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Modular Cascaded H-Bridge Multilevel PV Inverter with Distributed MPPT for Grid-Connected Applications

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Abstract:*This paper presents a modular cascaded H-bridge multilevel photovoltaic (PV) inverter for single- or three-phase gridconnected applications. The modular cascaded multilevel topology helps to improve the efficiency and flexibility of PV systems.To realize better utilization of PV modules and maximize the solar energy extraction, a distributed maximum power pointtracking control scheme is applied to both single- and three-phase multilevel inverters, which allows independent control of eachdc-link voltage. For three-phase grid-connected applications, PV mismatches may introduce unbalanced supplied power, leadingto unbalanced grid current. To solve this issue, a control scheme with modulation compensation is also proposed. Anexperimental three-phase seven-level cascaded H-bridge inverter has been built utilizing 9H-bridge modules (three modulesper phase).*

Keywords-Cascaded multilevel inverter, distributed maximum power point (MPP) tracking (MPPT), modular, modulation compensation, photovoltaic (PV).

I. INTRODUCTION

Solar-electric-energy demand has grownconsistently by 20%–25% per annum over the past20 years [1], and the growth is mostly in gridconnected applications. Because of the decreasingresources like fossil fuels and conventional energyresources and pollution problems. Thereforemarket demand for PV systems are gets increasing.[2]–[7]. The configurations of PV systems areshown in Fig. 1. Cascaded inverters consist ofseveral converters connected in series; thus, thehigh power and/or high voltage from thecombination of the multiple modules would favorthis topology in medium and large grid-connectedPV systems. configurations of the PV system ofFive inverter: 1) central inverters families; 2) stringinverters; 3) multistring inverters; 4) ac-moduleinverters; and 5) cascaded inverters There are twotypes of cascaded inverters. Fig. 1(e) shows acascaded dc/dc converter connection of PVmodules. Each PV module has its own dc/dcconverter, and the modules with their associatedconverters are still connected in series to create ahigh dc voltage, which is provided to a simplifieddc/ac inverter.

This approach combines aspects of stringinverters and ac-module inverters and offers thebenefits of individual module maximum point(MPP)tracking (MPPT), however it's less costlyand more efficient than ac-module inverters.However, there are 2 power conversion stages inthis configuration. Another cascaded inverter isshown in Fig. 1(f), where every PV panel isconnected to its own dc/ac inverter, and thoseinverters are then placed serial to achieve a highvoltage level. This cascaded inverter} wouldmaintain the advantages of “one converter perpanel,” such as higher utilization per PV module,capability of blending completely different sources,and redundancy of the system. additionally, thisdc/ac cascaded inverter removes the necessity forthe per-string dc bus and therefore the central dc/acinverter,that additional improves the potency. Thedistributed MPPT control scheme can be applied toboth single and three-phase systems. In addition,for the presented three-phase grid-connected PVsystem, if each PV module is operated at its ownMPP. The modular cascaded H-bridge multilevelinverter, which needs associate isolated dc supplyfor every H-bridge, is one dc/ac cascaded electricalconverter topology. The separate dc links withinthe structure inverter build independent voltagemanagement possible.

As a result, individual MPPT managementin every PV module will be achieved, and thereforethe energy harvested from PV panels will bemaximized. Meanwhile, the modularity and low cost of Multi level converters would position themas a first-ratecandidate for the next generation ofefficient, robust, and reliable

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grid connected solarenergy electronics. Astandard cascaded H-bridgestructure inverter topology for single- or threephase grid-connected PV systems ispresentedduring this paper. The panel mismatch issues areaddressed to show the necessity of individualMPPT control, and a control scheme withdistributed MPPT control is then proposed. Athree-phase modular cascaded multilevel inverterprototype has been built. Each H-bridge isconnected to a 185-W solar panel. The modulardesign will increase the flexibility of the systemand reduce the cost as well. To show the necessityof individual MPPT control, a five-level two-Hbridge single-phase inverter is simulated inMATLAB/SIMULINK.

