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Modular Grid-Connected Cascaded H-Bridge Multilevel PV Inverter Using Fuzzy Proportional Integral Derivative controller

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Abstract: This paper introduces a particular cascaded H-bridge multilevel photovoltaic (PV) inverter for single-or three-phase grid-connected applications. The measured cascaded multilevel topology enhances the proficiency and adaptability of PV systems. To acknowledge better use of PV modules and maximize the solar energy extraction, a dispersed most maximum power point following control plan is connected to both single-and three-phase multilevel inverters, which permits independent control of each dc-link voltage. For three-phase grid-connected applications, PV losses may introduce unbalanced supplied power, driving to unequal grid current. To comprehend this issue, The proposed controller is called Fuzzy logic proportional–integral–derivative (PID) controller. This paper provides an overview of performance conventional PI controller and Fuzzy PID controller A test three-phase seven-level cascaded H-bridge inverter has been fabricated using nine H-bridge modules (three modules for every phase).

Keywords: Photovoltaic (PV), MPPT, Fuzzy *Logic* Proportional Integral Derivative (PID) controller*;*

I. INTRODUCTION

Due to the lack of fossil energizes and natural issues created by routine power era, renewable energy, especially solar based energy, has turned out to be maximumly prevalent. Sun based electric-energy request has become reliably by 20%–25% for each annum in the course of recent years, and the development is for the most part in system connected applications. With the exceptional market development in grid connected photovoltaic (PV) systems, there are expanding interests in grid connected PV designs. Five inverter families can be characterized, which are identified with diverse designs of the PV system: 1) focal inverters; 2) string inverters; 3) multistring inverters; 4) air conditioning module inverters; what's more, 5) cascaded inverters. The designs of PV systems are appeared in Fig. 1. Cascaded inverters comprise of a few converters connected in arrangement; accordingly, the high power and/or high voltage from the mix of the different modules would support this topology in medium and substantial lattice connected PV systems. There are two sorts of cascaded inverters. Fig. 1(e) demonstrates a cascaded dc/dc converter association of PV modules. Each PV module has its own particular dc/dc converter, and the modules with their related converters are still connected in arrangement to make a high dc voltage, which is given to a rearranged dc/ac inverter.

This methodology consolidates parts of string inverters and ac module inverters and offers the benefits of person module most maximum power point (MPP) following (MPPT), yet it is not so much excessive but rather more productive than air conditioning module inverters. Notwithstanding, there are two power transformation phase s in this arrangement. Another cascaded inverter is appeared in Fig1(f), where each PV panel is connected with its own dc/ac inverter, and those inverters are then put in arrangement to achieve a high-voltage level. This cascaded inverter would keep up the advantages of "one converter for every panel, for example, better use per PV module, capacity of blending distinctive sources, and excess of the system. Furthermore, this dc/ac cascaded inverter expels the requirement for the per-string dc transport and the focal dc/air conditioning inverter, which further enhances the general proficiency. The measured cascaded H-bridge multilevel inverter, which requires a disconnected dc hotspot for every H- bridge, is one dc/air conditioning bridge inverter topology. The different dc links in the multilevel inverter make free voltage control conceivable.

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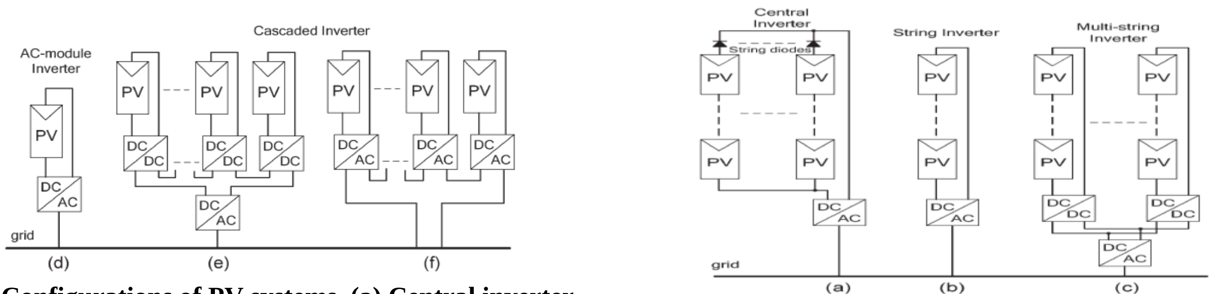

Fig.1. Configurations of PV systems. (a) Central inverter. (b) String inverter.(c) Multistring inverter. (d) AC- module inverter. (e) Cascaded dc/dc converter.(f) Cascaded dc/ac inverter.

As an outcome, individual MPPT control in each PV module can be accomplished, and the energy reaped from PV panels can be boosted. In the interim, the seclusion and ease of a measured cascaded H-bridge multilevel inverter topology for single-or three-phase grid connected PV systems is exhibited in this paper. The panel losses issues are tended to demonstrate the need of individual MPPT control, and a control plan with circulated MPPT control is then proposed. The distributed MPPT control plan can be connected to both single and three-phase systems. What's more, for the introduced three-phase grid connected PV system, if each PV module is worked at its own particular MPP, PV losses may acquaint unequal power supplied with the three-phase multilevel inverter, prompting introduce unbalanced grid current. To adjust the three-phase grid current, modulation compensation is additionally added to the control system.

II. SYSTEM DESCRIPTION

Modular cascaded H-bridge multilevel inverters for single and three-phase grid connected PV systems are appeared in Fig. 1.Each phase comprises of n H-bridge converters connected in arrangement, and the dc connection of every H-extension can be encouraged by a PV panel or a short string of PV panels. The cascaded multilevel inverter is connected with the grid through L channels, which are used to decrease the switching harmonics in the current. By various mixes of the four switches in each H-bridge module, three output voltage levels can be created: −vdc, 0, or +vdc. A cascaded multilevel inverter with n information sources will give 2n + 1 levels to blend the air conditioner output waveform. This (2n + 1)- level voltage waveform empowers the diminishment of music in the orchestrated current, lessening the measure of the required output channels. Multilevel inverters moreover have different points of interest, for example, diminished voltage weights on the semiconductor switches and having higher productivity when contrasted with other converter topologies

III. PANEL LOSSES

PV confound is an imperative issue in the PV system. Due to the unequal got irradiance, distinctive temperatures, and maturing of the PV panels, the MPP of each PV module might be distinctive. On the off chance that each PV module is not controlled autonomously, the effectiveness of the general PV system will be diminished. To demonstrate the need of individual MPPT control, a five-level two-H-bridge single- phase inverter is recreated in MATLAB/SIMULINK. Every H-bridge has its own particular 185-W PV Panel connected as a detached dc source. The PV panel is demonstrated by detail of the business PV panel from Astrometry CHSM-5612M. Consider a working condition that every panel has an alternate illumination from the sun; panel 1 has irradiance S = 1000 W/m2, and panel 2 has S = 600 W/m2. In the event that exclusive panel 1 is followed and its MPPT controller decides the normal voltage of the two panels, the power extricated from panel 1 would be 133 W, and the power from panel 2 would be 70 W, as can be found in Fig. 2(a). Without individual MPPT control, the total power gathered from the PV system is 203 W. In any case, Fig. 2(b) demonstrates the MPPs of the PV panels under the diverse irradiance. The most maximum output power qualities will be 185 and 108.5 W when the S qualities are 1000 and 600 W/m2, separately, which implies that the total power collected from the PV system would be 293.5 W if individual MPPT can be accomplished.

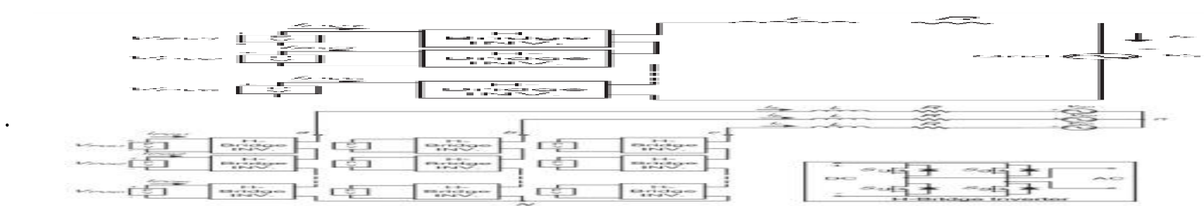

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Fig. 2. Topology of the modular cascaded H-bridge multilevel inverter for grid-connected PV systems.

