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An Advanced Control Strategy For Solar PV and Battery Storage Integration System

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Abstract-

In this venture, another design of a three-level unbiased point-clasped (NPC) inverter that can coordinate solar photovoltaic (PV) with battery storage in a framework associated framework is proposed. The quality of the proposed topology lies in a novel, expanded unbalance three-level vector adjustment procedure that can produce the right air conditioning voltage under lopsided dc voltage conditions. This venture introduces the outline examination of the proposed setup and the hypothetical system of the proposed regulation method. Another control calculation for the proposed framework is likewise introduced with a specific end goal to control the power conveyance between the sun based PV, battery, and matrix, which all the while gives most extreme power point following (MPPT) operation for the sun oriented PV. In this venture fuzzy controller used to lessened the music when contrasted with the PI controller. The viability of the proposed philosophy is examined by the reenactment of a few situations, including battery accusing and releasing of various levels of sunlight based light. The reenactment performed in MATLAB/SIMULINK condition.

Index Terms— Battery storage, solar photovoltaic (PV), space vector modulation (SVM), three-level inverter, fuzzy controller.

INTRODUCTION

Because of the world vitality emergency and natural issues brought on by customary power era, renewable vitality sources, for example, photovoltaic (PV) and wind era frameworks are turning out to be all the more encouraging other options to trade ordinary era units for power era. Propelled control electronic frameworks are expected to use and create renewable vitality sources. In sun based PV or wind vitality applications, using greatest power from the source is a standout amongst the most vital elements of the power electronic frameworks . In three-stage applications, two sorts of force electronic setups are generally used to exchange control from the renewable vitality asset to the network: single-stage and twofold phase transformation. In the twofold phase transformation for a PV framework, the primary stage is normally a dc/dc converter and the second stage is a dc/air conditioning inverter. The capacity of the dc/dc converter is to encourage the greatest power point following (MPPT) of the PV exhibit and to deliver the proper dc voltage for the dc/air conditioning inverter. The capacity of the inverter is to produce three-stage sinusoidal voltages or streams to exchange the ability to the lattice in a framework associated sunlight based PV framework or to the heap in a remain solitary framework . In the single-stage association, just a single converter is expected to satisfy the twofold phase capacities, and henceforth the framework will have a lower cost and higher effectiveness, be that as it may, a more intricate control strategy will be required. The present standard of the business for high power applications is a three-stage, single stage PV vitality frameworks by utilizing a voltage-source converter (VSC) for power transformation . One of the real worries of sun powered and wind vitality frameworks is their unusual and fluctuating nature. Network associated renewable vitality frameworks joined by battery vitality stockpiling can beat this worry. This likewise can expand the adaptability of force framework control and raise the general accessibility of the framework . More often than not, a converter is required to control the charging and releasing of the battery stockpiling framework and another converter is required for dc/air conditioning power change; along these lines, a three stage PV framework associated with battery stockpiling will require two converters. This paper is worried with the outline and investigation of a framework associated three-stage sun powered PV framework incorporated with battery stockpiling utilizing just a single three-level converter having the capacity of MPPT and air conditioning side current control, and furthermore the capacity of controlling the battery charging and releasing. This will bring about lower cost, better proficiency and expanded adaptability of force stream control.

II. STRUCTURE OF A THREE-LEVEL INVERTER AND ITS CAPACITOR VOLTAGE CONSIDERATIONS

A. Three-Level Inverter

Since the presentation of three-level inverters , they have been broadly utilized as a part of a few applications, for example, engine drives, STATCOM, HVDC, pulsewidth tweak (PWM) rectifiers, dynamic power channels (APFs), and renewable vitality applications . Fig. 1(a) demonstrates a run of the mill threephase three-level impartial point-cinched (NPC) inverter circuit

topology. The converter has two capacitors in the dc side to deliver the three-level air conditioning side stage voltages. Ordinarily, the

capacitor voltages are thought to be adjusted, since it has been accounted for that unbalance capacitor voltages can influence the acside voltages and can deliver unforeseen conduct on framework parameters, for example, even-symphonious infusion and power swell . A few papers have examined strategies for adjusting these capacitor voltages in different applications .

