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Power Conditioning NN Training Analysis of SVPWM Inverter PV System

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Abstract: **Solar energy is the most abundant and cleanest renewable energy source available in the world. The main objective of the designing of combined control for DC-DC and DC-AC converter algorithm to make the solar system suitable in operation and efficient performance. At last, the system has to be integrated with the utility grid system in order to make it available for driving different types of loads. In this work performance of the neural controller is studied for typical vector control conditions and compared with conventional control methods of the inverter. The work describes how programming methods are employed to train the neural network through a back propagation through time algorithm and then it will be followed by space vector control. The PV system was finally integrated with the power grid. The analysis was carried out for different loads so as to study the effect of power quality on the system.**

Keywords*:* PV system, MPPT, MPP, DC, AC.

I. INTRODUCTION

Solar energy is the most abundant and the cleanest renewable energy source available in the world, technically ready to use for a variety of applications, such as the generation of electricity for residential, commercial, or industrial consumption. It has become an essential part of modern energy systems due to the reduction in the photovoltaic (PV) module costs and the evolution of the classic power converter from the point of view of efficiency, reliability, and costs. Power electronics technology has become an important component in distributed generation (DG) and in facilitating the incorporation of renewable energy sources into the grid.

Photovoltaic converters are widely used to convert the DC voltage generated by the PV array to AC voltage. Two-stage power conversion is currently the most common approach to cope with the DC voltage range produced by the PV panel. This configuration consists of a DC-DC power converter, which achieves maximum power point tracking (MPPT) in combination with maximum power point (MPP) algorithms and a DC-AC power converter stage to supply power to the grid or the grid and local loads. Well-known control approaches such as Perturb and Observe (P&O), Incremental Conductance (INC), Constant Voltage (CV) algorithms, and improved versions of them have been developed to track the MPP operation.

Multiple-stage power conversion systems decrease the overall energy efficiency and reliability of the PV installation besides increasing the cost. Therefore, from the point of view of efficiency and reliability, single-stage grid-connected photovoltaic systems, which consist of a PV array and a DC-AC converter with MPPT, have been reported in some papers to control the active power and reactive power using conventional linear control techniques. Most of the studies have been developed for three-phase systems, which are widely utilized in PV systems but, due to the high-scale penetration of low-power single-phase PV systems, in last years some researchers have aimed their studies to single-phase systems not only from the efficiency and reliability point of view but also for grid support. Giving grid support could alleviate the adverse effects that could cause disconnecting the PV system from the grid in case of a grid fault as is required by current grid standards of some countries. In it is stated that in the near future PV systems should become more dynamic with functionalities such as low-voltage ride-through (LVRT) and grid support capability.

II. LITERATURE REVIEW

Yeqin Wang et al. [1] This item offers limited voltage current flow control for grid connected PV systems, whereby the existing robust UDE based current flow control is enhanced to provide AC voltage protection. When designing the limit voltage, the output voltage of the DC / AC converter always remains within the specified range, which prevents the integrator from winding due to the saturation unit if the reactive power reference is incorrectly adjusted. Simulations and experimental results are provided to demonstrate the effectiveness of the proposed strategies.

Beibei Ren et al. [2] This article proposes a new control structure for on-grid photovoltaic (PV) systems where the DC bus voltage is regulated by the DC / DC converter regulator while using the Maximum Power Point Tracking (MPPT) function and flow control. Power supply integrated into the DC / AC converter controller. A PV voltage control should establish the connection between the MPPT function and the power flow control. In this way, the DC / DC converter controller and the DC / AC converter controller are decoupled, which of course provides protection from the DC bus voltage.

Qing-Chang Zhong et al. [3] This article shows that these converters, either on the supply side or on the load side, can all be controlled to behave like virtual synchronous machines (VSMs) and possess the dynamics of synchronous machines, providing a unified interface for smart grid integration. Synchro converter technology and its developments are the focus of this article because the mathematical model of synchronous machines is embedded in the controller of synchro converters to provide close imitation. Power systems are going through a paradigm change from centralized generation to distributed generation and further on to smart grids.

