preferable choice over double stage topology as presented by wu et al. In [9].

II. LITERATURE SURVEY

In (Oct. 2019), C. Keerthisinghe, A. C. Chapman and G. Verbič, "Energy Management of PV-Storage Systems: Policy Approximations Using Machine Learning," the grid cannot be fed directly with power harnessed from the PV array thus, a power converter like voltage source converter (VSC) is essential for the DC-AC conversion process. Therefore, the combination of solar PV array and VSC at the point of intersection (POI) with utility grid, can be used in standalone and grid-connected systems. In standalone systems, the requirement of additional storage systems (batteries), is due to the nonconformity in time regarding the solar PV output and the energy requirement of the connected loads .

In (2017) V. N. Lal and S. N. Singh, "Control and Performance Analysis of a Single-Stage Utility-Scale Grid-Connected PV System," says the exclusion of battery storage bank is the primary benefit of grid connected solar PV systems, as the grid is utilized for energy storage [11] resulting in the considerable reduction of maintenance cost as well as initial cost. Nowadays, the rooftop PV systems are being encouraged further due to the key factors of reduction in land requirements and a decrease in size of mounting structures.

In (Sep. 2017] B. Singh, M. Kandpal and I. Hussain, "Control of Grid Tied Smart PVDSTATCOM System Using an Adaptive Technique," presents the grid voltage in addition, suffers from power quality problems of under voltage, over voltage and harmonics due to the irregular and nonlinear loads. These power quality issues lead to financial losses, equipment damage and loss of important data. In order to alleviate the power quality problems, VSC is also utilized as a distribution static compensator (DSTATCOM), which performs the function of power factor improvement and harmonics mitigation through an optimal control technique.

In (Apr. 2015] F. Wu, L. Zhang and J. Duan, "A New Two-Phase Stationary-FrameBased Enhanced PLL for Three-Phase Grid Synchronization," says There are numerous control techniques, which exist in the literature involving phase locked loops (PLLs) namely quadrature PLL (QPLL), enhanced PLL (EPLL) [15], modified EPLL, dual second order generalized integrator (DSOGI-PLL), fixed frequency PLL (FFPLL) and synchronous reference frame (SRF-PLL).

In (Mar. 2018) Lyden, S.; Haque, M.; Gargoom, A.; Negnevitsky, M. Review of maximum power point tracking approaches suitable for PV systems under partial shading conditions. says thatIn [15], track MP&O for MPPT at four sectors of operation of the solar system under different operating conditions with the help of the four sectors, change the size of the step is to get the maximum capability of the system connected to the grid.

III. MODELLING AND ALGORITHM

Electrical model of solar PV model with Single (one) diode model and Two Diode Model ofSolar PV model is shown in Figure 2.1 a) and b) respectively. Basic difference between thetwo models is that, realization of the model becomes more accurate with two diode model ascompared to one diode model.

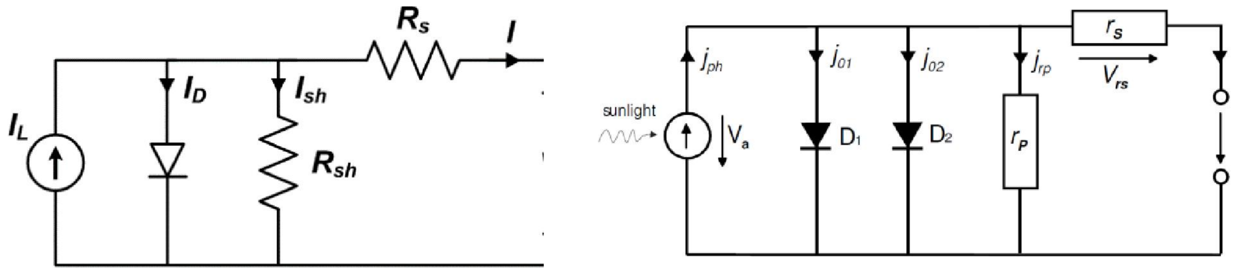

Figure 3.1: a) Single Diode Model of Solar PV System b) Two Diode Model of Solar PV Model