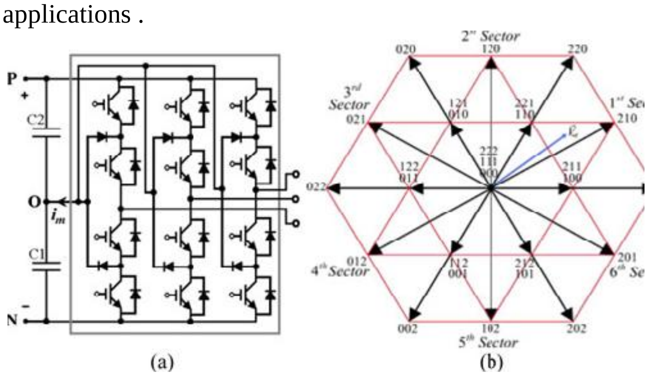

Fig. 1. Typical three-level inverter (a) structure of circuit, and (b) three-level inverter space vector diagram for balanced dc-link capacitors .

B. Balanced Capacitors Voltage

Different procedures have been proposed to adjust the capacitor voltages usingmodulation calculations, for example, sinusoidal carrierbased PWM (SPWM) or space vector pulsewidth tweak (SVPWM) . In SPWM applications, a large portion of the techniques depend on infusing the fitting zero-succession motion into the adjustment signs to adjust the dc-interface capacitors . In SVPWM applications, a superior comprehension of the impacts of the exchanging choices on the capacitor voltages in the vector space has brought about numerous procedures proposed to adjust capacitors voltages in the three-level NPC inverter. These incorporate capacitor adjusting utilizing ordinary SVPWM, virtual SVPWM (VSVPWM) and their blend . In vector control hypothesis, in a perfect world, the inverter must have the capacity to create the voltage yield promptly, taking after the reference vector (_Vref), produced by the control framework. In any case, in view of the constraint of the switches in the inverter, it is impractical to ensure that any asked for vector can be produced; actually, just a set number of vectors (27 vectors for three-level inverter) can be created. To defeat such challenges, in any space vector regulation (SVM) plan, for example, SVPWM and VSVPWM, the reference vector _Vref is created by choosing the proper accessible vectors in each time period in a manner that the normal of the connected vectors must be equivalent to the reference vector.

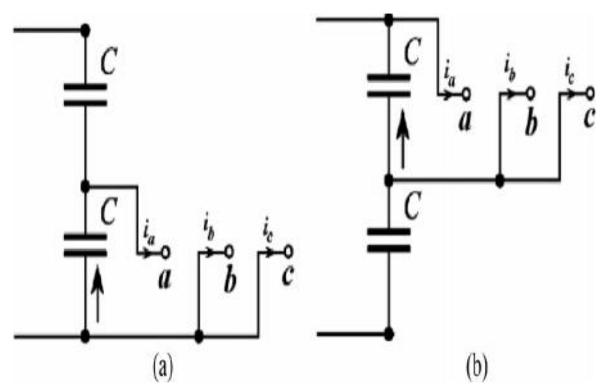

Fig. 2. Equivalent circuit and capacitors current with two different short vector. (a) Short vector—100. (b) Short vector—211.

Equation (1) shows the mathematical relation between the timing of the applied vectors and the reference vector

$$\begin{cases} T_s \vec{V}_{\text{ref}} = \sum_{i=1}^{n} T_i \vec{V}_i \\ T_s = \sum_{i=1}^{n} T_i \end{cases} \quad (1)$$