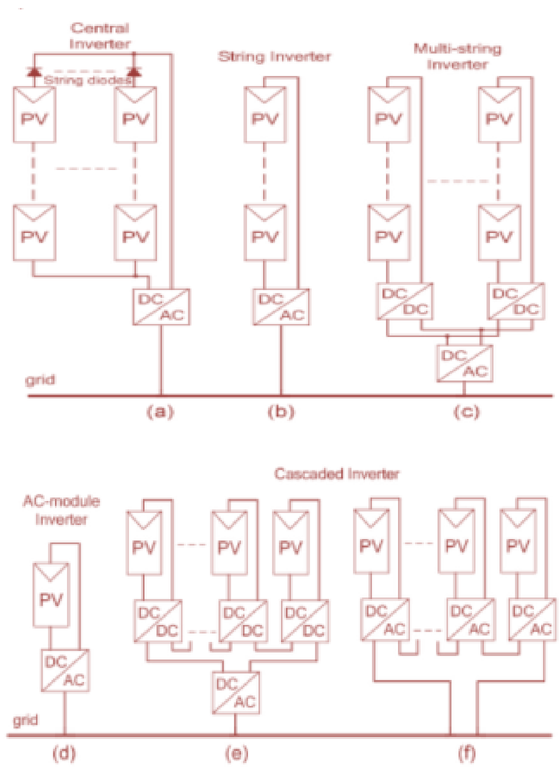

Fig. 1. Configurations of PV systems. (a) Central inverter. (b) String inverter.(c) Multistring inverter. (d) AC-module inverter.(e) Cascaded dc/dc converter.(f) Cascaded dc/ac inverter

II. CASCADED MULTILEVEL INVERTER

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 31.1. Each separate dc source (SDCS) is connectedto a single-phase full-bridge, or H-bridge, inverter.The ac outputs of each of the different full-bridge inverter levels are connected in series such that thesynthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverteris defined by m = 2s+1, where s is the number of separate dc sources. The Conducting angles θ1, θ2, θs, can be picked such that the voltage all out symphonious twisting is a base. By and large, theseedges are picked so that prevalent lower recurrence music, fifth, seventh, eleventh, and thirteenth, composition are executed. More detail onconsonant end systems will be displayed in the following area.Multilevel fell inverters have been proposed for such applications as static var era, an interface with renewable vitality sources, andfor battery-based applications.Has showed a model multilevel fell static var generator associated in parallel with the electricalframework that could supply or draw responsive current from an electrical framework the inverter could be controlled to either
manage the force component of the current drawn from the source or the transport voltage of the electrical framework where theinverter was associated. Have additionally demonstrated that a course inverter can be straightforwardly associated in arrangementwith the electrical framework for static var remuneration.Fell inverters are perfect for interfacing renewable vitality sources with an air conditioner lattice, in light of the requirement forindependent dc sources, which is the situation in applications, for example, photovoltaic or power modules. Fell invertershave likewise been proposed for use as the principle footing drive in electric vehicles, where a few batteries or ultra capacitors areappropriate to serve as SDCSs.The fell inverter could likewise serve as a rectifier/charger for the batteries of an electric vehiclewhile the vehicle was associated with an air conditioner supply .Additionally, the course inverter can go about as a rectifier in avehicle that utilizations regenerative braking. A course topology that uses various dc levels, which as opposed to being indistinguishable in worth are products of each other. It likewise utilizes a mix of major recurrence exchanging for a portion of the levels and PWM exchanging for part of the levels toaccomplish the yield voltage waveform. This methodology empowers a more extensive

differences of yield voltage extents;nonetheless, it additionally brings about unequal voltage and current evaluations for each of the levels and loses the upside of having
the capacity to utilize indistinguishable, secluded units for every level.

