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Design of PD-PWM Based Asymmetrical 15-Level ReducedSwitchMultilevelInverterfor PVApplications

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ABSTRACT:This paperpresents anewsingle-phase,15-levelinverter forsolarphotovoltaic(PV)applications. Itfeatures fewercomponentsandcanbeusedtoextractmoreenergyfromthemodules.Theproposedinvertercanhelpimprovesystemefficiencyandlowercosts. The proposed converter can be used to boost the output voltage of the solar PV modules from the MPPT to the maximum level. It istestedusingthedSPACERTI1104controllerandthesoftwarepackagesSimulinkandMATLAB.Theresultsofthestudydemonstratethatthepropo seddevice canperformwell underdifferentloadconditions.

keywords: Solarphotovoltaic(PV)inverter,MPPT,converter,totalharmonicdistortion(THD).

1.INTRODUCTION

Because of the vast usage of the fossil fuels, there is a sharp decrement in theavailability of fossil fuel resources. To meet the day-to-dayrequirementsofelectricity,it'stimetoshifttotherenewableenergysources.Withtheadvancementsinsolarenergy,thecontroltechniquesof grid connected inverters has been deploying from the few years. In order to obtain the above mentioned features , a multilevel inverterwith minimum number of switches can be implemented to get a smooth sine wave . MLI'sis widely used in high power applications suchaslarge inductiondrive, UPSsystemsandFACTSsystems.

Required output will be obtained from several level ofdc links that are used in the circuit .Most commonly there are three differenttypes of multilevel inverter topologies [1]-[2] used and they are Diode-clamped MLI's, Flying capacitor MLI's and Cascaded H-BridgeMLI's. Basically, three control techniques are available for controlling the grid connected multilevel inverters and those are Carrier wavecomparison technique, Hysteresis loop control technique and predictive control technique. The widely used technique is the carrier wavecomparison control, which tracks the output current by using a PI Controller [3]. But, it fails in reducing the steady-state error between thetarget current and the original current. The simplest control technique is the hysteresis loop control technique and it has the advantage ofhaving good robustness [4]-[6], but it has high ripple content in the output current, which may increase the losses and thereby reducing theefficiency of the system. The another major drawback is the unstable switching frequency. Model Predictive control is the main branch ofPredictive control techniques. A model has to be established for the system in MPC [7]-[12]. Depending upon the designed model, theupcoming values of the variables can be predicted. Based on the comparison of the predicted values and the required reference values, thecontrolactionatthispresentmomentwillbe taken.MPCstructureisverysimplefordesigningandmodelling.Predictivecontrolmodecanbeimplementedonadigitalsignal processorand itsoutputhassmall distortionsin the currentandharmonicsareminimized.

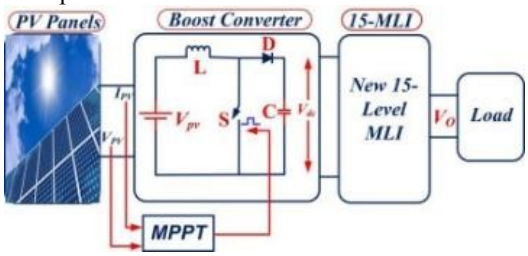


FIGURE1.Proposedsystemconfiguration.

1.CONFIGURATIONOFPROPOSEDSYSTEMS

Figure 1 depicts the proposedSolarPV Arrays-basedconverter boost converterwithanintegratedinverter. Cascadedor parallelphotovoltaic cells must be connected based on whether higher voltage or current is required. They are built to last and can withstand theharshest environmental conditions. This Solar PV cell design is accomplished by simulating natural environmental conditions, which arethen processed to produce the Irradiance vs Time graph and the Temperature vs Time graph, both of which have been simulated for tenseconds. A solar cell can be represented as a current source connected in parallel to a diode, with the output of the current source beingdirectly proportional to the amount of light falling on the cell. The diode thus defines the VI characteristics of the cell. It cannot use thismodel to simulate reality because it lacks other external factors besides sunlight. These, however, can be solved by increasing complexityand accuracy. The diodes are then connected in parallel with two distinct sets of saturation current. Consider the temperature dependenceofthe diode and itssaturationcurrentconnectedwitha seriesofresistancesinthisprogramme.