3.1 Current Source

Current source (Io) is proportional to the amount of sun irradiances, temperature and band of the material which is considered for preparation of solar cell. As most of the solar cell are prepared from Silicion substrate, hence band gaps can be treated as a constant for mathematical modelling of the solar cell. With reference to equation 1.2, it is clear that with increasing in the environmental temperature band gap of the material decreases. Decrease in the band gap, increases the amount of photos generated current. Photo generated current is given by ,

$$i_0 = \left(i_{0,STC} + k_T\cdot(T_0 - T_{0,cell})\right)\cdot\frac{P_0}{P_{0,STC}}$$

Here i0 and i0,STC represents Short Circuit Current at the operating point and at standard temperature condition. KT represents the temperature coefficient for short circuit current. T0 and T0,Cell represents the actual temperature of solar cell and temperature at the STC. P0 and P0,STC represents the solar irradiance fall on a particular area and the irradiance at standard

temperature condition, generally measured in W/m2. Solar irradiance at STC is generally 1000W/m2. If the solar PV module is temperature sensitive, then rating is generally written as WP.

3.2 Diode

Diode present in the Figure-2.5 represents the internal junction of the solar cell or the band gap which opposes the flow of electron in the opposite to the direction of flow of current. Diode current id can be written as,

$$i_d = i_{rs}\cdot\left(\exp\left(\frac{q\cdot u_d}{k.n.T_0}\right)-1\right)$$

Here irs represents the reverse saturation current representing the dark current of the solar PV cell. n represents the diode quality factor generally varies from 1 to 2. Most of the designer consider n as 1.2 for a better results. Increase in value of the diode quality factors sluggish the performance on the simulation. Reverse saturation current is linearly proportional to temperature; hence reverse saturation current must be taken into account for thermal modelling of solar cell.

$$i_{rs} = i_{rs,STC}\cdot\left(\frac{T_{cell}}{T_{STC}}\right)^3\exp\left(\frac{E_g q}{k.n}\left(\frac{1}{T_{STC}}-\frac{1}{T_{cell}}\right)\right)$$

3.3 Series & Parallel Resistance

As shown in Figure: 2.5 two resistances are connected in the solar cell modelling such asRsh and Rs. Where Rsh represents the shunt resistance and Rs represents the series resistance. These resistances are due to current collecting ducts connected between solar cell and the combination box or the inverter incase directly connected to the grid. Research also reveals that purity of the material and arrangement of solar lattice are the major cause of resistance. Shunt resistance Rsh is generally very high and also has little effect on the solar cell characteristics. Series resistance of solar cell is usually of 14mΩ. This results in, for a cell of 20V open circuit voltage and 4.5Amp short circuit current, power loss occurring in the cell becomes 0.2Watt.

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3.4 Junction Capacitance of Solar PV Cell

Junction formed due to over lapping of two junction i.e. P and N junction forms parasitic capacitance. Capacitance of solar cell is defined as Here ε0, represents the permittivity of free space having dielectric constant of 8.85 X 10-12 F/m and εr, represents the relative permittivity of the solar cell. For silicon based wafer relative permittivity is approximately 11.7.