III. PANEL MISMATCHES

PV mismatch is an essential issue in the PV framework. Because of the unequal got irradiance, diverse temperatures, and maturingof the PV boards, the MPP of each PV module might be distinctive. In the event that each PV module is not controlled freely, theeffectiveness of the general PV framework will be diminished. To demonstrate the need of individual MPPT control, a five-leveltwo-H-span single-stage inverter is recreated in MATLAB/SIMULINK. Every H-span has its own 185-W PV board associated as aconfined dc source. The PV board is demonstrated by detail of the business PV board from Astrometry CHSM-5612M. Consider aworking condition that every board has an alternate illumination from the sun; board 1 has irradiance S = 1000 W/m^2, and board 2has S = 600 W/m2. In the event that lone board 1 is followed and its MPPT controller decides the normal voltage of the two boards,the force extricated from board 1 would be 133 W, and the force from board 2 would be 70W, as can be found in Fig. 3. Withoutindividual MPPT control, the aggregate force reaped from the PV framework is 203W. Be that as it may, Fig. 4 demonstrates theMPPs of the PV boards under the distinctive irradiance. The most extreme yield power qualities will be 185 and 108.5 W when theS qualities are 1000 and 600 W/m2, separately, which implies that the aggregate force collected from the PV framework would be293.5 W if individual MPPT can be accomplished. This higher worth is around 1.45 times of the one preceding. In this way,individual MPPT control in each PV module is required to build the proficiency of the PV framework. In a three-stage matrixassociated PV framework, a PV confuse may bring about more issues. Beside diminishing the general productivity, this could evenacquaint unequal force supplied with the three-stage network associated framework. On the off chance that there are PV befuddlesbetween stages, the information force of every stage would be distinctive. Since the network voltage is adjusted, this distinction ininformation force will bring about lopsided current to the framework, which is not permitted by matrix models. For instance, tounbalance the current per stage more than 10% is not took into account a few utilities, where the rate lopsidedness is ascertained bytaking the greatest deviation from the normal current and isolating it by the normal current.

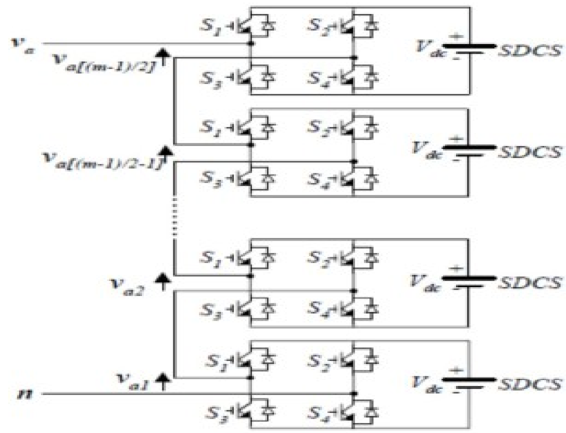

Figure 2.Single-phase structure of a multilevel cascaded H-bridges inverter.

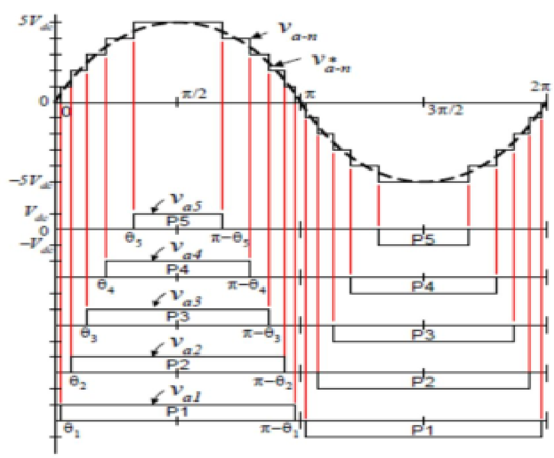

Figure 3.Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

To solve the PV mismatch issue, a control scheme with individual MPPT control and modulation compensation is proposed. Thedetails of the control scheme will be discussed in the next section.