where Ts is the time period and wanted to be as short as could reasonably be expected. It can be considered as a control overhaul period where a normal vector will be scientifically created amid this time term. Ti is the comparing time portion for chose inverter vector _Vi and n is the quantity of connected vectors. For the most part, the reference vector is created by three distinctive vector (n = 3), and (1) can be changed over to three diverse condition with three factors T1, T2 , and T3 to be figured. A few vector PWM strategies introduced in [6], [7], [9]–[11], and [13]–[15] apply comparative system of timing computation. Fig. 1(b) demonstrates the space vector chart of a three-level inverter for adjusted dc-interface capacitors [6]. It is comprised of 27 exchanging states, from which 19 distinctive voltage vectors can be chosen. The number related with every vector in Fig. 1(b) speaks to the exchanging condition of the inverter stages separately. The voltage vectors can be sorted into five gatherings, in connection to their amplitudes and their consequences for various capacitor voltages from the perspective of the inverter air conditioning side. They are six long vectors (200, 220, 020, 022, 002, and 202), three zero vectors (000, 111, and 222), six medium vectors (210, 120, 021, 012,102, and 201), six upper short vectors (211, 221, 121, 122, 112,and 212), and six lower short vectors (100, 110, 010, 011, 001, and 101). For creating _Vref , when one of the choices (_Vi), is a short vector, then there are two decisions that can be made which can deliver the very same impact on the air conditioner side of the inverter in the three wire association (if voltages are adjusted). For instance, the short vector "211" will have an indistinguishable impact from "100" on the air conditioner side of the inverter. In any case, this decision will have diverse impact on the dc side, as it will make an alternate dc capacitor be decided for the exchange of force from or to the air conditioner side, and an alternate capacitor will be charged or released relying upon the exchanging states and the course of the air conditioner side current. For instance, Fig. 2 demonstrates the association of the capacitors when "100"or "211" is chosen, exhibiting how distinctive capacitors are included in the exchange of force. Capacitor adjusting in most announced three-level NPC inverter applications is accomplished by the correct determination of the short vectors. Keeping in mind the end goal to deliver the air conditioner side waveform, the vector outline of Fig. 1(b) is utilized, where the dc capacitor voltages are thought to be adjusted.

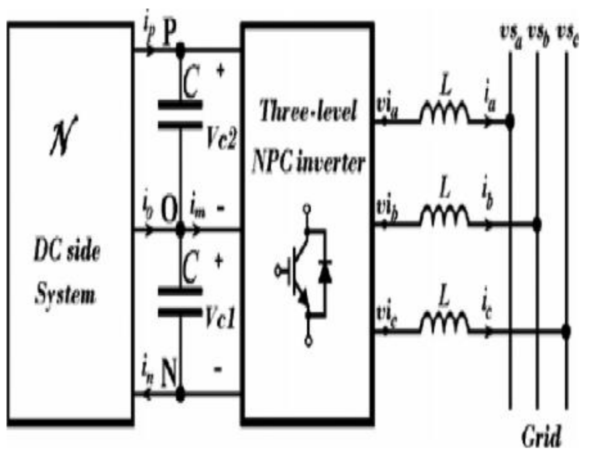

Fig. 1(b) can then be utilized to decide the proper vectors to be chosen and to compute their comparing timing (Ti) for executing the required reference vector in light of the expression given in (1). Despite the fact that the control framework is attempting to guarantee adjusted capacitor voltages, ought to any unbalance happen amid a transient or a surprising operation, the above technique will create an incorrect air conditioning side waveform which can be not quite the same as the real asked for vector by the control framework. This can bring about the creation of even-music, uneven present and unpredicted element

conduct. Be that as it may, in a few applications, the necessity of having adjusted capacitor voltages might be excessively prohibitive. It is conceivable to work with either adjusted or lopsided capacitor voltages. The strategy proposed in this paper depends on the opportunity of having parity or lopsided capacitor voltages. In such applications, it is imperative to have the capacity to create a precise reference vector in view of (1), independent of whether the capacitor voltages are adjusted or not, to accomplish the craved destinations of the framework.

C. Uneven Capacitor Voltages

Fig. 3 demonstrates a general structure of a matrix associated threelevel inverter demonstrating the dc and air conditioning sides of the inverter. The dc-side framework, appeared as "N" can be comprised of many circuit designs, contingent upon the utilization of the inverter.

For example, the dc-side framework can be a sun oriented PV, a twist generator with an amending circuit, a battery stockpiling framework or a blend of these frameworks where the dc voltage over every capacitor can be distinctive or break even with. One of the fundamental thoughts of this paper is to have a general perspective of the exchanging consequences for a three-wire association of a three-level NPC inverter with a mix of these frameworks on the dc side. Numerically, in a three-wire association of a two-level inverter, the dq0 field, vd, vq , and v0 of the inverter in vector control can be considered as having two degrees of flexibility in the control framework; on the grounds that the zero arrangement voltage, v0 will have no impact on the framework conduct in both the dc and the air conditioner side of the inverter. Be that as it may, in the three-level three-wire application showed in Fig. 3, with settled vd and vq despite the fact that v0 will have no impact on the air conditioner side conduct, it can be valuable to exploit v0 to give another level of opportunity to control the sharing of the capacitor voltages in the dc transport of the inverter. By doing this, it is currently conceivable to work and control the inverter under both adjusted and unequal capacitor voltages while keeping on producing the right voltages in the air conditioner side. This component is especially valuable in applications where the two capacitor voltages can be distinctive, for example, while associating two PV modules with various MPPT focuses, or interfacing a PV module over the two capacitors and including battery stockpiling at the midpoint of the two capacitors, or interfacing battery stockpiling to each of the capacitors with the capacity to exchange diverse power from every battery stockpiling.