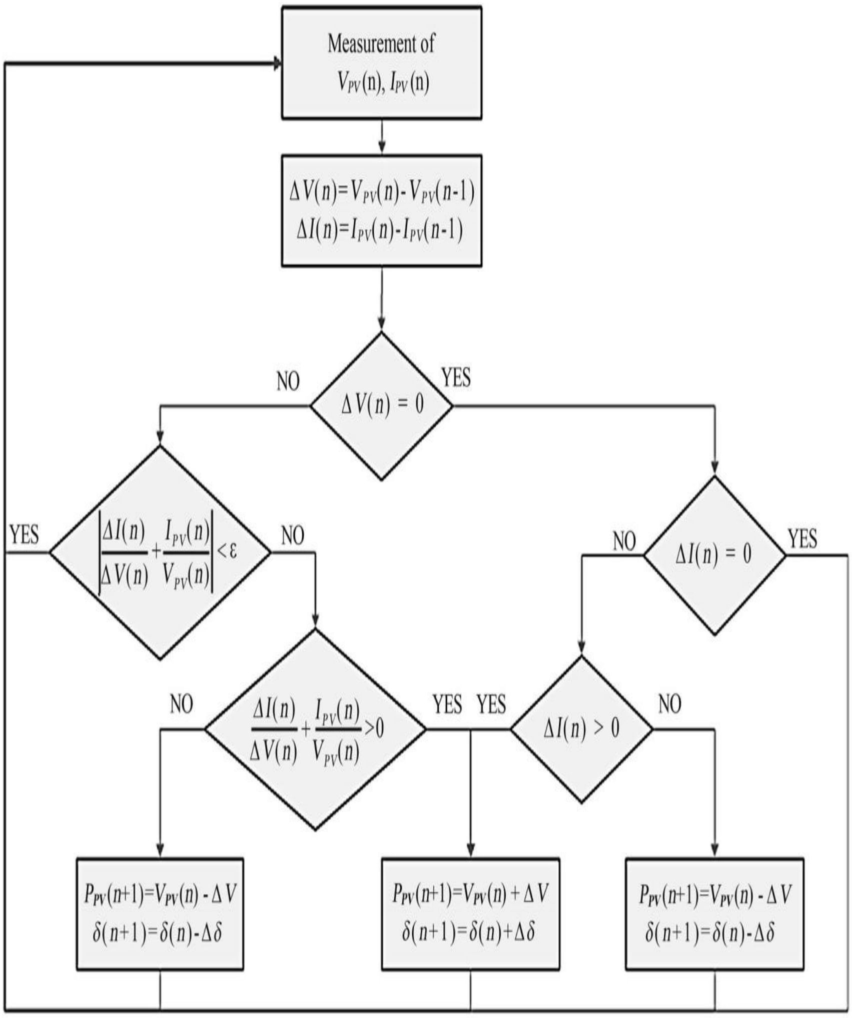


Figure. 3.3. Algorithm for IncrementalConductanceBased MPPT Topology

This algorithm suffers from determination of global maxima under shadow or partial shadow Photovoltaic Solar cell and its characteristics was introduced in this chapter with little history about the evolution and present day scenario of global solar PV penetration. Research concludes that among the different types of PV module, Multi-crystalline is the best one ascompared to other PV module technology in terms of performance and cost. Modes of operation of PV cell was also discussed.

3.5 Delta-Bar-Delta Neural Network (Nn) Based Control Approach

The grid tied solar PV system is implemented using a control structure. The maximum power point is determined through the use of an incremental conductance (INC) method in order to improve the efficiency of the solar PV array. The extraction of fundamental load active power component is achieved through the usage of a delta-bar delta NN control algorithm as depicted in,

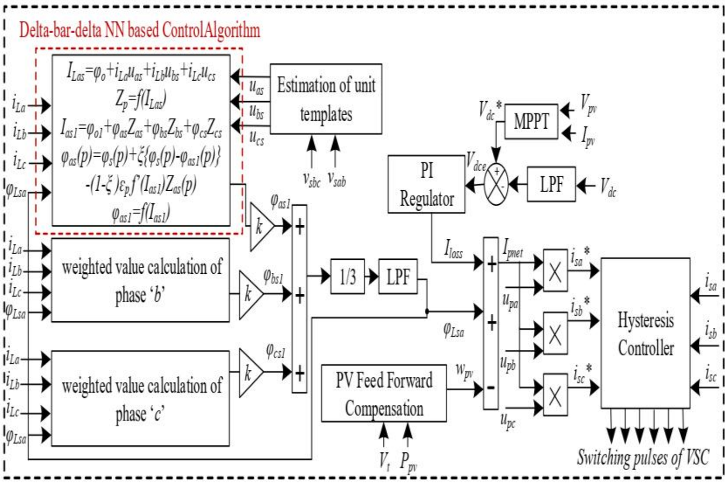
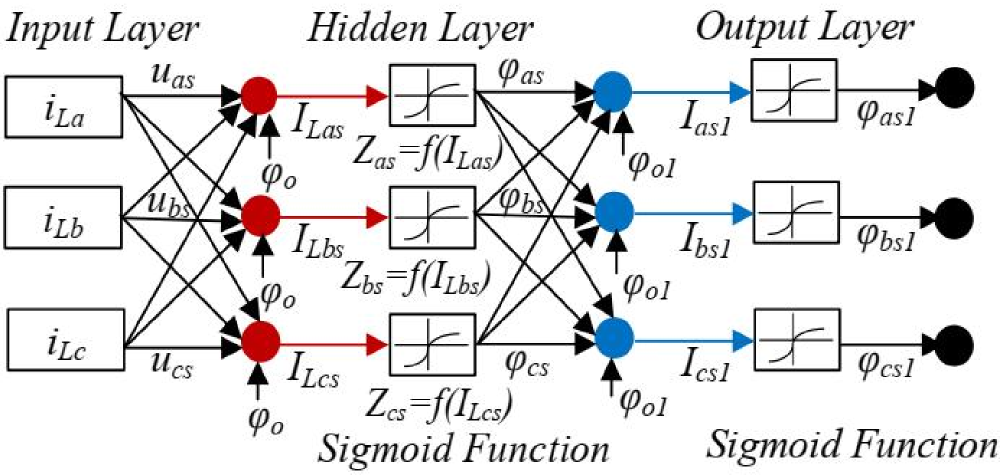