A. Distributed MPPT Control

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Keeping in mind the end goal to dispense with the antagonistic impact of the confounds and expand the effectiveness of the PVframework, the PV modules need to work at various voltages to enhance the use per PV module. The different dc joins in the fell Hspan multilevel inverter make autonomous voltage control conceivable. To acknowledge individual MPPT control in each PVmodule, the control plan proposed is upgraded for this application. The conveyed MPPT control of the three-stage fell H-spaninverter is appeared in Fig. 5. In every H-span module, a MPPT controller is added to create the dc-join voltage reference. Every dcjoin voltage is contrasted with the comparing voltage reference, and the entirety of all mistakes is controlled through an aggregatevoltage controller that decides the present reference Idref. The receptive current reference Iqref can be set to zero, or if responsiveforce pay is required, Iqref can likewise be given by a responsive current number cruncher. The synchronous reference outline stagebolted circle (PLL) has been utilized to discover the stage point of the matrix voltage. As the great control plan in three-stageframeworks, the matrix streams in abc directions are changed over to dq arranges and managed through proportional–integral (PI)controllers to create the tweak list in the dq organizes, which is then changed over back to three stages.The appropriated MPPT control plan for the single-stage framework is about the same. The aggregate voltage controller gives thesize of the dynamic current reference, and a PLL gives the recurrence and stage point of the dynamic current reference. The presentcircle then gives the tweak record. To make each PV module work at its own particular MPP, take stage a for instance; the voltages
vdca2 to vdcan are controlled exclusively through n − 1 circles. Every voltage controller gives the regulation list extent of one Hspan module in stage a. After increased by the regulation record of stage a, n − 1 balance lists can be acquired. Likewise, the balancelist for the primary H-scaffold can be acquired by subtraction. The control plans in stage's b and c are just about the same. The maindistinction is that all dc-join voltages are directed through PI controllers, and n tweak record extents are gotten for every stage.

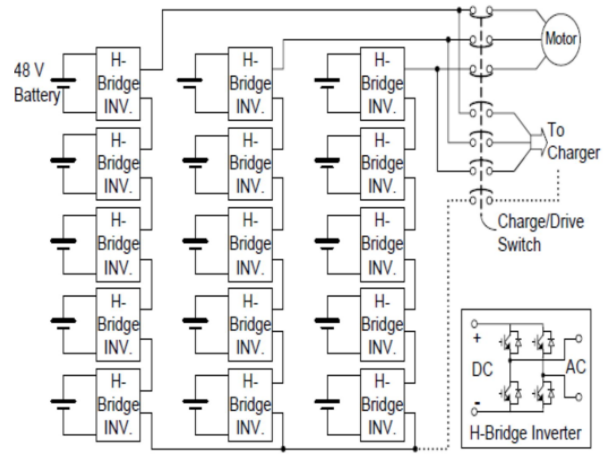

Figure 4.Three-phase wye-connection structure for electric vehicle motor drive and battery charging.

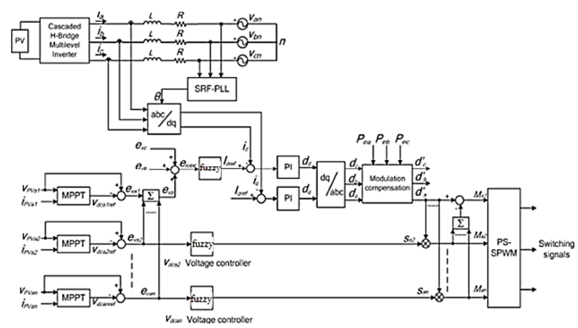

Fig. 5. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.

A phase-shifted sinusoidal pulse width modulation switching scheme is then applied to control the switching devices of each H-bridge. It can be seen that there is one H-bridge module out of N modules whose modulation index is obtained by subtraction. Forsingle-phase systems, N = n, and for three-phase systems, N = 3n, where n is the number of H-bridge modules per phase. The reasonis that N voltage loops are necessary to manage different voltage levels on N H-bridges, and one is the total voltage loop, whichgives the current reference. So, only N − 1 modulation indices can be determined by the last N – 1 voltage loops, and onemodulation index has to be obtained by subtraction. Many MPPT methods have been developed and implemented. The incrementalconductance method has been used in this paper. It lends itself well to digital control, which can easily keep track of previous valuesof voltage and current and make all decisions.

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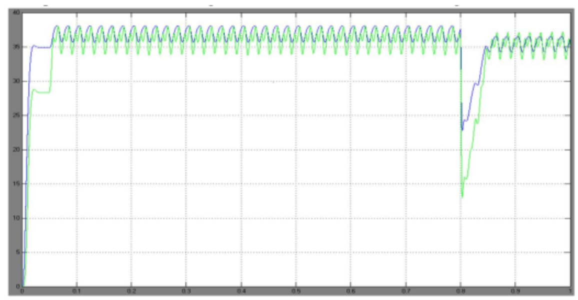
B. Modulation Compensation