Beibei Ren et al. [4] In this paper, a robust Uncertainty and Disturbance Estimators (UDE) based power flow controller for grid connected inverters is developed to achieve accurate grid power. The UDE method is introduced in the controller design to handle model uncertainties (e.g., output impedance and power angle), coupling effects and external disturbances and variations in both the frequency and the amplitude of the mains voltage). Experimental results are provided to demonstrate the effectiveness of the proposed method for various interference suppression scenarios, low voltage pass-through capability, and low network capability

III. Objective

The below work is aimed at attaining the following key objectives from the modeled system:

- Designing of a renewable energy based solar photovoltaic system in MATLAB/SIMULINK environment for making it efficient in driving residential load
- Designing of a DC to DC boost converter with an appropriate algorithm preferably p and O based switching mode controller such that it will enhance the DC input voltage to the inverter for further conversion to AC voltage waveform.
- Designing of a neural network based learning algorithm for vector selection in inverter control for active power optimization and distortion control in output electrical parameters.
- The designing of combined control for DC-DC and DC-AC converter algorithm to make the solar system suitable in operation and efficient performance. At last the system has to be integrated with the utility grid system in order to make it available for driving different types of loads.

IV. Methodology

The modeling of hybrid DC grid system is done which is capable of feeding the load with either solar or wind resources depending on the availability thus making the system more reliable. The two resources have been connected to the load through a DC bus which is being fed by the either sources. As shown in fig. 1 basic architecture of the system has been modeled to meet the requirements.

Modeling of various parts of the system has been discussed further. The modeled PV system with MPPT technique for its optimum operation,

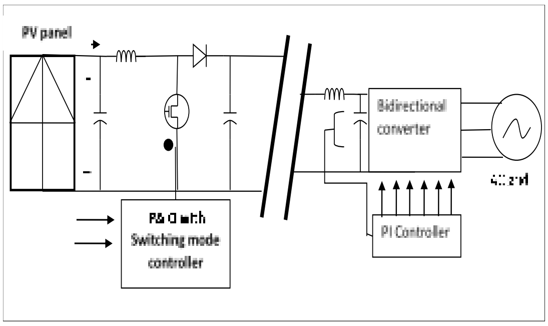

Fig. 1 Basic architecture of a PV system

A. *PV Module Modelling*

PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I. A simple equivalent circuit of PV cell is shown in Fig. 6.

The MPPT algorithm has been employed in order to obtain the operation of solar module at maximum power continuously.

A cell series resistance (Rs) is connected in series with parallel combination of cell photocurrent (I_{ph}),exponential diode (D), and shunt resistance (R_{sh}) , I pv and Vpv are the cells current and voltage respectively. It can be expressed as

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

Where:

I_{ph} - Solar-induced current

I_S - Diode saturation current

q - Electron charge (l.6e^{-l9}C)

K - Boltzmann constant (l.38e^{-23}J/K)
n - Ideality factor (l~2)
T - Temperature ^{0}K

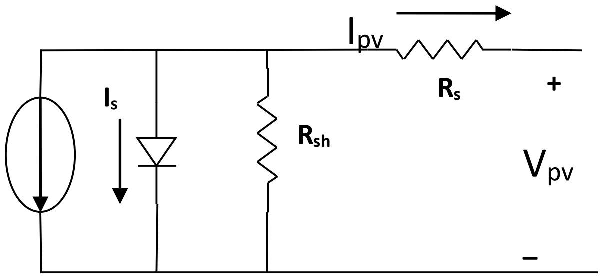

Fig. 2 Equivalent circuit of solar pv cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$$

Where:
I_{SC} Short-circuit current of cell at STC
k_i Cell short-circuit current/temperature coefficient (A/K)
I_r Irradiance in w/m

T_C ,T_r Cell working and reference temperature at STC

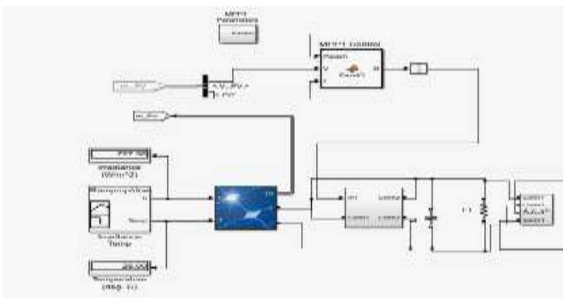

Fig. 3 Modeled solar PV system in MATLAB/SIMULINK

B. Modeling of proposed SVPWM inverter

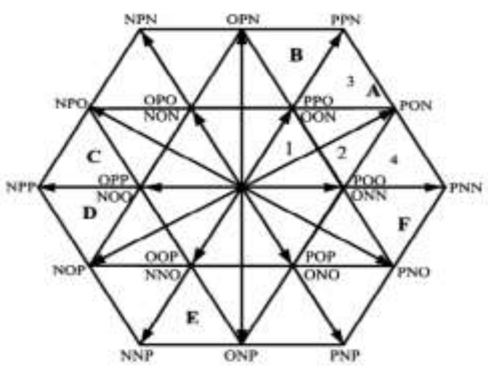

Fig. 4 Space-vector diagram of the three-level converter

Assuming the instantaneous voltage value of three-phase sine wave is respectively:

$U_a = V_m \, Sin(wt)$

$U_b = V_m \, Sin(wt - 2\pi/3)$

$U_c = V_m \, Sin(wt + 2\pi/3)$

The magnitude and angle of the rotating vector can be found as below:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = 2/3 \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix}$$

$$\overrightarrow{V_{ref}} = V_\alpha + jV_\beta = {}^2/_3 \, (U_a + aU_b + a^2 U_c)$$

Where

$$a = e^{j2\pi/3}$$
$$|\overrightarrow{V_{ref}}| = \sqrt{V_\alpha{}^2 + V_\beta{}^2} \quad , \theta = \tan^{-1}(V_\beta / V_\alpha)$$

If θ is between 0° ≤θ< 60°, then Vref will be in Sector A.
If θ is between 60° ≤θ< 120°, then Vref will be in Sector B.
If θ is between 120° ≤θ< 180°, then Vref will be in Sector C.
If θ is between 180° ≤θ< 240°, then Vref will be Sector D.
If θ is between 240° ≤θ< 300°, then Vref will be Sector E.
If θ is between 300° ≤θ< 360°, then Vref will be Sector F.

The main idea of the simplified algorithm is how to achieve the Calculation Flow based only on one sector instead of six as demonstrated in Fig. 6, just by knowing the relationships in Dwell Time calculations and arrangement for switches between the first sector and the others as explained below:

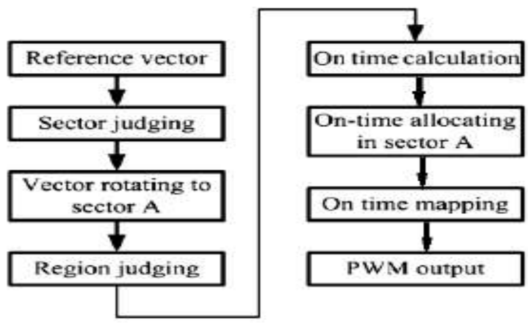

Fig. 5 Calculation flow for the three-level SVPWM Simplified calculation

Suppose reference vector A stays in region 2 of sector A, while reference vector B is obtained by rotating vector A counterclockwise by 60° as shown in Fig.

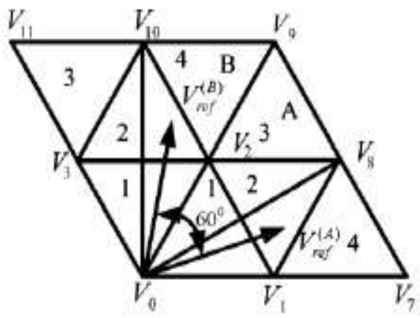

Fig. 6 Two vectors with 60° shifting in the sector A and B.

So the reference vector V_{ref} can be expressed in the following form.

$$V_{ref}^{B} = V_{ref}^{A} * e^{\frac{j\pi}{3}} = 2/3(-U_b - U_c e^{\frac{j2\pi}{3}} - U_a e^{\frac{-j2\pi}{3}})$$

And when the reference vector is in the other sectors, it will be rotated to sector A by$n\pi/3$where (n=1, 2, 3, 4, 5).The corresponding reference vector in other sectors can be constructed as given in Table 1.

Table 1 Relationships Of Voltages Constructing The Reference Vectors In Six Sectors.

Sectors	Phase Voltage A	Phase Voltage B	Phase Voltage C
A	U_a	U_b	U_c
B	$-U_b$	$-U_c$	$-U_a$
C	U_c	U_a	U_b
D	$-U_a$	$-U_b$	$-U_c$
E	U_b	U_c	U_a
F	$-U_c$	$-U_a$	$-U_b$

C. Modeling of proposed boost Converter

DC-DC Boost converter is a fundamental converter in power electronics that can efficiently steps up the input voltage.

The Boost Converter block represents a converter that steps up DC voltage as driven by an attached controller and gate-signal generator. Boost converters are also known as step-up voltage regulators because they increase voltage magnitude.

The Boost Converter block allows you to model an asynchronous converter with one switching device or a synchronous converter with two switching devices like GTO Gate turn-off Thyristor, IGBT, MOSFET and Thyristors.