This higher quality is around 1.45 times of the one sometime recently. In this manner, individual MPPT control in each PV module is required to build the effectiveness of the PV system. In a three- phase system connected PV system, a PV confound may bring about more issues. Beside diminishing the by and large effectiveness, this could even present lopsided power supplied to the three- phase system connected system. In the event that there are PV crisscrosses between phase s, the info power of every phase would be distinctive. Since the grid voltage is adjusted, this distinction in info power will bring about uneven current to the grid, which is not permitted by lattice norms. For instance, to unbalance the current per phase more than 10% is not took into account a few utilities, where the rate unevenness is ascertained by taking the most maximum deviation from the normal current and isolating it by the normal current. To tackle the PV mismatch issue, a control plan with individual MPPT control and balance pay is proposed. The points of interest of the control plan will be examined in the tracking segment.

IV. CONTROL SCHEME

A. Distributed MPPT Control

In order to eliminate the adverse effect of the mismatches and increase the efficiency of the PV system,, the PV modules need to work at various voltages to enhance the usage per PV module. The different dc links in the cascaded H-bridge multilevel inverter make autonomous voltage control conceivable. To figure it out individual MPPT control in each PV module, the control plan proposed is redesigned for this application. The appropriated MPPT control of the three- phase cascaded H-bridge inverter is appeared in Fig. 3. In every H-bridge module, a MPPT controller is added to create the dc-link voltage reference. Every dc-link voltage is contrasted with the comparing voltage reference, and the total of all blunders is controlled through an total voltage controller that decides the current reference I_{dref}. The receptive current reference I_{qref} can be set to zero, or if receptive power remuneration is required, I_{qref} can likewise be given by a responsive current adding machine. The synchronous reference outline phase locked loop (PLL) has been used to discover the phase edge of the grid voltage. As the exemplary control plan in three- phase systems, the grid streams in abc directions are changed over to dq organizes and managed through proportional–integral (PI) controllers to produce the weak record in the dq organizes, which is then changed over back to three phase s.

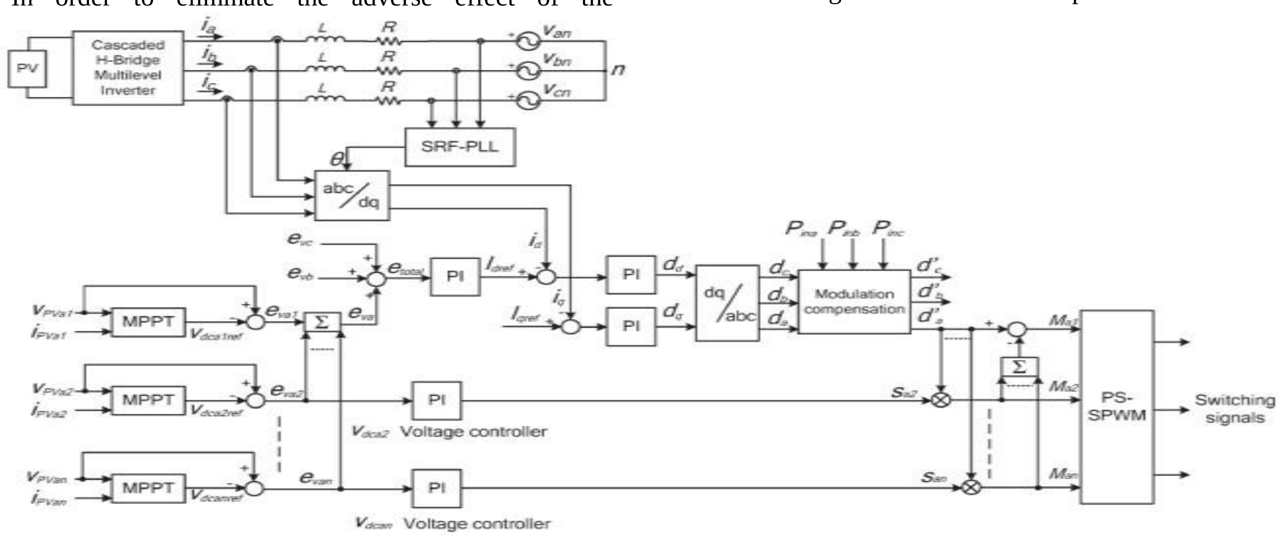

Fig. 3. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.

The circulated MPPT control plan for the single- phase system is about the same. The total voltage controller gives the extent of the dynamic current reference, and a PLL gives the frequency and phase point of the dynamic current reference. The present loop then gives the adjustment list. To make each PV module work at its own MPP, take phase an as an illustration; the voltages vdca2 to vd can are controlled independently through n − 1 loops. Every voltage controller gives the tweak list extent of one H-bridge module in phase a. After duplicated by the balance file of phase a, n − 1 tweak lists can be acquired. Likewise, the balance file for the main H-extension can be gotten by subtraction. The control plans in phase s b what's more, c are practically the same. The main contrast is that all dc-link voltages are managed through PI controllers, and n balance list extents are acquired for every phase. A phase-shifted sinusoidal pulse width modulation switching scheme is then connected to control the switching devices of each H-bridge. The incremental conductance technique has been utilized in this paper. It lends itself well to computerized control, which can effectively monitor past estimations of voltage and current and settle on all choices.

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B. Modulation Compensation

As specified before, a PV confuse may bring about additional issues to a three-phase measured cascaded H-bridge multilevel PV inverter. With the individual MPPT control in each H-bridge module, the info solar based power of every phase would be distinctive, which acquaints lopsided current with the system. To tackle the issue, a zero arrangement voltage can be powered upon the phase legs so as to influence the present streaming into each phase. In the event that the overhauled inverter output phase voltage is relative to the unbalanced power, the present will be adjusted. In this manner, the modulation compensation block, as appeared in Fig. 4, is added to the control arrangement of three-phase modular cascaded multilevel PV inverters. The key is the manner by which to overhaul the balance record of every phase without expanding the complexity of the control system. To start with, the unbalanced power is weighted by proportion rj, This is as certained as

$$r_j = \frac{P_{\text{inav}}}{P_{\text{inj}}} \quad (1)$$

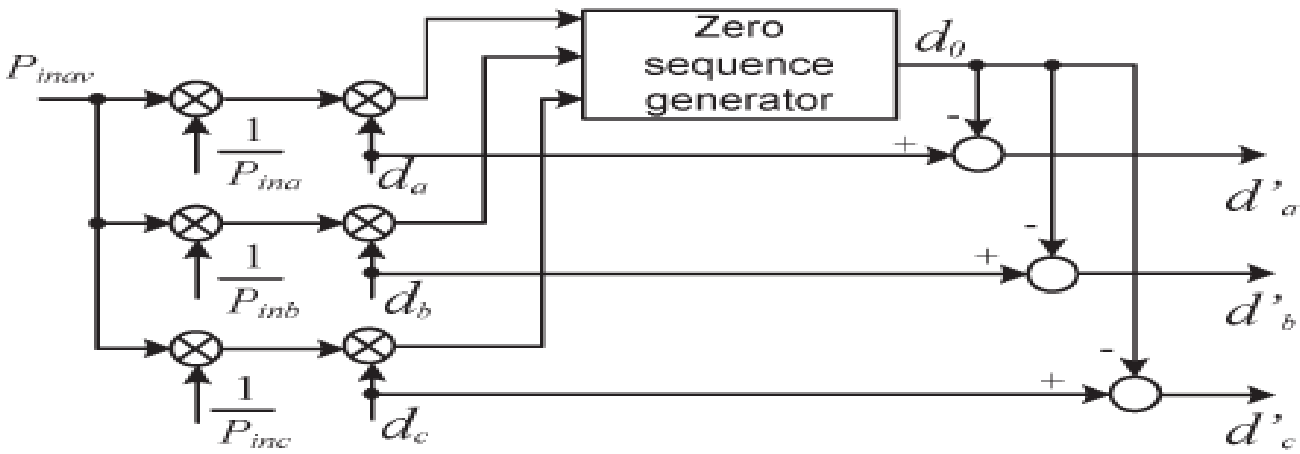

Fig. 4. Modulation compensation scheme.