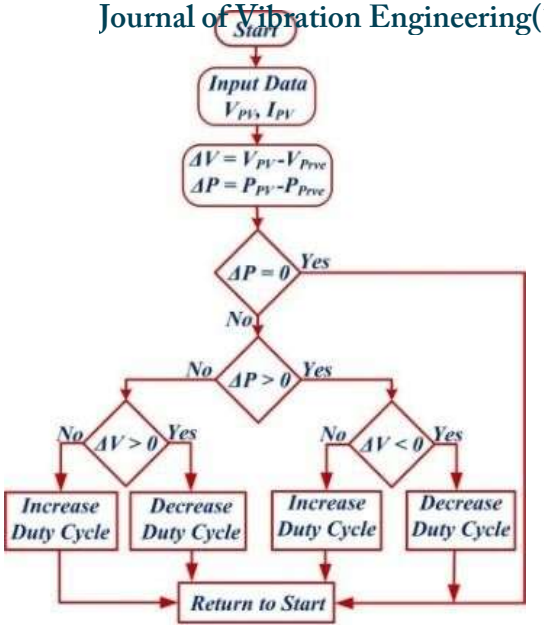


FIGURE2.MPPTflowchart.

The quality of the output of a power-producing device is determined by its ability match the curve. This is because, unlike other facilities,renewable sources can't be easily controlled. They have various external factors that can affect the output, which is why algorithms aredevelopedtoensurethatthepowersupplyisalwaysregulated.Thiscaseinvolvestheimplementationofamodifiedversionofthealgorithmknown as the maximum power point tracking. This electronic boost converter is used in combination with a solar cell array to provide thebest possible power output. This model was chosen to study the scope of work and the various aspects of a project in the context of thedevelopment of a tracking algorithm for real-time radiation therapy. It takes into account the various peak power points of the system andcomparesthemtothestrategiesandconfigurationsthatcanbeusedtoachievethebestpossibleresults.TheconventionalDCtoDCconverteris necessary because the voltage generated by renewable sources is extremely low and difficult to regulate. As a result, these convertersassist the system in reaching the required voltage level for long-term practical operation. C and L are the names given to the capacitor andinductorwithvaluesof3.2nFand94.22uH, respectively.

TABLE1.Systemvariables.

Item	Parameters
VPV	115V
Vo	400V
fs	100kHz
Capacitor	3.2nF
Inductor	94.22Uh
Duty ratio	71.25%
IGBT	CM75DU-12, 600V, 75A
dSPACE RTI Controller	1104

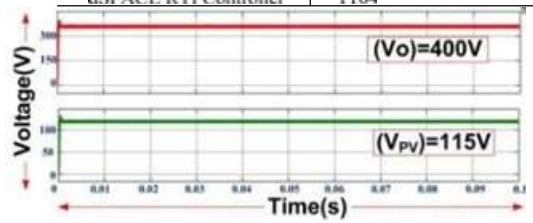
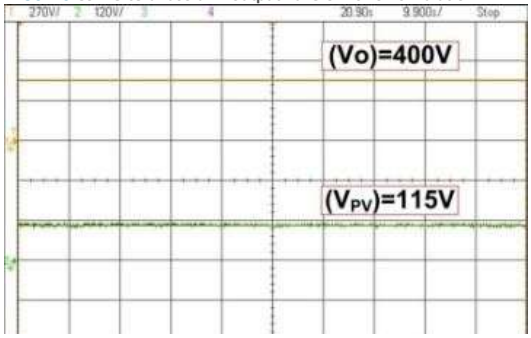


FIGURE3.ConverterandsolarPVoutputwaveformsfromsimulation.



Itactsasagatepulsetotheboostconverter,whichaddsadelaytothesystem'smaximumpowerpointtracker.Tomeasurethecurrentandvoltageofthedevice,setupanammeterandavoltmeter.Then,booststheconverterandasnubbercircuit,whichhasaresistanceof100,bysettingthecapacitor'smaximumandinfinitevalues.After0.019seconds,theboostvoltageoftheconverter,whichis400volts,isgenerated.Vo= $\frac{Vpv}{(1-D)}$(1)

Thesourcesfortheproposedsystemaretakenintoaccountbythe PV simulator 5kW&8A.Theconvertersimulationandexperimental results are displayed in Figures 3–4 for solar PV. Increased DC-linking voltage from solar PV is possible with the boost converter. Theobtained DC-linkvoltagecanbefedintotheproposedinverter,whichwillgenerate anACsteppedwaveform.

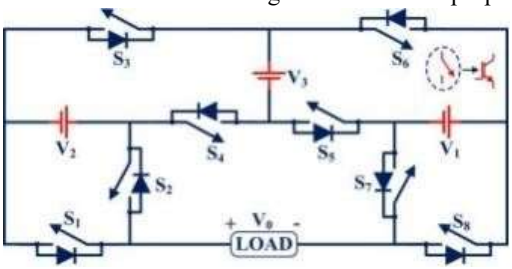


FIGURE5. Proposedtopologyof15levels.