The classic control techniques, using PI or PID controller, are the most commonly used in the industry, as they are simple to synthesize, easy to implement, and could guarantee good performances in many cases. Nevertheless, for nonlinear system, these techniques have a limited validity (around local operating points) and cannot achieve good performances in the large domain of system operation. Thus designing of efficient yet simple controller can serve the purpose for a better voltage based control. In our work we have designed a

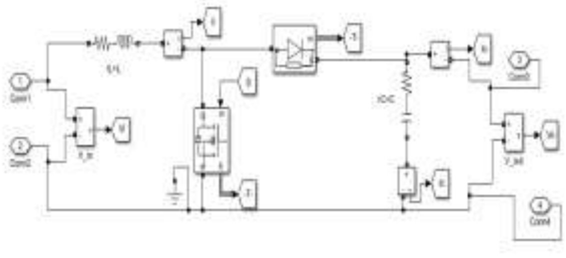

Fig. 7 MATLAB/SIMULINK model of proposed switching mode controlled DC boost converter

V. RESULTS

This study comprises with an analytical and numerical description of proposed algorithm for sentiment analysis of movie review which is simulated to obtain the performance of the proposed algorithm.

In order to evaluate the performance of proposed algorithm scheme, the proposed algorithm is simulated in following configuration:

Pentium Core I5-2430M CPU @ 2.40 GHz

4GB RAM

64-bit Operating System

MATLAB Platform

A. Simulation Environment

MATLAB stands for MATrix LABoratory, which is a programming package exclusively designed for speedy and effortless logical calculations and Input/output. It has factually hundreds of inbuilt functions for a large form of computations and plenty of toolboxes designed for specific analysis disciplines, as well as statistics, optimization, solution of partial differential equations, information analysis.

In this research work MATLAB platform is used to show the implementation or simulation of implemented algorithm performance. Artificial Intelligence system toolboxes are used and some inbuilt functions for generating graphs are used. Simulation results and comparison of the performance of implemented model with some existing ones are calculated by MATLAB.

Pulse Width Modulation (PWM) DC-DC converters have gained a very strong emphasis owing to their various features and their broad applicability. DC-DC converters are evolved to spread to almost every sector including transport, space and avionics, telecommunication, medicine and renewable energy. This is mainly thanks to new power semiconductor devices, new circuit structures and modern control techniques.

In this work we have model a solar photovoltaic system with DC output voltage. This output voltage is fed into a DC to DC boost converter and then is converted into AC voltage waveform via an inverter. The output from the inverter is fed into the Transformer for stepping up and further integrating the renewable energy system with the grid energy source. This

AC voltage waveform is made to drive loads of different capacity.

The discusses the two types of DC to DC boost converter and the respective output waveforms from the system. The proposed PV system is modeled with a boost converter having P&O based switching controller for enhancing DC voltage output from the Solar PV system and thereby enhancing the AC power output also.

CASE 1: System having only P and O based MPPT boost converter and basic PI controlled inverter

CASE 2: Proposed System having P and O with switching mode controller boost converter and Neural Network (NN) modulated Sector learning in Space vector pulse width modulation inverter

The work has been done by providing variable irradiation to the solar module. The temperature input to the solar module is kept to be approximately 25 degree Celsius. The system model is being for the analyst for active and reactive power output along with improvement in DC input voltage to the inverter using that proposed design of DC to DC boost converter having p and O based switching mode controller.

The figure shows the irradiation and temperature input to the solar panels.

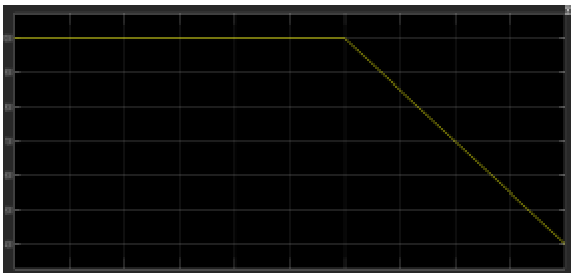

Fig. 8 Variable radiation input to the solar panels

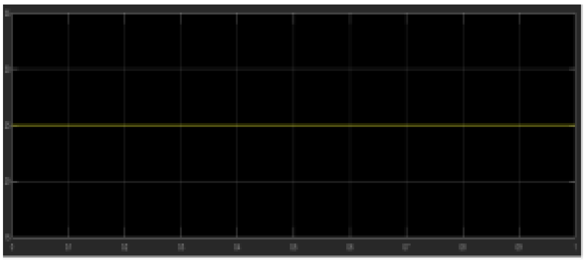

Fig. 9 Temperature input to the solar Panels

B. CASE 1: System having only P and O based MPPT boost converter and basic PI controlled inverter

Solar Energy Grid Integration Systems concept will be key to achieving high penetration of photovoltaic (PV) systems into the utility grid. Advanced, integrated inverter/controllers will be the enabling technology to maximize the benefits of residential and commercial solar energy systems, both to the systems owners and to the utility distribution network as a whole.