Where P_{inj} is the info power of phase (j = a, b, c), and P_{inav} is the normal info power. At that point, the infused zero arrangement adjustment file can be produced as

$$d_0 = \frac{1}{2}\left[\min(r_a \cdot d_a, r_b \cdot d_b, r_c \cdot d_c) + \max(r_a \cdot d_a, r_b \cdot d_b, r_c \cdot d_c)\right] \quad (2)$$

Where d_j is the adjustment record of phase (j = a, b, c) and is dictated by the present loop controller. The adjustment record of every phase is redesigned by

$$d'_j = d_j - d_0 \quad (3)$$

Just straightforward estimations are required in the plan, which won't build the many-sided quality of the control system. A case is displayed to demonstrate the adjustment remuneration plot all the more unmistakably. Expect that the information power of each phase is unequal

$$P_{ina} = 0.8 \qquad P_{inb} = 1 \qquad P_{inc} = 1 \quad (4)$$

By infusing a zero succession tweak list at t = 1 s, the adjusted tweak file will be redesigned,

C. Extension

PID *Control*

Consider the characteristics parameters – proportional (P), integral (I), and derivative (D) controls, as applied to the diagram below in Fig.5.

A PID controller is simple three-term controller. The letter P,I and D stand for P- Proportional, I- Integral, D-Derivative. The transfer function of the most basic form of PID controller ,is

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$$C(s) = K_p + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_p S + K_I}{S} \quad (1)$$

Where K_P = Proportional gain, K_I = Integral gain and K_D = Derivative gain.

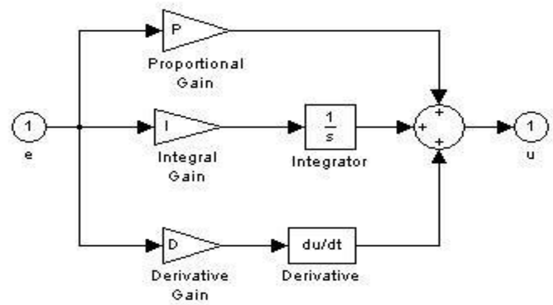

Figure 5. Simulation model of PID Controller

The control u from the controller to the plant is equal to the Proportional gain (K_P) times the magnitude of the error pluse the Integral gain (K_I) times the integral of the error plus the Derivative gain (K_D) times the derivative of the error.

$$u = K_p e + K_i \int e\,dt + K_d \frac{de}{dt}$$

Due to its simplicity and excellent if not optimal performance in many applications, PID controllers are used in more than 95% of closed-loop industrial processes

The Values of Kp, Ki and Kd values of PID Controller is shown in below Table III are obtained by using the ZN method

TABLE III. PID VALUES

controller	K_p	K_i	K_d
PID	0.8	48	0.01

Fuzzy Logic: Fuzzy rationale is a type of numerous esteemed rationales in which reality estimations of variables might be any genuine number somewhere around 0 and 1. By differentiation, in Boolean rationale, reality estimations of variables may just be 0 or 1. Fuzzy rationale has been stretched out to handle the idea of halfway truth, where reality quality may extend between totally genuine and totally false. Besides, when etymological variables are utilized, these degrees might be overseen by particular capacities. Normally fuzzy rationale control framework is made from four noteworthy components exhibited on Figure fuzzification interface, fuzzy induction motor, fluffy principle grid and defuzzification interface. Every part alongside fundamental fuzzy rationale operations will be depicted in more detail below

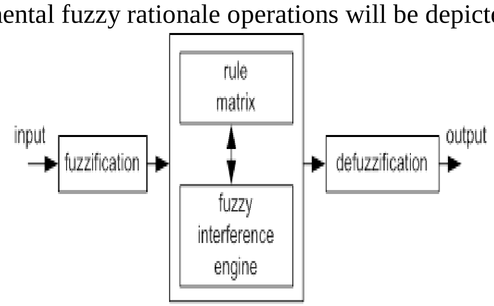

Fig.5.1. fuzzy logic system

The fuzzy rationale investigation and control strategies appeared in Fig. 5.1. can be depicted as:

- Receiving one or expansive number of estimations or other appraisal of conditions existing in some system that will be dissected or controlled.
- Processing all got inputs as indicated by human based, fuzzy "assuming then" standards, which can be communicated in basic dialect words, and consolidated with conventional non-fuzzy preparing.

Averaging and weighting the outcomes from all the individual principles into one single output choice or sign which chooses what to do or advises a controlled system what to do. The outcome output sign is an exact defuzzified esteem. First of all, the

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different level of output (high speed, low speed etc.) of the platform is defined by specifying the membership functions for the fuzzy sets.

Design of Fuzzy PID Control

In drive operation, the speed can be controlled indirectly by controlling the Voltage Source inverter. The speed is controlled by fuzzy logic controller whose output is the inner dc Voltage controller. The Voltage is controlled by varying the dc voltage. The drive performance of voltage source controller is improved by employing two sets of fuzzy logic controllers. One set of fuzzy logic controller is used in the inner loop for controlling the torque of the motor which is proportional to DC link current Idc, and another set is used in the outer loop for controlling the actual motor speed. Fuzzy PID controller used in this paper is based on two input FLC structure with coupled rules. The overall structure of used controller is shown in Fig. 4. Real interval of variables is obtained by using scaling factors which are Se, Sde and Su. The fuzzy control rule is in the form of: IF e=Ei and de=dEj THAN UPD=UPD(i,j). These rules are written in a rule base look-up Table IV. The rule base structure is Mamdani type.

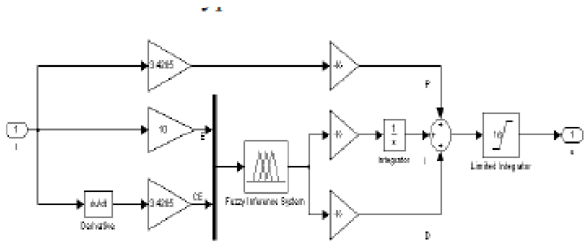
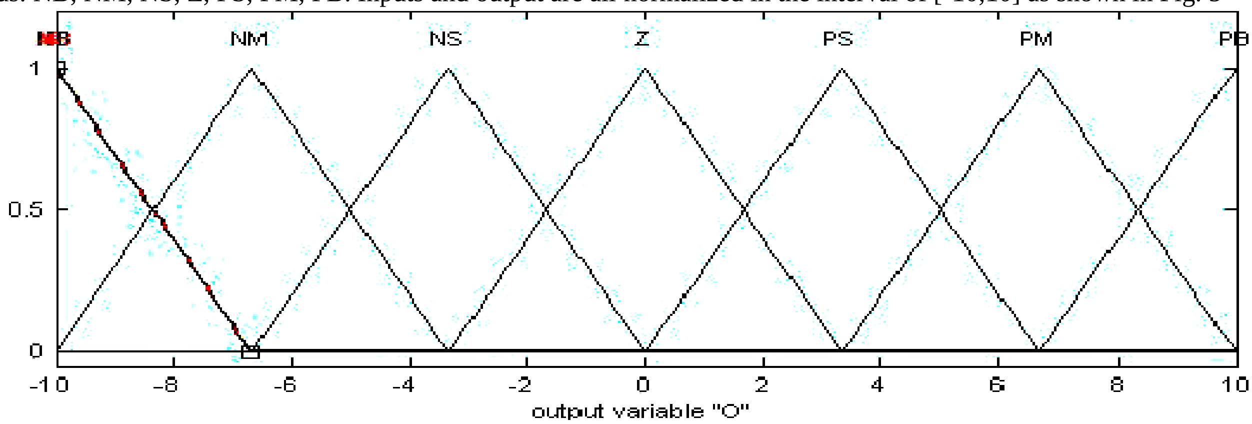


Figure 4. Simulation of Fuzzy PID Controller

FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. Linguistic variables which implies inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs and output are all normalized in the interval of [-10,10] as shown in Fig. 5



The two input fuzzy controller with coupled rules formed by combining both PI and PD actions. The final fuzzy PID controller signal can be given as:

$$U_{PID}(t) = S_u \left\{ K_{PI} \sum_{i=0}^{t} U_{PD}(i) + K_{pI} U_{PD}(t) \right\} \qquad (3)$$

The linguistic labels used to describe the Fuzzy sets were 'Negative Big' (NB), 'Negative Medium' (NM), 'Negative Small' (NS), 'Zero' (Z), 'Positive Small' (PS), 'Positive Medium' (PM), 'Positive Big' (PB). It is possible to assign the set of decision rules as shown in Table IV. The fuzzy rules are extracted from fundamental knowledge and human experience about the process. These rules contain the input/the output relationships that define the control strategy. Each control input has seven fuzzy sets so that there are at most 49 fuzzy rule.