TABLE2. SwitchingstatesfOr15L-MLI

1	S2, S3, S5, S7
2	S2, S3, S5, S8
3	S1, S3, S7, S5
4	S1, S3, S5, S8
5	S2, S3, S6, S7
6	S2, S3, S6, S8
7	S1, S3, S6, S7
8	S2, S4, S5, S7
9	S2, S4, S5, S8
10	S1, S4, S5, S7
11	S1, S4, S5, S8
12	S2, S4, S6, S7
13	S2, S4, S6, S8
14	S1, S4, S6, S7
15	S1, S4, S6, S8

1. PROPOSED15-LEVELMLI

Anew15-levelinvertershowninFigure5isbasedonaboostconverter'sDC-linkvoltage.Itfeatureseightswitchesandthree DC-sources.The design of the proposed inverter takes into account the strategy of keeping short circuits out of the path of current. The initial level canbe achieved by switching the switches S2, 3, S5, S7, and S8 in a closed path. The total voltage of the system is calculated by taking intoaccount the blocking voltage of the switches. In the second mode, the switches S8, S2, and S3 are conduction. These are chosen to avoidshortcircuits,andeventhesumofthelowertheblockingvoltagesofasemiconductorswitch,theloweritscost-effectivenessandtheTSV.Table1showstheselectionpatternsofswitchesupto15levels,andthesearechosenbasedontheconditions.Theoverallloop oftheswitchconduction helpsinreducingthevoltage acrosstheswitchesand improvingthe efficiencyof an inverter.

Inordertogenerate15levelsofoutputvoltage,aninverterisproposedwithasymmetricalDCinputsourcesina1:2:5ratio.Sourcevoltagesare taken as Vdc = V1 = 57.15V, V2 = 114.3V, and V3 = 285.75V, respectively, as shown in Table 2. Gate pulses are generated using thestaircasePWMtechnique.Inmode1,thenumberofV2+V3switchesthatareONwhiletheotherswitchesareOFFdeterminestheoutputvoltage.

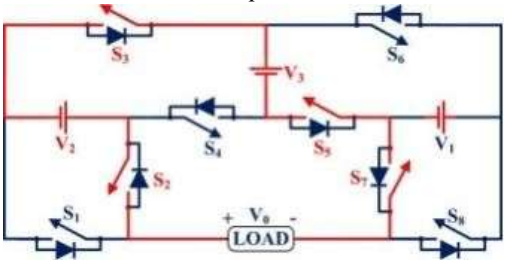


FIGURE6. Case-1forthe15MLI

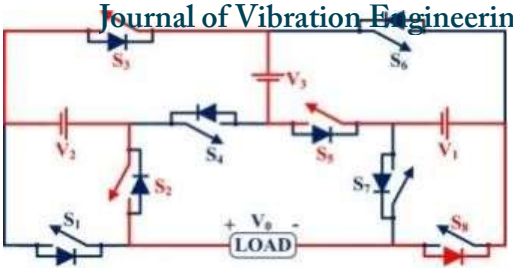


FIGURE7.Case-2forthe15MLI.

The output voltage in mode-2 is V1 + V2 + V3, the S2, S3, S5, S8, and S9 switches are ON, and the remaining switches are OFF. Inmode-3,theS1,S3,S7,andS5switchesareON,whiletheremainingswitchesareOFF,andtheoutputvoltageisV3.Inmode-4,theoutputvoltage is the number of V1 + V3, the S1, S3, S5, and S8 switches are turned on, and the remaining switches are turned off. In mode-5, theoutput voltage equals V1 + V2, the S2, S3, S6, S7 switches are turned on, and the remaining switches are turned off. The output voltage ofthe S2 and S3 switches is equal to V2. The other switches are turned on and off. In mode 6, the output voltage of the S6 and S8 switches isequalto V2.In mode7,theoutputvoltageoftheS1andS3switchesisequaltoV1.Theremaining switchesarealsoturnedon.Inmode8,theoutputvoltageoftheS2andS4switchesisON,whiletheotherswitchesareoff.TheS2,S4,S5,S8andotherswitchesareONinmode9, while the others are off. In mode 10, the S1, S4, S5, S7 and other switches are ON, while the others are off. In mode 11, the S1, S4, S5,S8andotherswitchesareON,whiletheothersareoff.Theoutputvoltageis -(-V1+V3)inmode-12,withtheS2,S4,S6,S7switchesONand the remaining switches OFF. In mode-13, the S2, S4, S6, S8, and S10 switches will be ON, while the remaining switches will be OFF;the output voltage is -V3. The output voltage is - (-V1+V2+V3) in mode-14, with the S1, S4, S6, S7 switches ON and the remaining switchesOFF. In mode-15, the S1, S4, S6, and S8 switches are turned on, while the remaining switches are turned off, and the output voltage is -(V2 + V3). AlloperationalmodesaredepictedinFig.6 toFig.21based onthe conductionofswitchesandtheexpectedwaveform.