Fig. 3.4 Block diagram of Delta-Bar-Delta NN based control structure

Fig. 3.2 The estimation of reference grid currents, is performed by the control approach through appropriate switching of VSC, and therefore, the harmonics are eliminated in the proposed system.

The detailed control structure is composed of (a) MPPT controller of a solar PV array utilizing an incremental conductance technique, (b) calculation of load active power current component, (c) implementation of delta-bar-delta learning technique, (d) assessment of grid currents active power components and generating switching pulses of VSC.



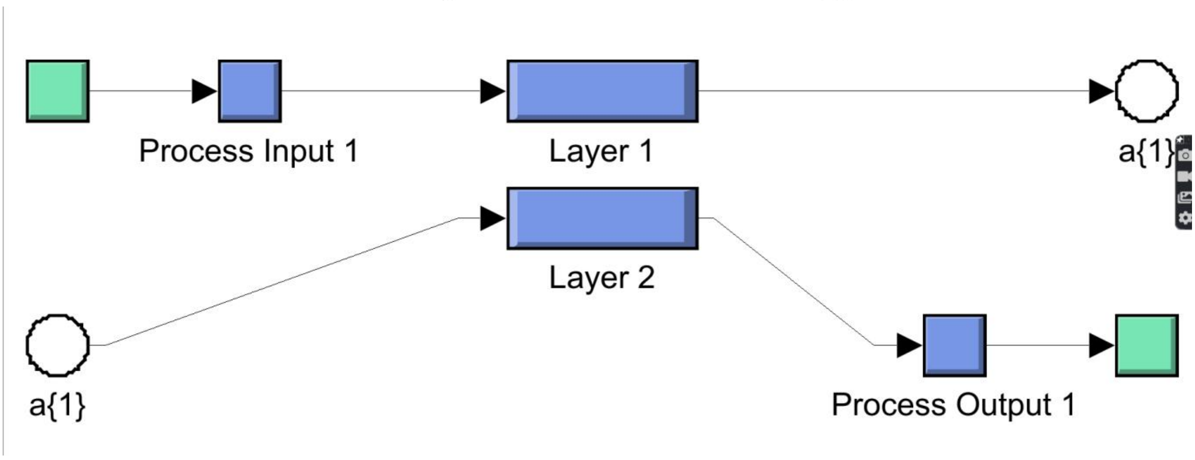


Fig. 3.5 Proposed model of Delta-Bar-Delta NN based extraction of weighted fundamental load active power component