TABLE IV. TABLE OF FUZZY RULE

CE \ E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

V. SIMULATION RESULTS

A. Existing Simulation Results

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To confirm the proposed control plot, the three-phase grid connected PV inverter is mimicked in two distinctive conditions. In the first place, all PV panels are worked under the same irradiance S = 1000 W/m2 and temperature T = 25 ◦C. At t = 0.8 s, the sun powered irradiance on the first and second panels of phase a declines to 600 W/m2, and that for alternate panels sticks with it same. The dc-link voltages of phase are appeared in Fig. 6. At the starting, all PV panels are worked at a MPP voltage of 36.4 V. As the irradiance changes, the first and second dc- link voltages abatement and track the new MPP voltage of 36 V, while the third panel is still worked at 36.4 V as shown in Fig.7.

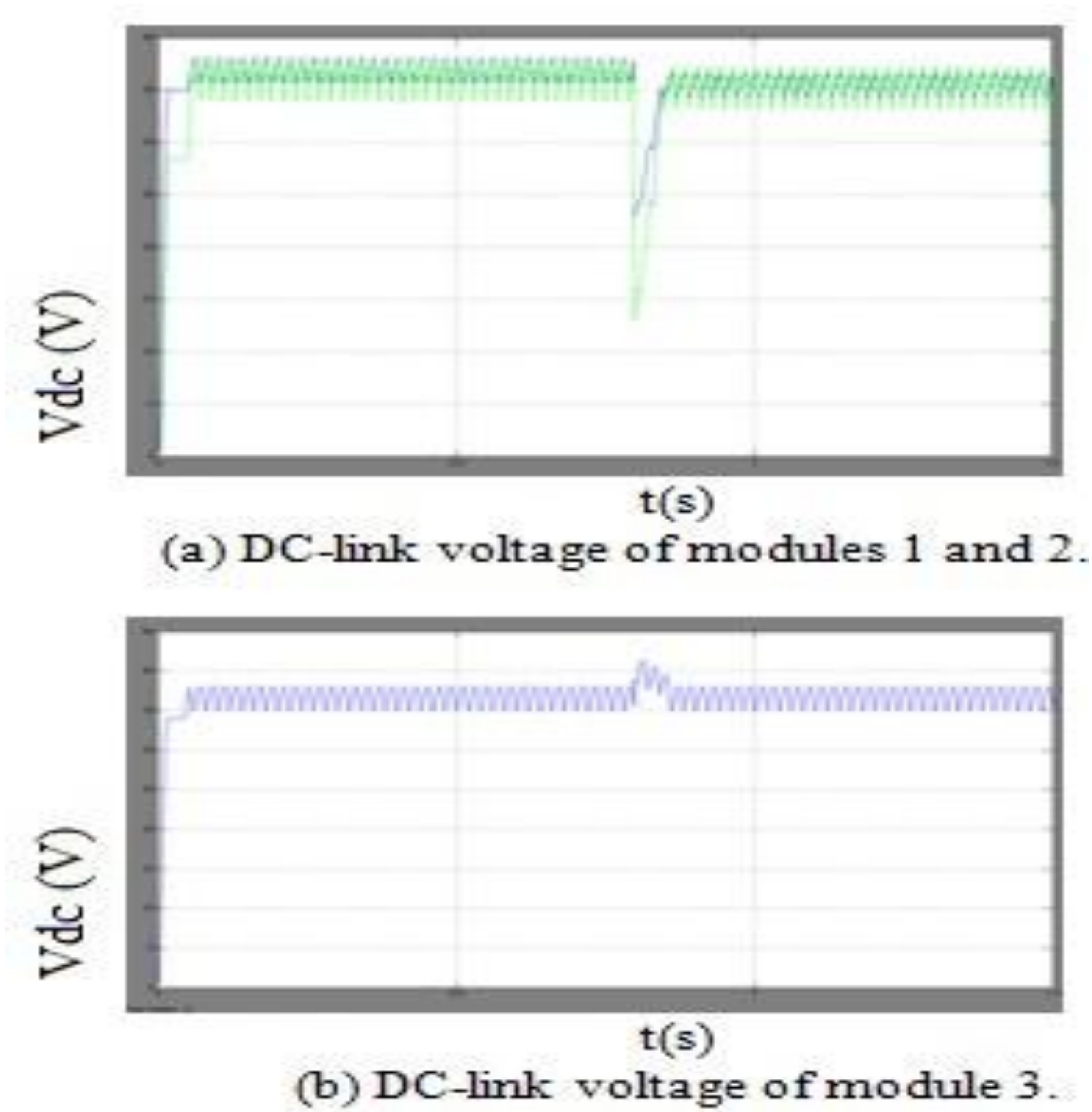

Fig.6. DC-link voltages of phase a with distributed MPPT (25.C).