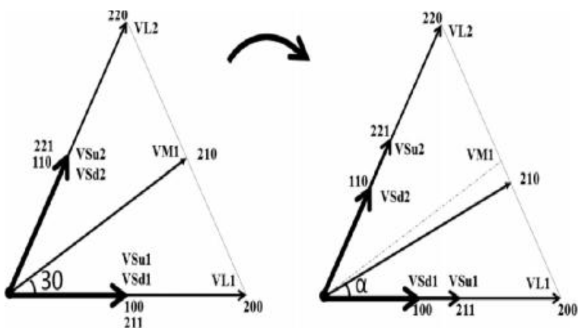

Fig. 4. Vector diagram in the first sector of Fig. 1(b) showing the change of the vectors using balanced dc and unbalanced dc assuming $Vc1 < Vc2$.

D. Effect of Unbalanced Capacitor Voltages on the Vector Diagram

In the vector diagram shown in Fig. 1(b), capacitor voltage unbalance causes the short and medium vectors to have different magnitudes and angles compared to the case when the capacitor voltages are balanced. Fig. 4 shows the differences between two cases as highlighted in the first sector of the Fig. 1(b) for $VC1 < VC2$. Vector related to the switching state _VI can be calculated from the reference paper[1].

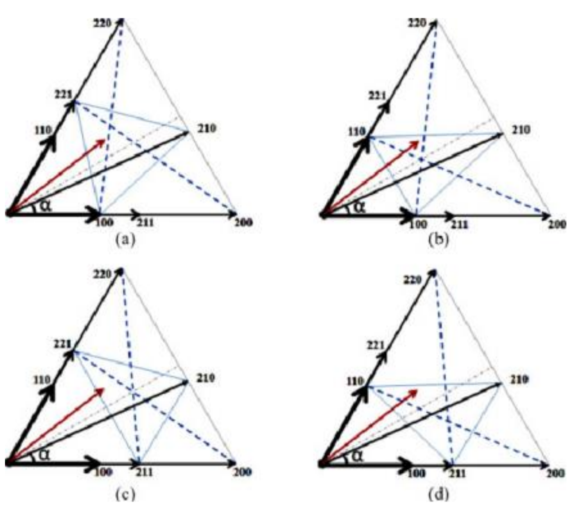

Fig. 5. Different possible vector selection ideas.

Traditionally, each pair of short vectors is considered to be redundant, as the selection of any of the short vectors at any instance will have the same effect on the ac side. However, when the two capacitor voltages are different, the short vectors cannot be considered to be redundant any more. Thus, when h _= 0.5, each different short vector needs different timing to generate the requested vector based on (1).

E. Selecting Vectors Under Unbalanced DC Voltage Condition and Their Effects on the AC Side of Inverter

To produce a reference vector in view of (1), unique blends can be actualized. Fig. 5 indicates distinctive conceivable vector choices to create a reference vector (_V ∗) in the main area in view of the determinations of various short vectors. For instance, to create _V ∗ in view of Fig. 5(a), one of taking after mixes can be chosen with legitimate planning in light of (1). The mixes are: (221–210–100), (221–220–100), (221– 200–100), (221–200–Zero), (000–220–Zero), (220–200–Zero), where "Zero" can be "000" or "111" or "222". This exhibits there is adaptability in picking the right vector determinations. Albeit these choices with appropriate planning can create a similar reference vector, they impactsly affect the dc and air conditioning side of the inverter in their quick conduct. To explore the air conditioner side conduct, the exactness of the created voltage must be analyzed. To the extent the air conditioner side is concerned, in a perfect world the asked for voltage_V ∗ (t) ought to be precisely and at the same time created in the three periods of the inverter to have the right quick current in the air conditioner side of the framework. In any case, as a result of the impediment of the inverter to create the correct estimation of the asked for voltage in each stage, in the brief timeframe Ts , just the normal estimation of the asked for vector _V ∗ for the predetermined time window of Ts can be delivered. To research the consistent time conduct of the air conditioner side voltages, the blunder vector _e (t) can be figured so as to decide how far the created voltage digresses from the asked for vector as takes after:

$$\vec{e}(t) = \vec{V}^*(t) - \vec{V}_{\mathrm{apl}}(t)$$

$$E(t) \triangleq \left| \int_0^t \vec{e}(t)dt \right|; \qquad 0 \le t \le T_s \tag{2}$$

where _Vapl(t) is the connected vector at the time "t". This mistake can bring about consonant current over the impedance associated between the inverter and the matrix. In the event that this impedance is an inductor then the swell in the inductors current _IrL can be communicated as To determine (13), it is expected that the asked for vector _V ∗ (t) will produce sinusoidal current in the inductor, which is regularly worthy in the persistent time conduct of the framework. In light of (11) and (12), the total estimation of mistake E(t) is specifically identified with the greatness of the inductors current swell. Albeit in light of (1) and (11), E (Ts) = 0 or the whole of mistakes amid the period Ts is zero; yet to lessen the extent of high recurrence swells, it is imperative to limit the blunder at each time moment. To accomplish this, the three closest vectors (TNV) are typically utilized. For instance, in Fig. 5(a), to create the asked for vector _V ∗, in the TNV strategy, the gathering (221, 210, 100, or 211) seems, by all accounts, to be the best three closest vectors to be picked. Likewise, to reduceE (t), a brilliant planning calculation for every vector in the TNV strategy has been proposed, for example, partitioning an opportunity to apply every vector into at least two shorter circumstances. In any case, this will have the impact of expanding exchanging misfortunes. Partitioning by two is normal, worthy arrangement. Also, lessening Ts will decrease the blunder E (t) while enhancing the exactness of the asked for vector produced by the control framework. Concurring tothe essential govern of advanced control, exactness of the asked for vector estimation can be enhanced by decrease of the testing time and the vector count time.

F. Choosing Vectors Under Unbalanced DC Voltage Conditions and Their Effects on DC Side of the Inverter

To the extent the dc side is concerned, diverse vectors effectsly affect the capacitor voltages which rely on upon the

entirety of the approaching streams from the dc side and the inverter side. Fig. 3 demonstrates ip, io , and in as dc-side framework streams which are reliant on the dc-side framework circuit topology and capacitor voltages. The streams originating from the inverter are identified with the inverter exchanging and the air conditioner side of inverter ebbs and flows which can be straightforwardly influenced by the actualized vectors in the inverter. Choosing distinctive vectors will exchange air conditioning side streams and power contrastingly to the capacitors .These vector determination conditions are depicted in the paper[1].

III .Fuzzy controller:

Fuzzy rationale has two unique implications. In a limited sense, fuzzy rationale is a consistent framework, which is an augmentation of multivalve rationale. Be that as it may, in a more extensive sense fuzzy rationale (FL) is practically synonymous with the hypothesis of fuzzy sets, a hypothesis which identifies with classes of articles with unsharp limits in which enrollment involves degree. In this point of view, fuzzy rationale in its restricted sense is a branch of fl. Indeed, even in its more limited definition, fuzzy rationale varies both in idea and substance from customary multivalve legitimate frameworks.

In fuzzy Logic Toolbox programming, fuzzy rationale ought to be deciphered as FL, that is, fuzzy rationale in its wide sense. The fundamental thoughts hidden FL are clarified unmistakably and adroitly in Foundations of Fuzzy Logic. What may be included is that the fundamental idea hidden FL is that of a phonetic variable, that is, a variable whose qualities are words as opposed to numbers. Basically, quite a bit of FL might be seen as a philosophy for registering with words instead of numbers. In spite of the fact that words are inalienably less exact than numbers, their utilization is nearer to human instinct. Moreover, figuring with words abuses the resilience for imprecision and in this way brings down the cost of arrangement.

Another fundamental idea in FL, which assumes a focal part in the vast majority of its applications, is that of a fuzzy if-then run or, basically, fuzzy run the show. Despite the fact that control based frameworks have a long history of utilization in Artificial Intelligence (AI), what is lost in such frameworks is a system for managing fuzzy consequents and fuzzy forerunners. In fuzzy rationale, this system is given by the math of fuzzy guidelines. The analytics of fuzzy guidelines fills in as a reason for what may be known as the Fuzzy Dependency and Command Language (FDCL).