The figure shows the system having boost converter with only P&O based control for DC to DC boost converter in solar photovoltaic system. The system is integrated with the grid system for driving residential type of loads. The DC output from the solar panel is fed to the inverter through a DC to DC boost converter.

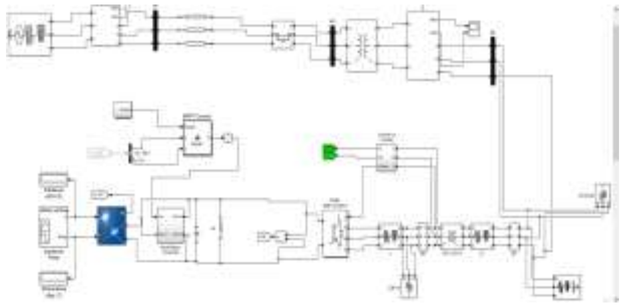

Fig. 10 System without Switch Mode controller

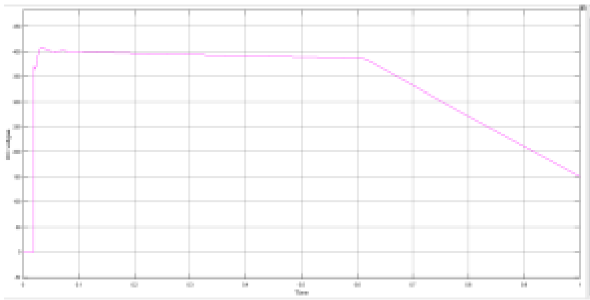

Fig. 11 DC output voltage waveform from the system

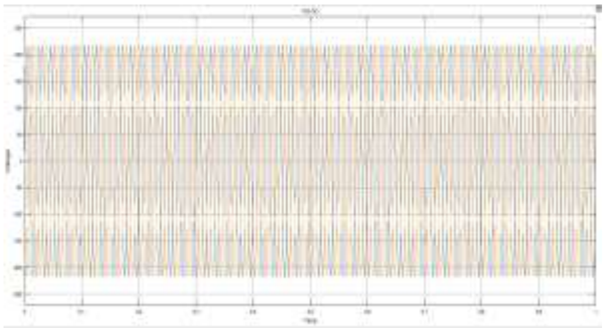

Fig. 12 AC output voltage waveform

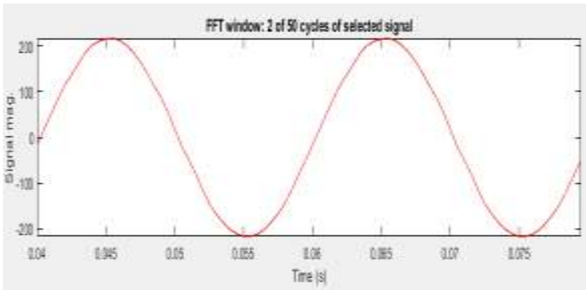

Fig. 13 FFT analysis of voltage output waveform

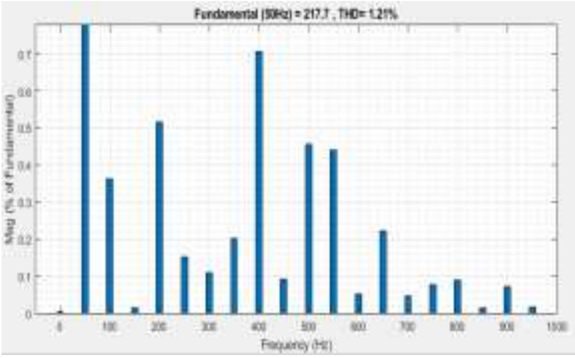

Fig. 14 THD % (1.21%) in voltage output waveform

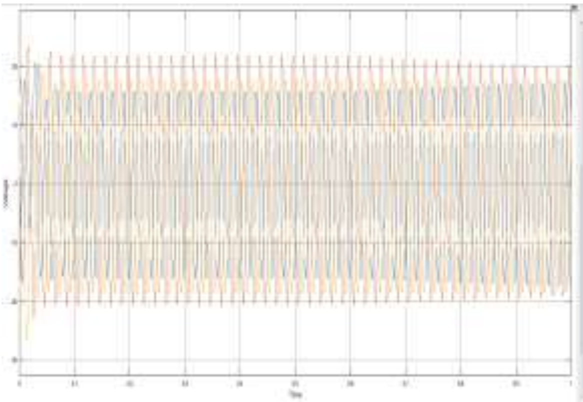

Fig. 15 AC output current waveform

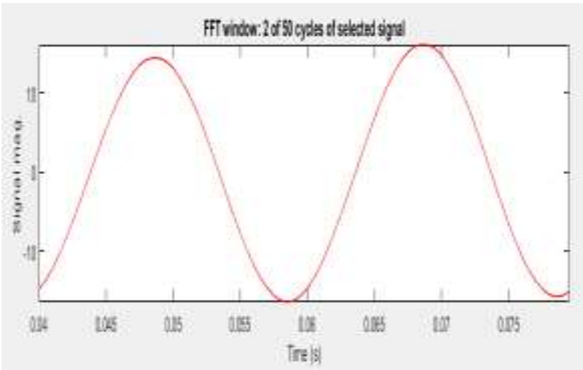

Fig. 16 FFT analysis of current output waveform

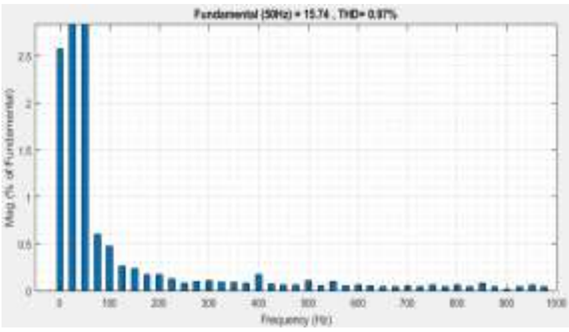

Fig. 17 THD % (0.97%) in current output waveform

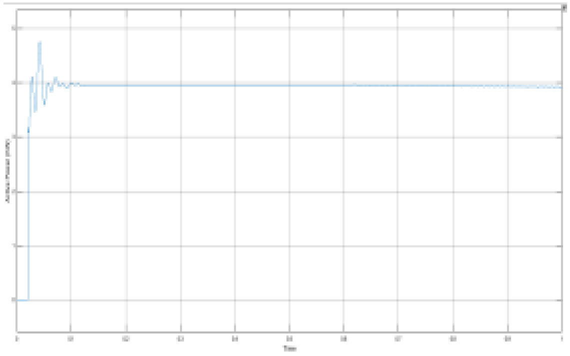