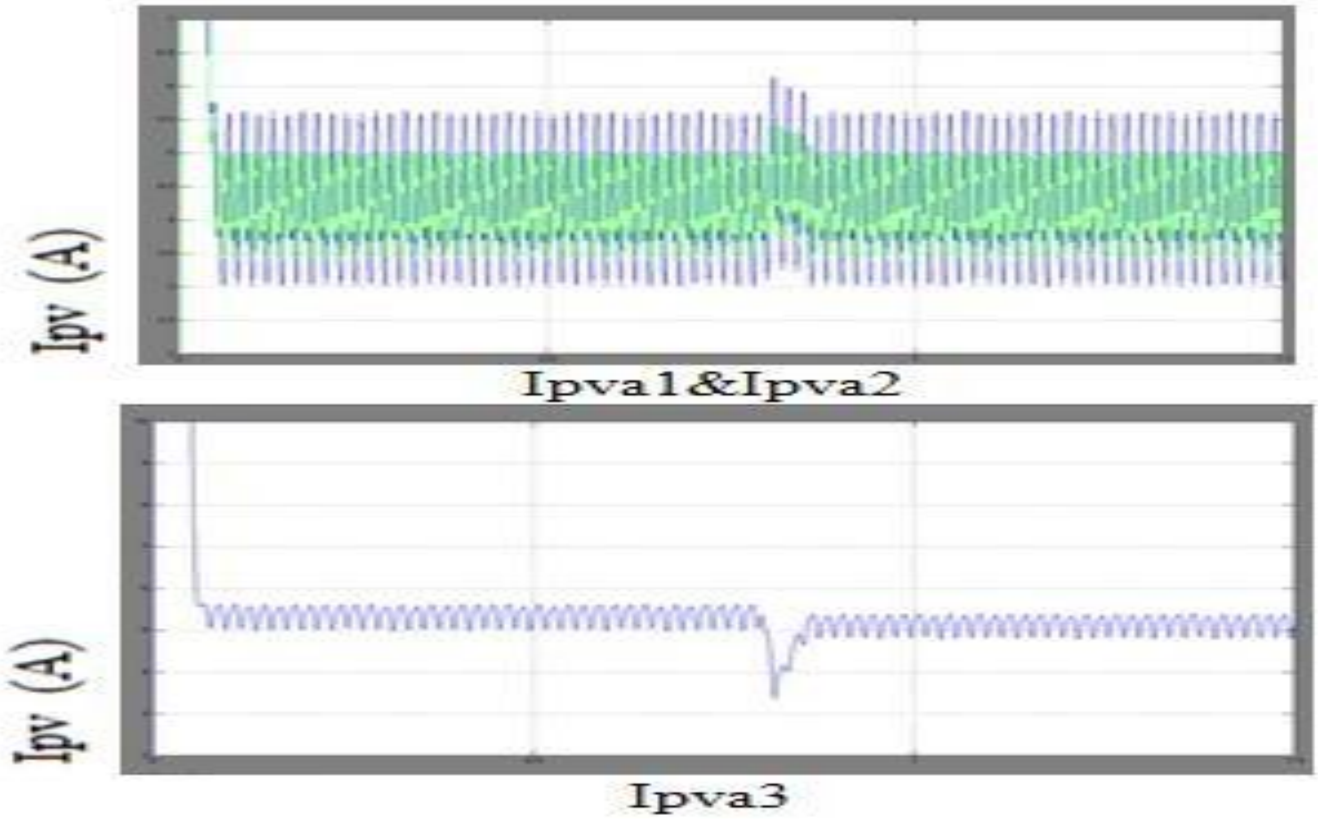

Fig.7. PV currents of phase a with distributed MPPT (T=25.C) The dc-link voltages of phase b are appeared in Fig. 8. All phase b panels track the MPP voltage of 36.4 V, which appears that they are not affected by other phases. With the conveyed MPPT control, the dc-link voltage of every H- bridge can be controlled freely.

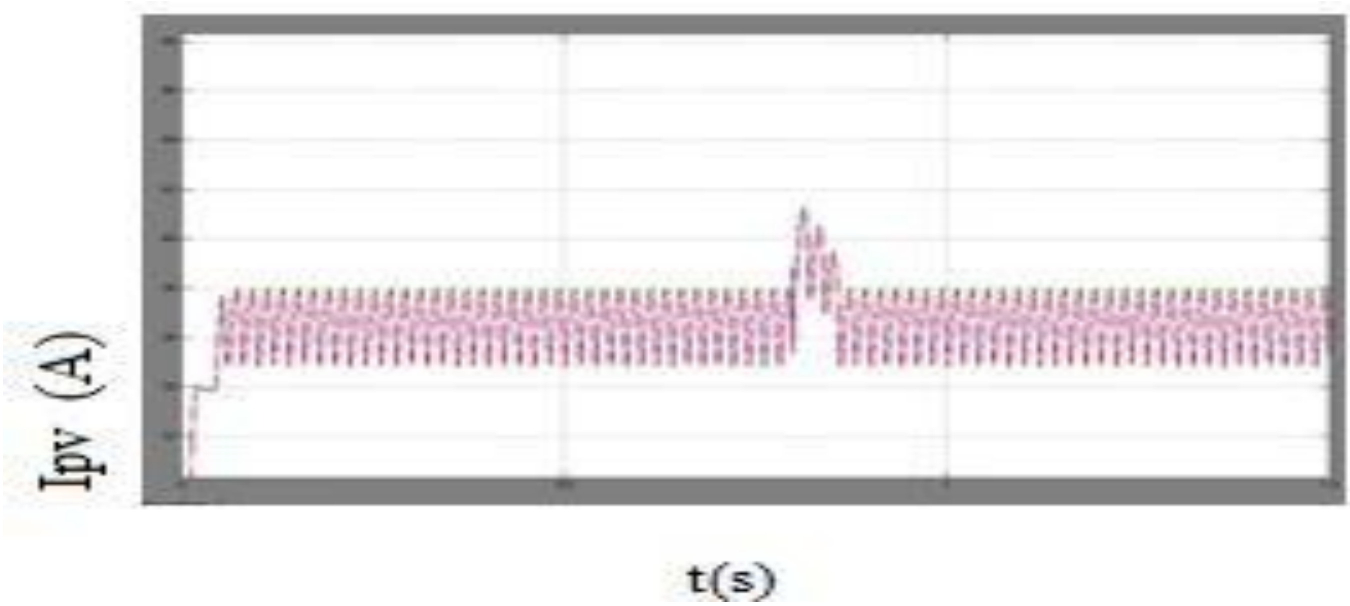

Fig.8. DC-link voltages of phase b with distributed MPPT (T = 25 ◦C).

At the end of the day, the connected PV panel of every H-bridge can be worked at its own particular MPP voltage also, won't be impacted by the panels connected with other H-bridges. In this way, more solar energy can be extricated, and the effectiveness of the general PV system will be expanded. Fig.9. demonstrates the power extricated from every phase. Toward the starting, all panels are worked under irradiance S = 1000 W/m2, and each phase is creating a maximum power of 555 W. After t = 0.8 s, the power reaped from phase a declines to 400 W, and those from the other two phases stick with it. Clearly, the power supplied to the three-phase grid connected inverter is uneven.

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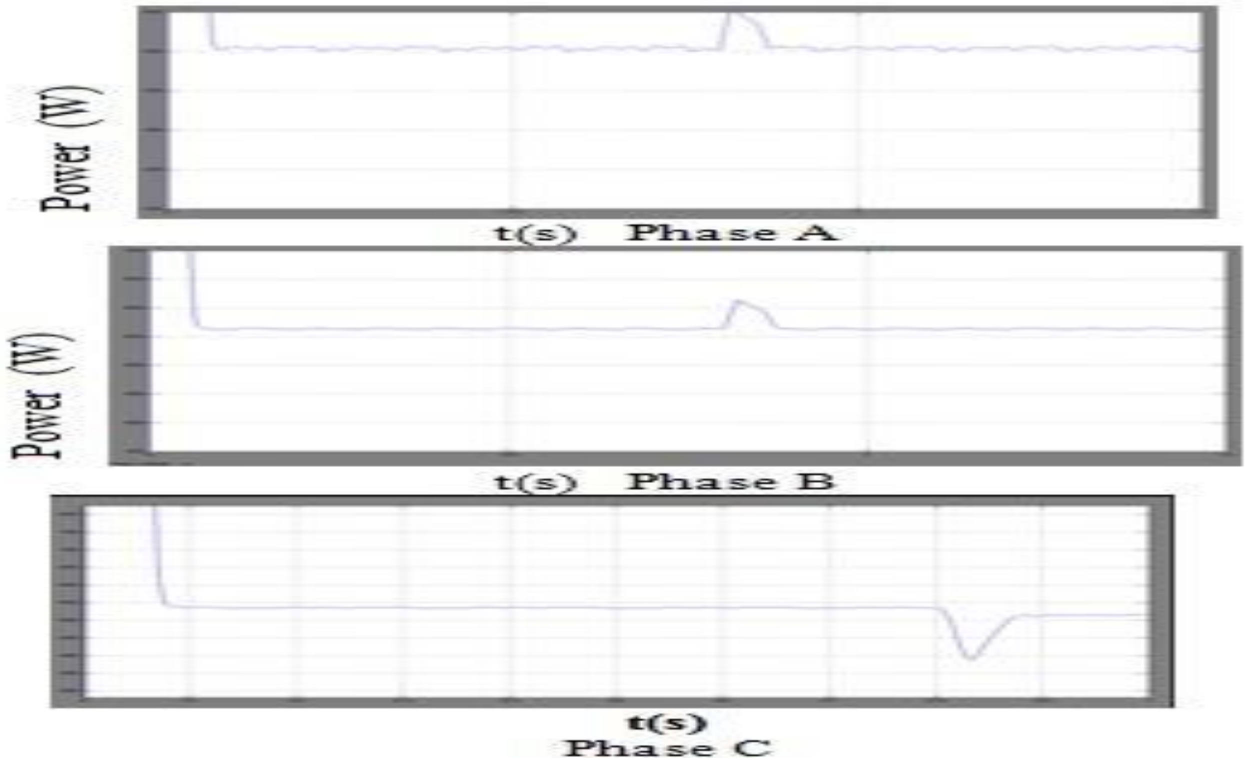

Fig.9.Power extracted from PV panels with distributed MPPT.

Be that as it may, by applying the modulation compensation, the power infused to the grid is still adjusted, as appeared in Fig.10. It can be seen that there is no additional power misfortune brought on by the modulation compensation scheme plan.