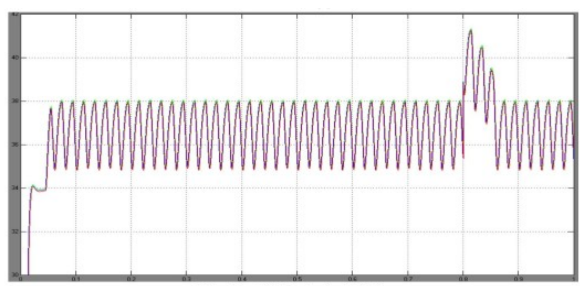
As mentioned earlier, a PV mismatch may bring about more issues to a three-stage secluded fell H-span multilevel PV inverter.With the individual MPPT control in every H-span module, the information sunlight based force of every stage would be distinctive,which acquaints unequal current with the framework. To tackle the issue, a zero arrangement voltage can be forced upon the stagelegs keeping in mind the end goal to influence the present streaming into every stage. In the event that the overhauled inverter yieldstage voltage is corresponding to the uneven force, the present will be adjusted.Accordingly, the regulation pay hinder, as appeared in Fig. 6, is added to the control arrangement of three-stage measured fellmultilevel PV inverters. The key is the means by which to overhaul the regulation record of every stage without expanding theComplexity of the control system.

IV. SIMULATION RESULTS

To verify the proposed control scheme, the three-phase gridconnected PV inverter is simulated in two different conditions. First, allPV panels are operated under the same irradiance S=1000W/m^2 and temperature T=25◦C. At t=0.8s, the solar irradiance on thefirst and second panels of phase adecreases to 600W/m^2, and that for the other panels stays the same. The dc-link voltages of phase a are shown in Fig. 6. At thebeginning, all PV panels are operated at an MPP voltage of 36.4V. As the irradiance changes, the first and second dcjoin voltages abatement and track the new MPP voltage of 36 V, while the third board is still worked at 36.4V. The PV currentwaveforms of stage an are appeared in the Fig. 7. After t= 0.8s, the streams of the first and second PV boards are much littler becauseof the low irradiance, and the lower swell of the dc-join voltage can be found in Fig. 6(a). The dc-join voltages of stage b areappeared in Fig. 8.



(a)



(b)

Figure. 6. DC-link voltages of phase a with distributed MPPT (T = 25 ◦C).(a) DC-link voltage of modules 1 and 2. (b) DC-link voltage of module 3

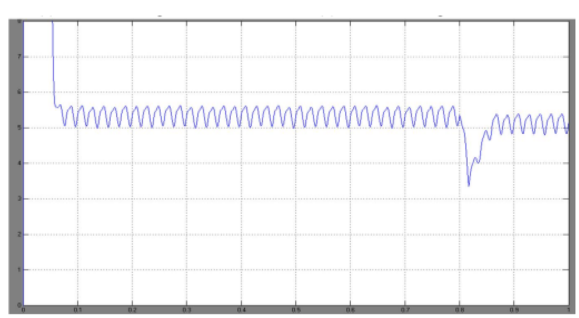


Figure 7. PV currents of phase a with distributed MPPT (T = 25 ◦C).

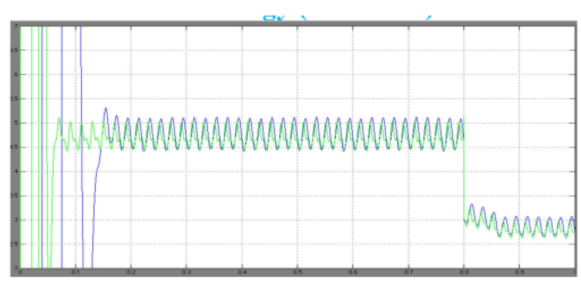


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Figure 8. PV currents of phase a with distributed MPPT (T = 25 ◦C).

CONCLUSION

In this paper, a measured H-span multilevel inverter for network associated PV applications has been displayed. The multilevelinverter topology will enhance the usage of associated PV modules if the voltages of the different dc connections are controlledfreely. In this way, an appropriated MPPT control plan for both single-and three-stage PV frameworks has been connected toincrease the general output of PV frameworks. For the three-stage framework associated PV framework, PV modules maypresent unequal supplied power, bringing about uneven infused network current. A tweak pay plan, which won't expand the manysided quality of the control framework or cause additional force misfortune, is added to adjust the lattice current.

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