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IV. RESULT ANALYSIS

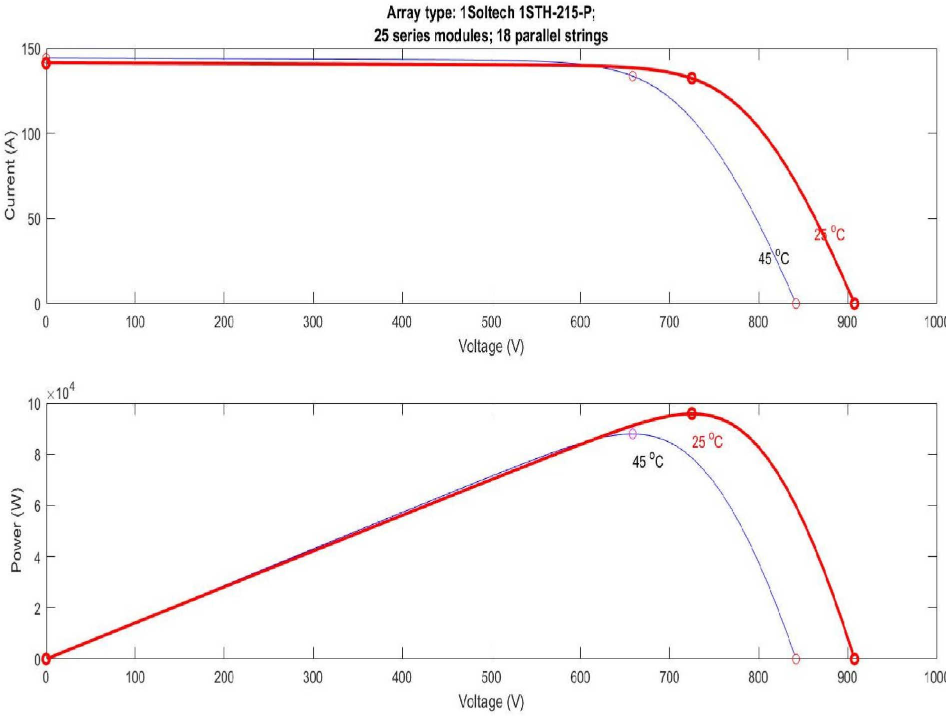

Fig. 4.1 Current (Amp) V/S Voltage (V) and Power (W)V/S Voltage (V) across the Pv Panel

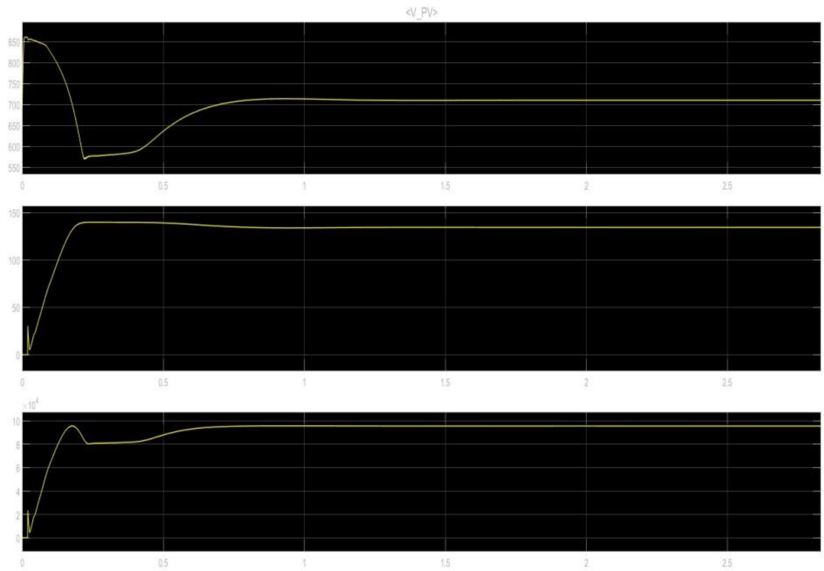

Fig. 4.2 Current (Amp) , Voltage (V) and Power (W) across the Pv Panel.

By opening one of the load lines (phase 'a'), the load disturbance condition is emulated, which emulates unbalanced load and causes reduction in the effective load. In Figs. 5 (a-c), the phase 'a' load is disconnected at 0.5s in case of nonlinear load unbalanced condition. Therefore, as shown in fig. 4.7 the load current of phase 'a' is equal to zero. After load removal condition, an increase in the grid currents (isabc) is observed as the net power being fed to the grid increases. However, the grid currents are maintained sinusoidal in case of load unbalancing.

Moreover, in 'a' phase vsc current (ivsca), a change in the wave-shape can be observed, where it becomes sinusoidal as vsc need not feed any harmonics current in phase 'a' after load removal. The dc link voltage is maintained constant during this unbalance, with the use of output of pi controller as shown in fig. 4.8 no change is observed in pv power, pv current and solar insolation due to unbalanced load condition. In the waveform of the extracted active power component of load current (φas1) is depicted and the dynamics in uas remains unchanged. However, the loss component (iloss) shows a slight change during the unbalanced load condition. The reference grid currents obtained are sinusoidal in nature and for 'a' phase an increase in the grid and reference currents, is observed, due to a decrease in the load currents.