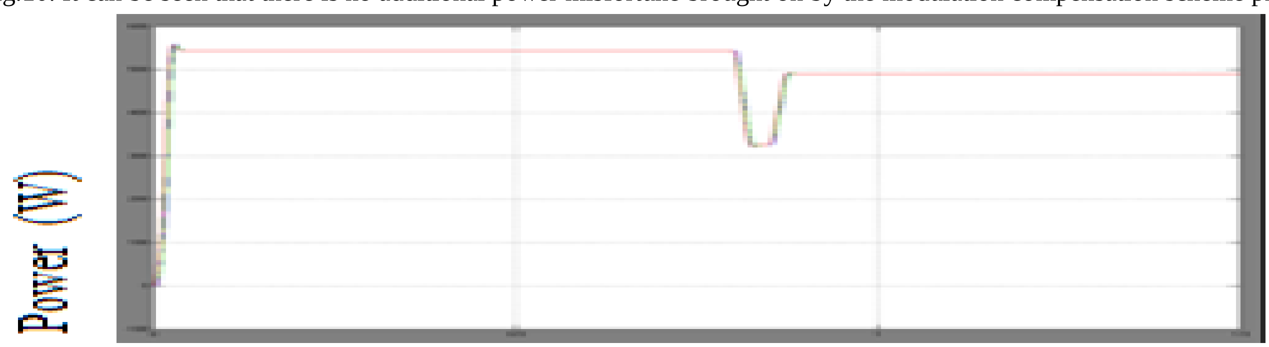

Fig.10. Power injected to the grid with modulation compensation.

Fig.11. shows the output voltages (v_{jN}) of the three-phase inverter. Due to the injected zero sequence component, they are unbalanced after t = 0.8 s, which help to balance the grid current as shown in Fig. 12.

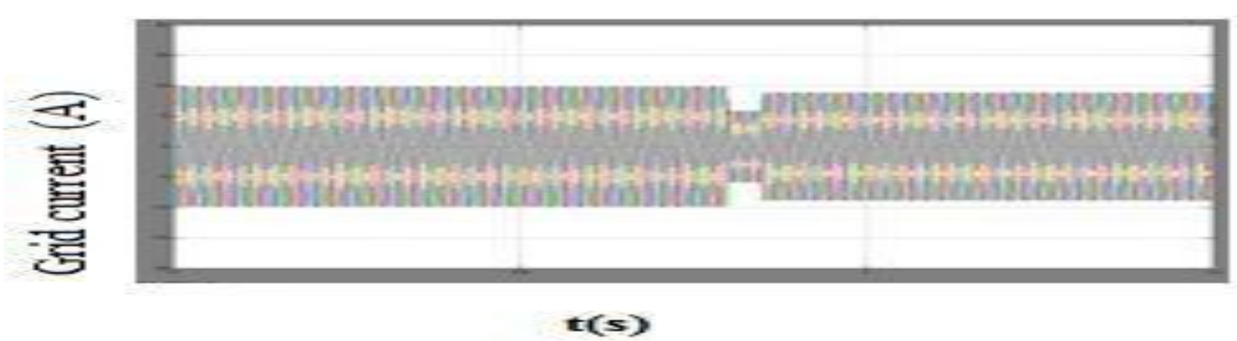

Fig.11. Three-phase grid current waveforms with modulation compensation.

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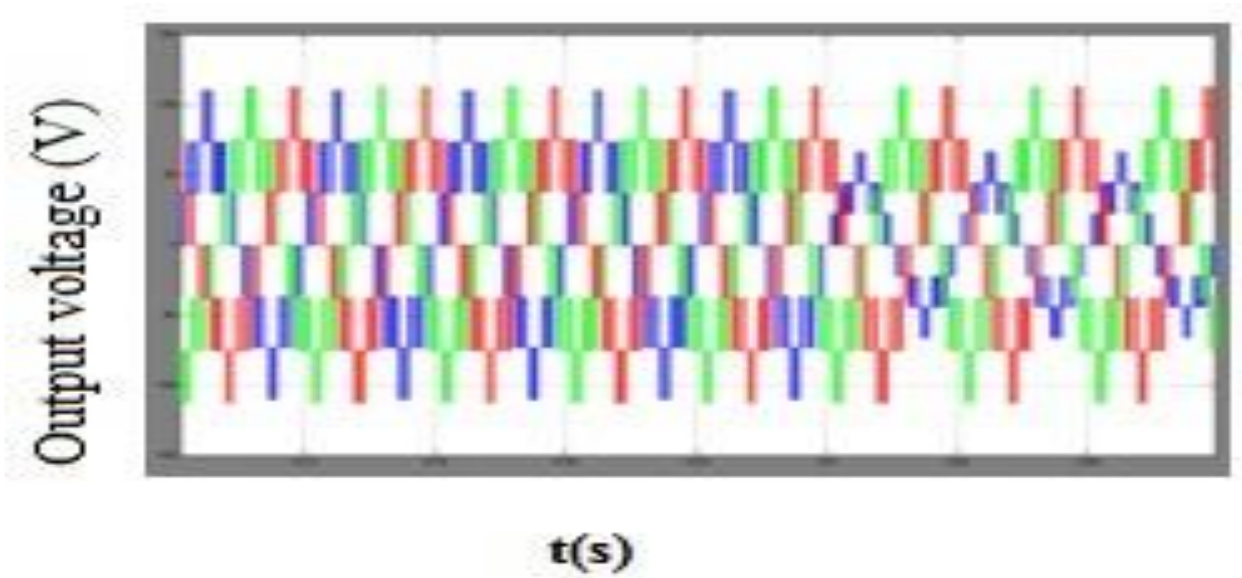

Fig.12. Three-phase inverter output voltage waveforms with modulation compensation.

B. Existing Model Voltage and Current THD Values

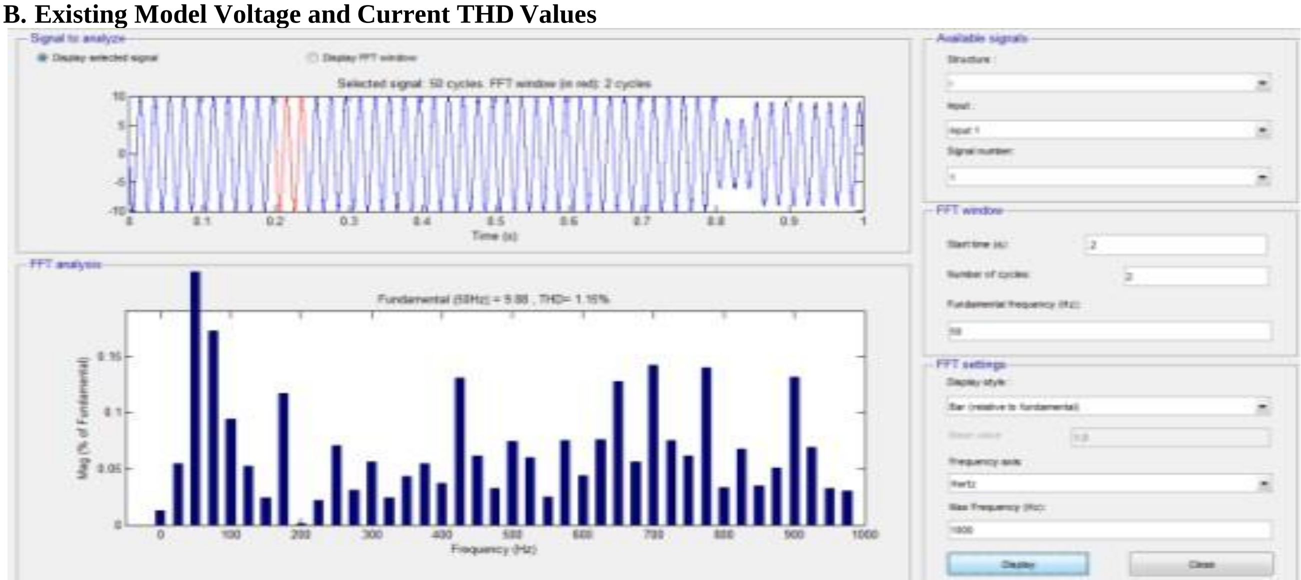

Fig.13.