Fig. 18 Active Power output waveform

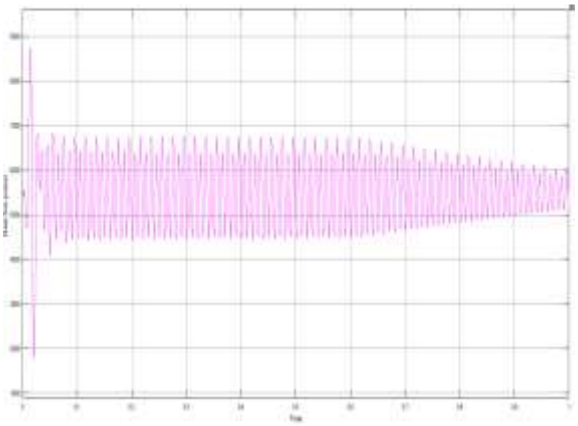

Fig. 19 Reactive Power output waveform

C. CASE 2: Proposed System having P and O with Switching mode controller boost converter and NN modified Sector Controlled on inverter

Adaptive intelligent switching mode control methods are developed for a single-phase photovoltaic (PV) grid-connected system with a boost chopper and a DC-AC inverter which is modeled with space vector pulse width modulation.

The presented controller includes system uncertainties, like capacitor tolerances, measurement small errors, and variable irradiation. So, the performance and robustness of the proposed new P&O based switching mode controller is validate in a real platform in suitable and adverse conditions for two different types of disturbances, measured DC PV voltage variation due to irradiation and thereby altering AC output power.

The switching mode controller is also compared with a conventional DC to DC boost converter with P&O controller only.