IV.SIMULATION CIRCUITS AND RESULTS

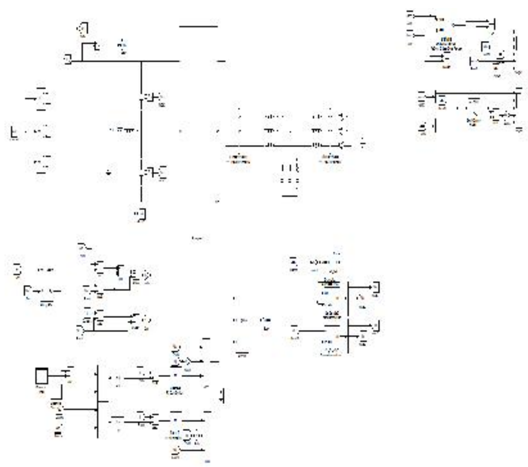

FIG6: Control system diagram to integrate PV and battery storage.

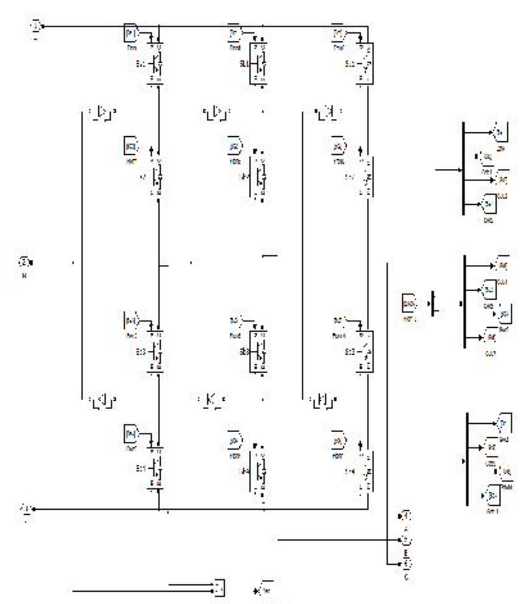

FIG7:NPC INVERTER

A. First Theoretical Scenario

In the primary situation, it is accepted that the sunlight based illumination will deliver ISC = 5.61 An in the PV module as indicated by (21). The MPPT control square, appeared in Fig. 6, decides the asked for PV module voltage V ∗ dc , which is 117.3 V to accomplish the most extreme power from the PV framework that can produce 558 W of electrical power. The asked for dynamic energy to be transmitted to the framework is at first set at 662Wand is changed to 445Wat time t = 40 ms and the responsive power changes from zero to 250 VAr at timet = 100 ms. Fig. 8 demonstrates the consequences of the principal situation recreation. Fig. 8(a) and (b) demonstrates that the proposed control framework has accurately taken after the asked for dynamic and receptive power, and Fig. 8(c) demonstrates that the PV voltage has been controlled precisely (to be 177.3 V) to get the greatest power from the PV module. Fig. 8(d) demonstrates that battery is releasing when the lattice power is more than the PV power, and it is charging when the PV power is more than the framework control. Fig. 8(d) demonstrates that before time t = 40 ms, the battery releases at 1.8 A since the power produced by the PV is lacking. After time t = 40 ms, the battery current is about –1.8 A, meaning that the battery is being charged from the additional force of the PV module. Fig. 8(e) demonstrates the inverter air conditioning side streams, and Fig. 8(f) demonstrates the lattice side streams with a THD under 1.29% due to the LCL channel. The recreation brings about Fig. 8 demonstrate that the entire framework delivers a decent element reaction. Fig. 10 demonstrates the inverter waveforms for a similar situation. Fig. 9(a) demonstrates the line-to-line voltage *Vab* , and Fig. 9(b) shows the phase to midpoint voltage of the inverter *Vao* . Fig. 9(c) and (e) shows *Vao*, *V*on, and *Van* after mathematical filtering to determine the average value of the PWM waveforms.