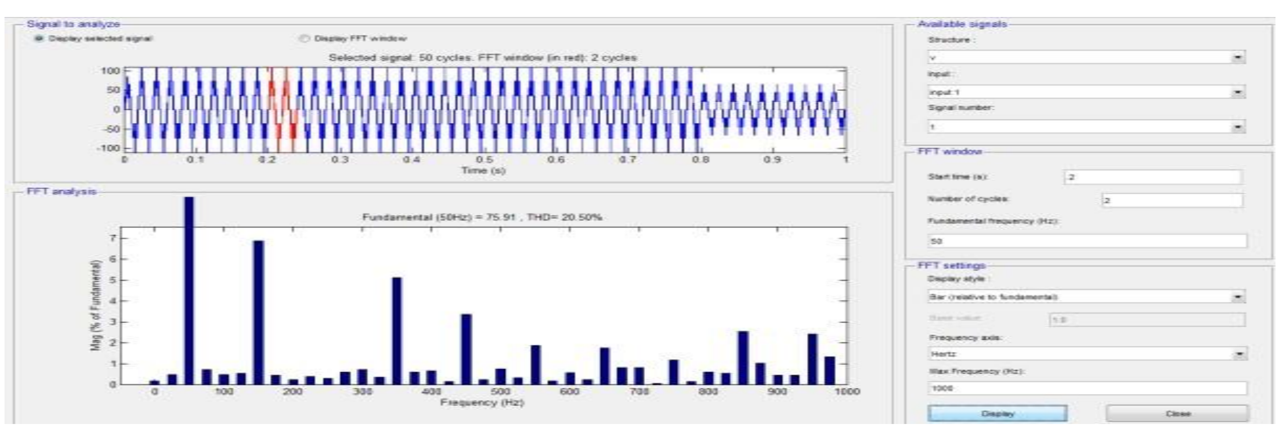

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Fig.14.

TABLE I: Existing Model Voltage and Current THD Values

Load voltage THD	20.50%
Load current THD	1.15%

C. Proposed Simulation Results

In our proposed method PI controller is used. To get a better performance we used FUZZY controller instead of PI controller. A versatile fuzzy induction system or versatile system based fuzzy surmising system is a sort of manufactured neural system that depends on fuzzy derivation system. The procedure was produced in the mid 1990s.Since it incorporates both neural systems and fuzzy rationale standards; it can possibly catch the advantages of both in a solitary structure. Its surmising system relates to an arrangement of fuzzy IF–THEN decides that have learningability to rough nonlinear functions. Hence, FUZZY is thought to be a widespread estimator. For utilizing the FUZZY as a part of a more productive and ideal way, one can utilize the best parameters acquired by hereditary algorithm. The PI controller requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances, etc. Recently, Fuzzy Controllers have been introduced in various applications and have been used in the power electronics field. The advantages of FUZZY controllers over conventional PI controllers are that they do not need an accurate mathematical model, Can work with imprecise inputs and Can handle non-linearity and are more robust than conventional PI controllers.

D. Summary

This chapter discusses the Simulation model and simulation results of •PI, Fuzzy & FUZZY by soft computing technique. From the FFT analysis it is cleared by using Artificial Neuro fuzzy logic system (FUZZY) the Total Harmonic Distortion (THD) is reduced compare to Fuzzy Logic Control (FLC) and frequency fluctuations are also reduced.

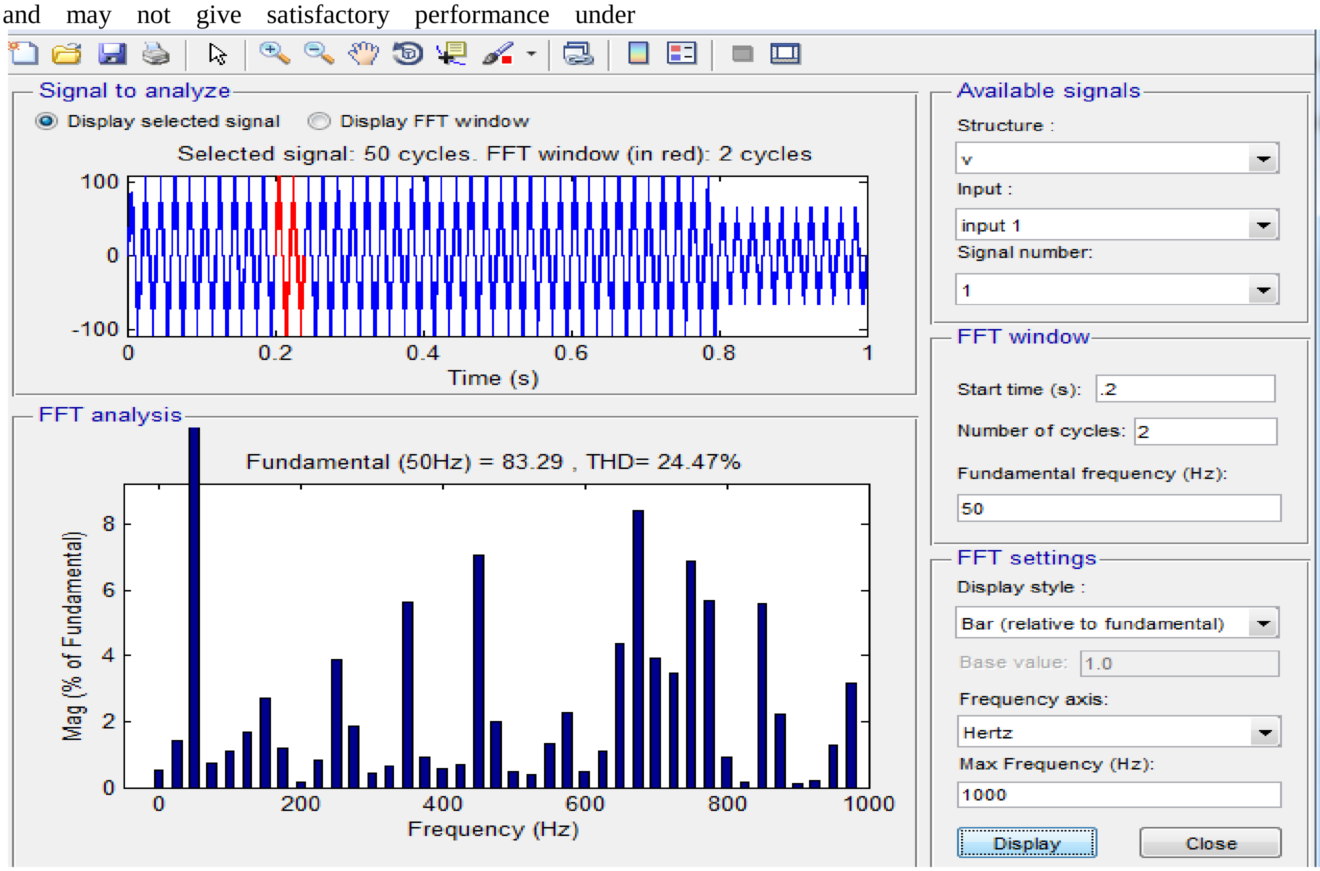

Fig.15.

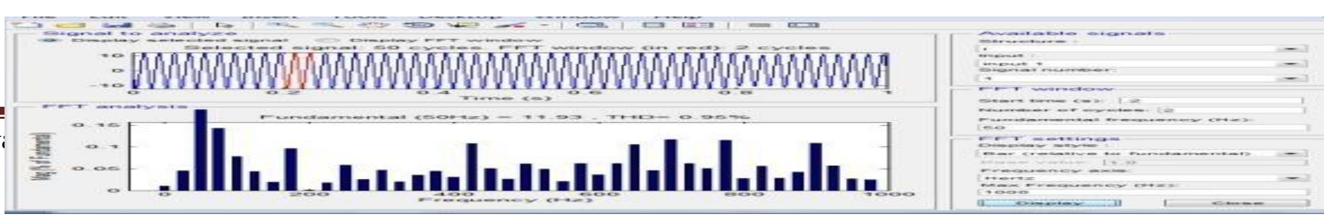

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Fig.16.