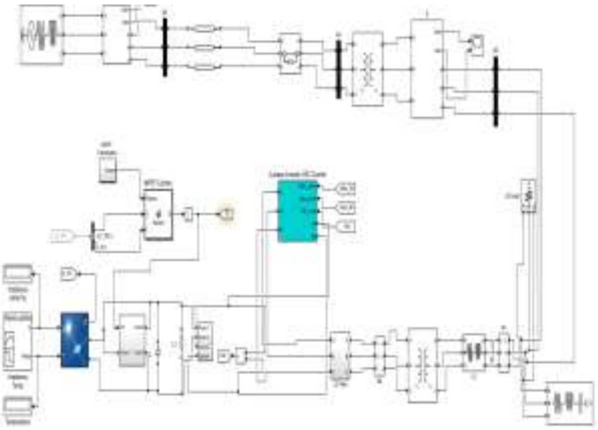

Fig. 20 System with Switch Mode control

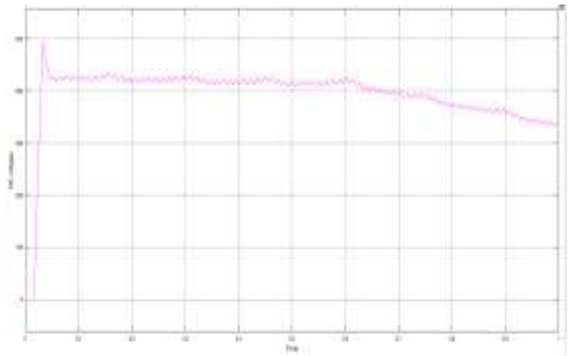

Fig. 21 DC output voltage waveform

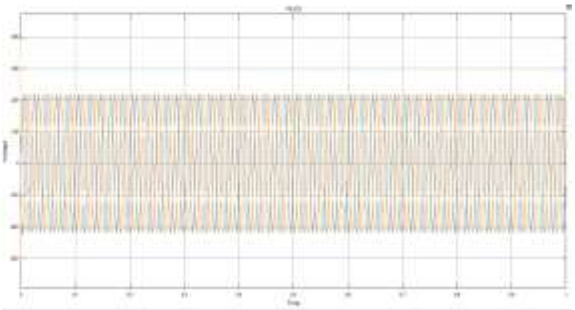

Fig. 22 AC output voltage waveform

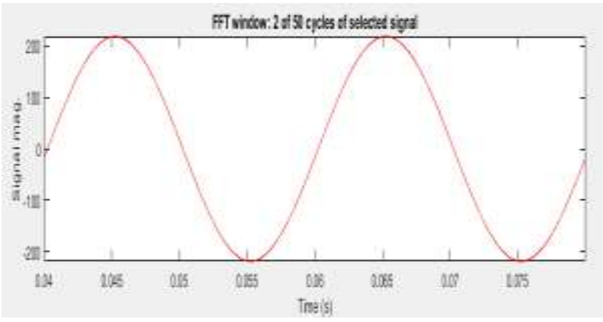

Fig. 23 FFT analysis of voltage output waveform

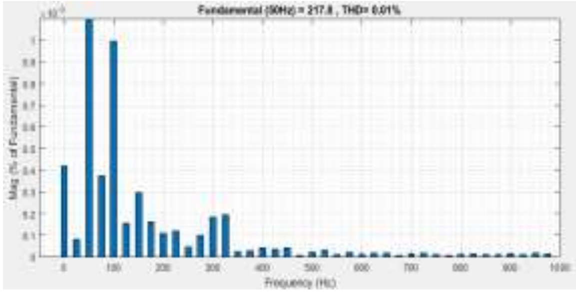

Fig. 24 THD % (0.01%) in voltage output waveform

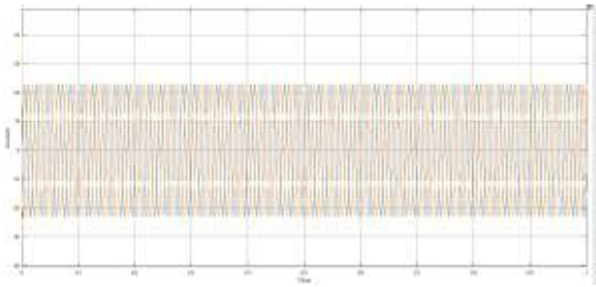

Fig. 25 AC output current waveform

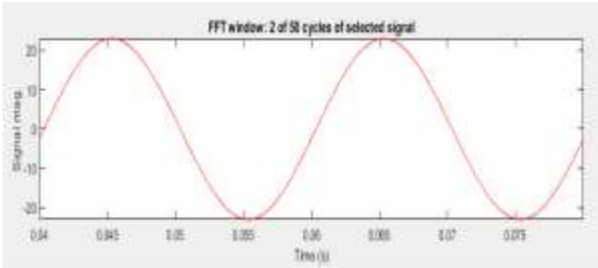

Fig. 26 FFT analysis of current output waveform

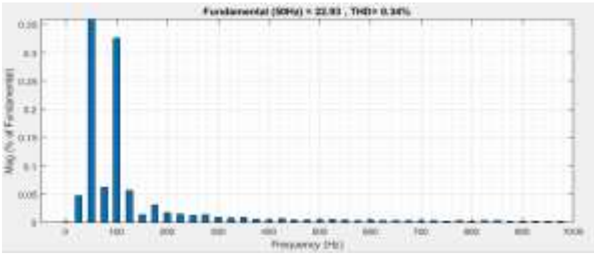

Fig. 27 THD % (0.34%) in current output waveform

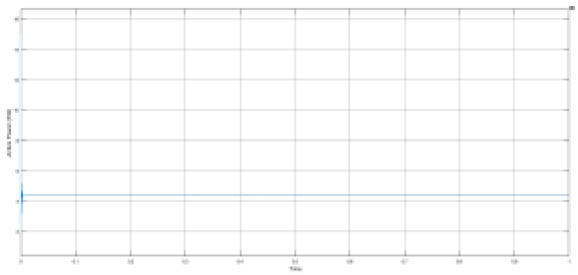

Fig. 28 Active Power output waveform

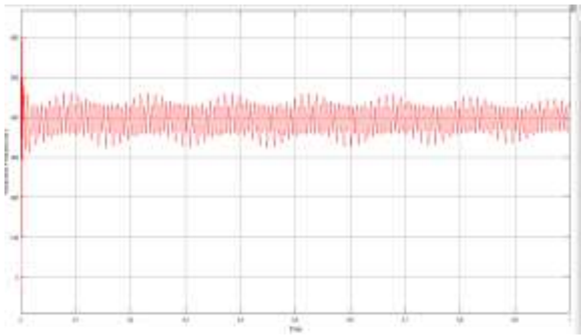

Fig. 29 Reactive Power output waveform

D. Validation

The chapter has analyzed various waveforms on the solar systems in both the two cases. The system active power and reactive power has been compared to find out the system with better control of inverter. The two cases one with inverter having basic PI control and the other one with neural network (NN) based learning sector space vector control. The discussion on the output parameters being studied concludes the efficiency of the system having neural network artificial learning technique.

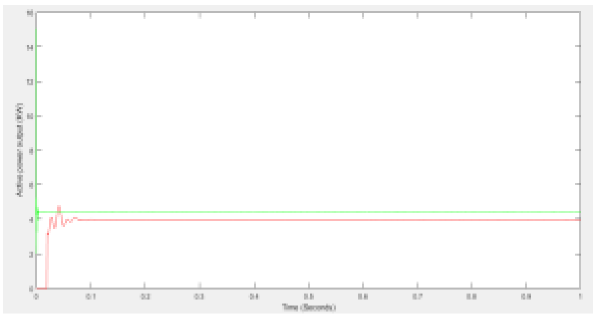

Fig. 30 Comparative analysis of active power outputs

The graph above depicts the comparative values of active power outputs from the two systems. Red graph depicts the power output from the system having simple PI based inverter control and green graph depicts the active power output from the system having neural modified space vector modulation control (NN-VC) of inverter in solar photovoltaic system. It was found that the active power output from the system with neural modified space vector modulation control of inverter is approximately 4 kilowatt and from the system with basic PI control is approximately 4.39 kilowatt. Also it was found that the system with neural control is able to significantly adjust the variation in irradiation input to the solar panel by maintaining the power output constant.

Table 2: comparison of output parameters in the systems

Parameters	System with PI control	System with NN modified sector control
THD in voltage	1.21 %	0.01 %