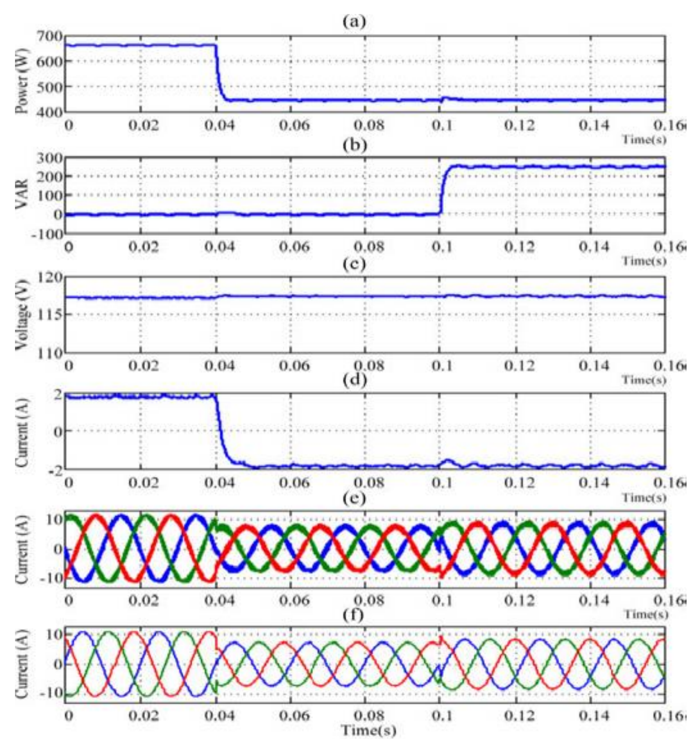

Fig. 8. Simulated results for the first scenario. (a) Active power injected to the grid. (b) Reactive power injected to the grid. (c) PV module DC voltage.
(d) Battery current. (e) Inverter AC current. (f) Grid current.

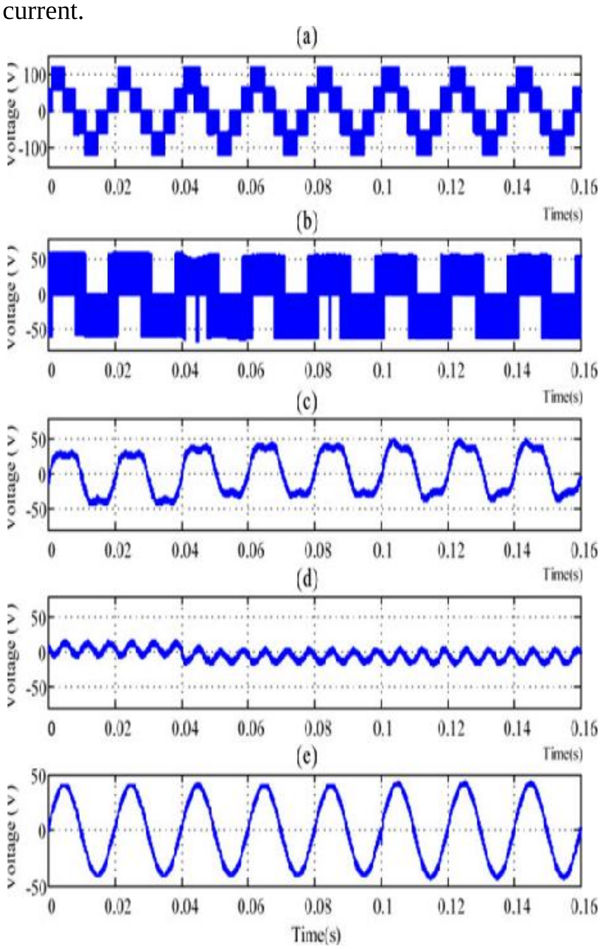

Fig. 9. Simulated inverter waveforms. (a) Vab-Phase to phase inverter voltage. (b) Vao-Inverter phase voltage reference to midpoint. (c) Filtered Von-
Filtered inverter phase voltage reference to midpoint. (d) Filtered Von-Filtered midpoint voltage reference to neutral. (e) Filtered Van-Filtered phase voltage reference to neutral.

B. Second Theoretical Scenario

In the second scenario, it is assumed that the solar irradiation will change such that the PV module will produceI_{SC} = 4.8, 4, and 5.61 A. The MPPT control block determines that V_{dc} needs to be 115.6, 114.1, and 117.3 V to achieve the maximum power from the PV units which can generate 485, 404, and 558 W, respectively. The requested active power to be transmitted to the grid is set at a constant 480 W and the reactive power is set to zero during the simulation time. Fig. 10 shows the results of the second scenario simulation. Fig. 10(a) shows that the inverter is able to generate the requested
active power. Fig. 10(b) shows that the PV voltage was controlled accurately for different solar irradiation values to
obtain the relevant maximum power from the PV modules. Fig. 10(c) shows that the charging and discharging of the
battery are correctly performed. The battery has supplemented the PV power generation to meet the requested demand by the grid. Fig. 10(d) illustrates that the quality of the waveforms of the grid-side currents are acceptable, which signifies that the correct PWM vectors are generated by the proposed control strategy. By using the proposed strategy, the inverter is able to provide a fast transient response. Fig. 10(e) shows the *a*-phase voltage and current of the grid, which are always in-phase signifying that the reactive power is zero at all times.