TABLE II: Existing Model Voltage and Current THD Values

Load voltage THD	24.47%
Load current THD	0.95%

E. Proposed Simulation Results

In our proposed method PI controller is used. To get a better performance we fuzzy logic pid controller.

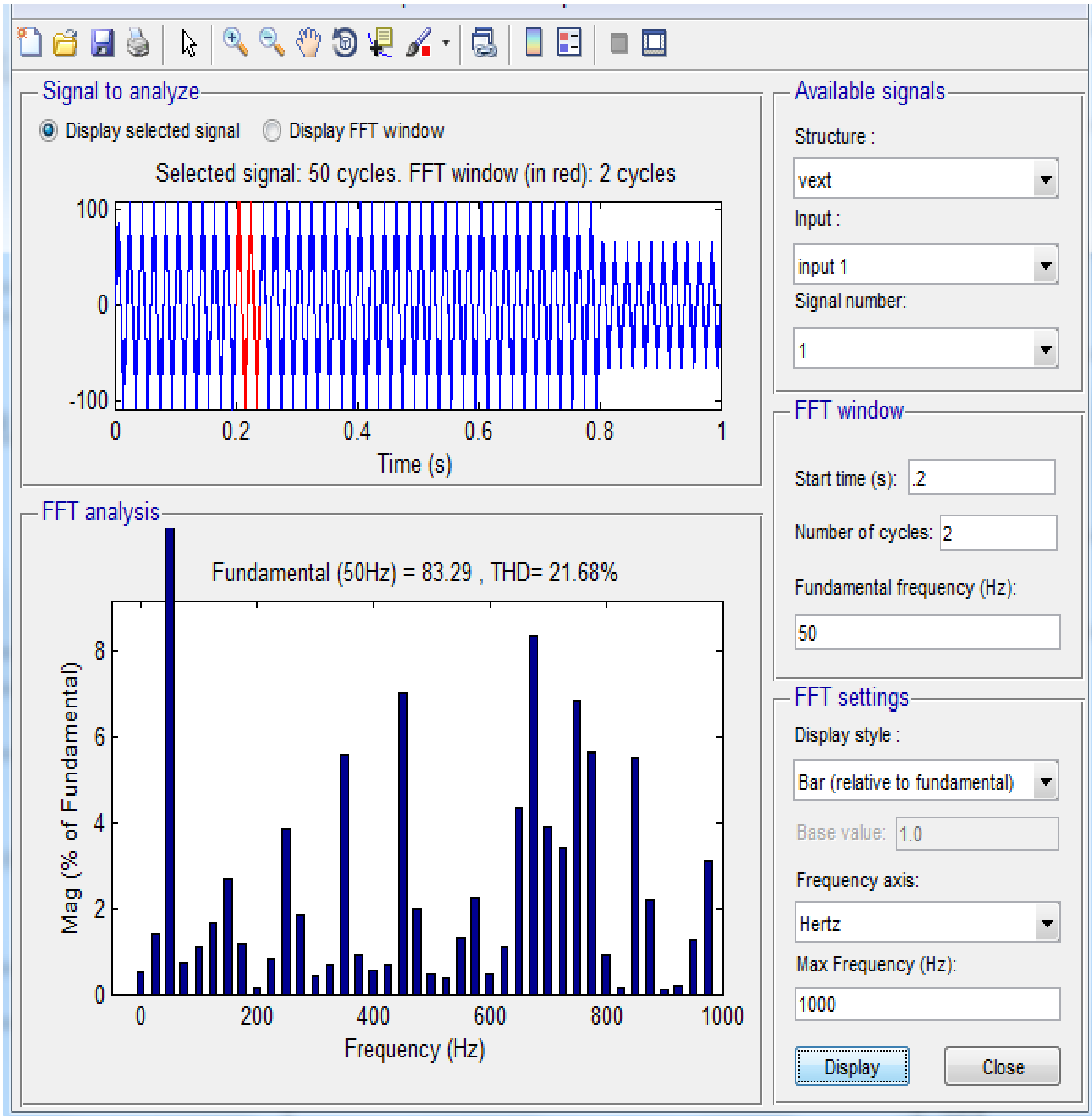

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Fig.17.

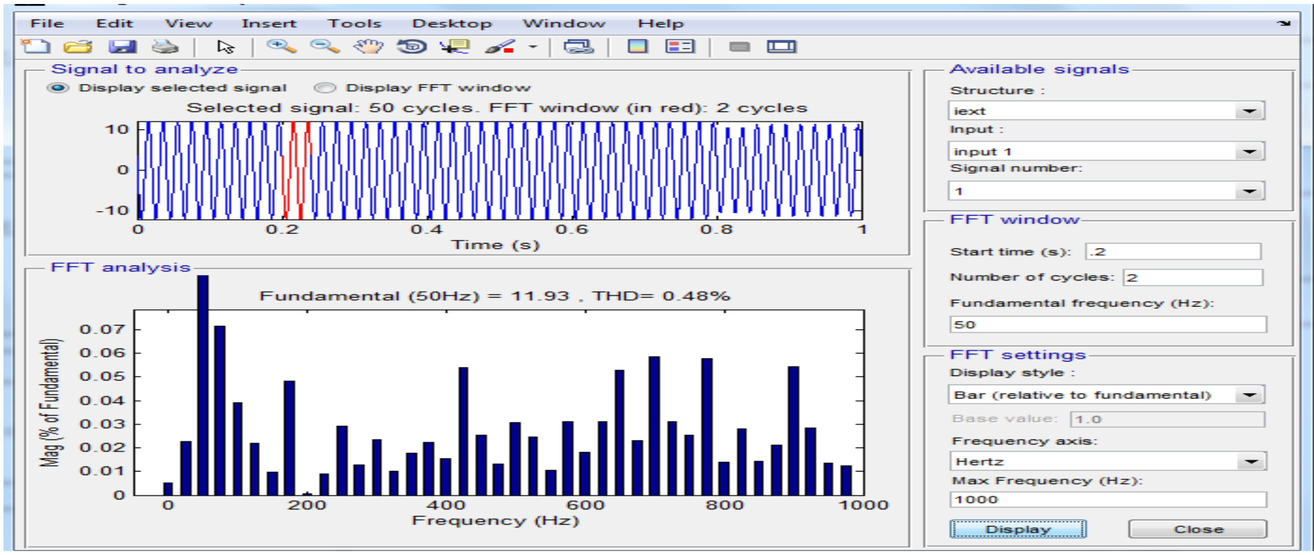

Fig.18.

Inputs and Can handle non-linearity and are more robust than conventional PI controllers.

TABLE III: Fuzzy PID Model Voltage And Current THD Values

Load voltage THD	2.86%
Load current THD	0.48%

TABLE IV: Comparison of THD Values

Names	Load voltage THD values	Load current THD values
Fuzzy PID	2.86%	0.48%
PI	24.47%	0.95%

VI. CONCLUSION

In this project, a modular cascaded H-bridge multilevel inverter for grid-connected PV applications has been presented. The multilevel inverter topology will help to improve the utilization of connected PV modules if the voltages of the separate dc links are controlled independently. Thus, a distributed MPPT control scheme for both single- and three-phase PV systems has been applied to increase the overall efficiency of PV systems. For the three- phase grid-connected PV system, PV mismatches may introduce unbalanced supplied power, resulting in unbalanced injected grid current.A modulation compensation scheme, which will not increase the complexity of the control system or cause extra power loss, is added to balance the grid current. A modular three-phase seven-level cascaded H-bridge inverter has been built in the laboratory and tested with PV panels under different partial shading conditions. With the proposed control scheme, each PV module can be operated at its own MPP to maximize the solar energy extraction, and the three-phase grid current is balanced even with the unbalanced supplied solar power. From the above results we can conclude that the multilevel inverter topology will enhance the use of connected PV modules if the voltages of the different dc connections are controlled autonomously. And finally by observing the THD values this system gives better performance when FUZZY controller was used.

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