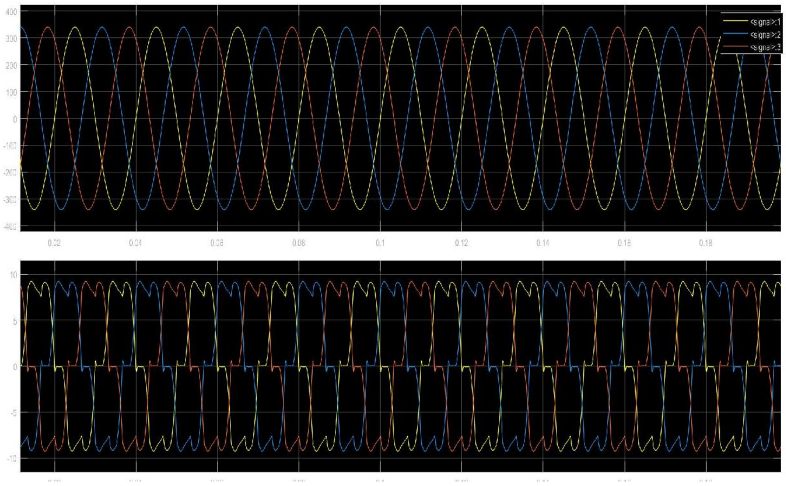

Fig. 4.3 Response under variable solar condition of grid connected solar PV system at nonlinear load.

4.1 Behavior at Variable Solar Insolation and Nonlinear Load

The nonlinear loads are connected at POI, as presented in Figs. 6 (a-c), under variable solar insolation. At 1.3s, the change in solar insolation level is observed from 1000 W/m2 to 800 W/m2. A decrease in solar array current can be observed, therefore, the solar array power is reduced while the load power consumption remains same and hence, the grid currents (isabc) are decreased that decreasing solar insolation, leads to a subsequent reduction in VSC currents (iVSCa, iVSCb, iVSCc). In accordance with the reference value obtained from the MPPT, the DC link voltage is maintained constant.

With a decrease in solar insolation, the solar PV power (Ppv), solar PV current (Ipv) are decreased. the internal control signals are observed where the load current active power components do not experience any change during changing solar insolation condition. The in-phase unit template (uas) is maintained sinusoidal. A slight change is observed in the loss component (Iloss). Moreover, the reference grid current of 'a' phase (isa*) is observed to decrease in magnitude during the decrease in solar insolation. Similarly, the reference currents of remaining phases are decreased due to the decreasing solar insolation condition. The decrease in the grid current of phase 'a', has also been shown in fig 4.4

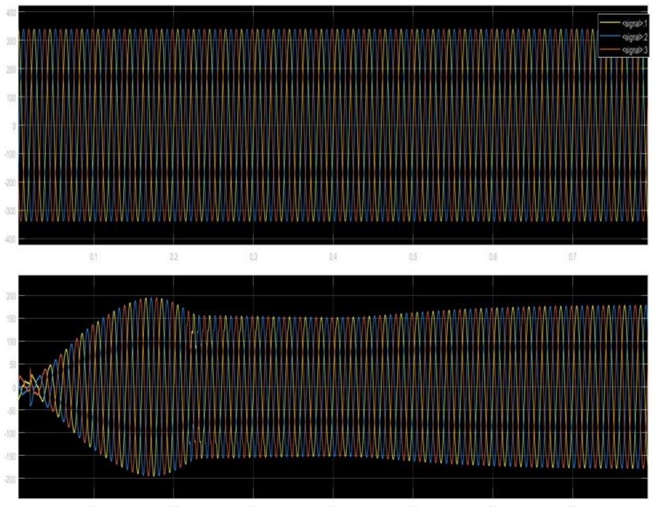

Fig.4.4 Response under unbalanced nonlinear load of grid connected solar PV system.

The decrease in solar insolation from 1000 W/m2 to 800 W/m2 is presented by waveforms of There is no change observed in grid voltage (vsab), terminal voltage (Vt) due to the changing solar insolation conditions. The reference grid currents are reduced in magnitude as presented which are generated by the control approach. In addition, shows a decrease in magnitude of the grid currents due to the decrease in insolation and a reduction in w pv and Ipv is also observed. the internal signals are observed with the decrease in solar insolation. Vdc is maintainedalmost constant by using a PI controller for satisfactory performance. In a decrease in VSC (iVSCa, iVSCb, iVSCc) currents, is presented due to decrease in solar irradiation.

V. CONCLUSION

A simple framework was proposed to balance the demand-supply equation for PV systems designed for peak-load. The framework comprises of predictive models for solar energy and load and real-time controllers. The predictive models were designed using the nonlinear autoregressive neural network with exogenous input (NARX) including time and weather parameters. OPPT controllers were designed using a modified Perturb and Observed algorithm and Fuzzy Logic to control the power flow between SCA and the load. Simulation results showed that the controller results in realistic source-load balance. With the designed P&O OPPT controller, tracking is more reliable than the fuzzy logic controller.

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