Table1:comparison of PI and FUZZY controller thd for different scenario’s

THD FOR	1^{ST} SCENARIO	2^{ND} SCENARIO	3^{RD} SCENARIO
INPUT VOLTAGE	4.16%	4.13%	4.19%
INPUT CURRENT	3.58%	3.29%	7.66%

THD FOR	1^{ST} SCENARIO	2^{ND} SCENARIO	3^{RD} SCENARIO
INPUT VOLTAGE	0.38%	0.28%	0.30%
INPUT CURRENT	0.20%	0.18%	2.68%

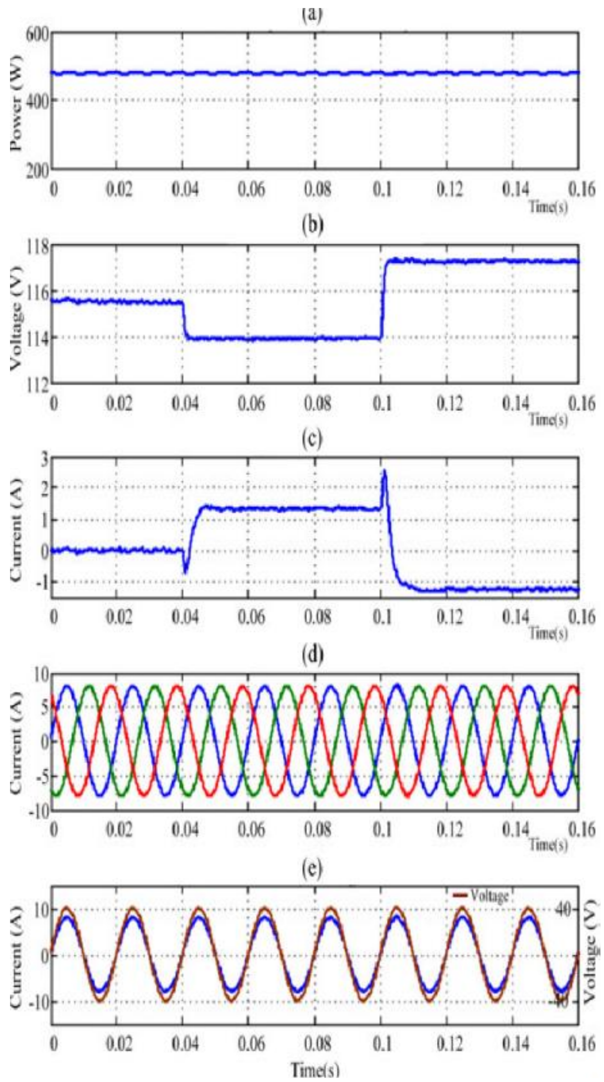

Fig. 10. Simulated results for the second scenario. (a) Active power injected to the grid. (b) PV module DC voltage. (c) Battery currents. (d) Grid side currents. (e) Grid side Phase (a) voltage and its current.

V. CONCLUSION

A novel topology for a three-level NPC voltage source inverter that can incorporate both renewable vitality and battery stockpiling on the dc side of the inverter has been introduced. A hypothetical system of a novel amplified unbalance three-level vector adjustment strategy that can create the right air conditioning voltage under uneven dc voltage conditions has been proposed. Another control calculation for the proposed framework has likewise been introduced so as to control stream between sun oriented PV, battery, and lattice framework, while MPPT operation for the sunlight based PV is accomplished at the same time. The viability of the proposed topology and control calculation was tried utilizing reproductions and results are displayed. The outcomes show that the proposed framework can control air conditioning side current, and battery charging and releasing streams at various levels of sunlight based illumination. In this venture fuzzy controller used to lessened the sounds when contrasted with the PI controller. The recreation performed in MATLAB/SIMULINK condition.

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