THD in current	0.97 %	0.34 %
Active power output	3.92 KW	4.39 KW
DC input to inverter	400 volts	425 Volts

The effectiveness of the system with the proposed two controllers can be drawn from the table in terms of AC as well as DC output waveforms from the systems. The Total harmonic distortion levels in the system in voltage as well as current waveforms was reduced to 0.01 % and0.34% respectively

VI. CONCLUSION

The amount of power generated by a solar energy system at a particular site depends on how much of the sun's energy reaches it, and the size of the system itself. The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs. The inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads.

In this work performance of the neural controller is studied for typical vector control conditions and compared with conventional control methods of inverter. The work describes how programming methods are employed to train the neural network through a back propagation through time algorithm and then it will be followed by space vector control. Following main conclusions were drawn from the work.

- Enhancement in Active power delivered by the inverter at the AC side from approximately 4 KW to 4.39 KW.
- The NN training of the input output parameters resulted in enhancement in DC out put voltage from the DC-DC boost converter utilizing SMC controller
- The delivered power quality to the load improved as there was reduction in total harmonic distortion level of the voltage and current waveform. The THD % in voltage came down from 1.21% in system with basic PI control of inverter to 0.01% in proposed system having NN modified sector controlled inverter
- The distortion level in the current waveform was reduced to 0.34% form 0.95%.

The PV system was finally integrated with the power grid. The analysis was carried out for different loads so as to study the effect of power quality on the system

A. Future Scope

- By connecting the super capacitor to the link of an inverter the converter can be designed for a higher voltage and a topology with transformer has to be used.

- Also the inverter control can be improved employing certain changes in the SPVM using machine learning algorithms such that it can handle balanced and unbalanced DC voltages in put with higher variation

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