A. CIRCUITPARAMETERSDESIGN

Theoversimplifiedquestionnairesbelowcanbeusedtocalculatethesuggestedinvertercircuitparameters,suchasthenumberoflevels(NL),numberof switches(NSW), numberofDCsources(NSDC),andpeakoutputvoltage (VOP).

NSDC =n (2)

NSW =(2nk1+1)+(2nk2+1) +..... +(2nkj+1)(3)

NL=(2nk1+1−1)+(2nk2+1−1)..+(2nkj+1−1) (4)

VOP=((2nk1+1 −2)/2+(2nk2+1 −2)/2 + ... +(2nkj+1−2)/2)×Vdc (5)

Wheren and k represent the proposed inverter's sources and modules, respectively. Equations (2), (3), (4), and (5) are solved for theparameterswithn=3and

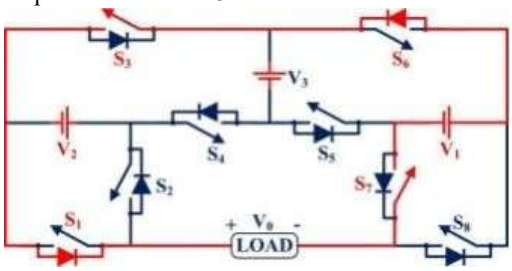


FIGURE12.Case-7forthe 15MLI.

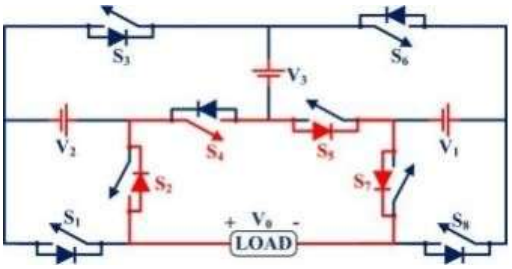


FIGURE13.Casee-8forthe15MLI.

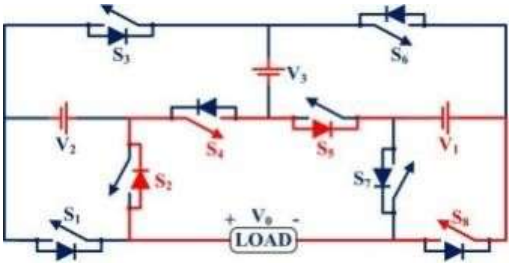


FIGURE14.Case-9forthe 15MLI.

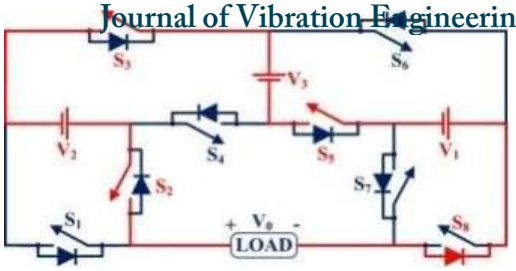


FIGURE15.Case-10forthe15MLI.

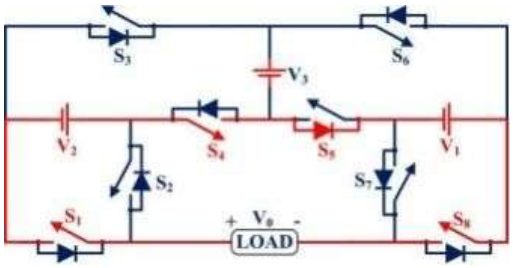


FIGURE16.Case-11forthe15MLI.

$k=1$ and $V_{dc}=V_1=57.15$V, respectively. The $N_{SDC}=3$, $N_{SW}=(2^{3+1})=8$, $N_L=(2^{3+1}-1)=15$, and

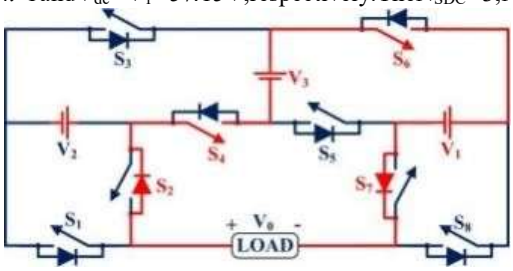


FIGURE17.Case-12forthe15MLI.

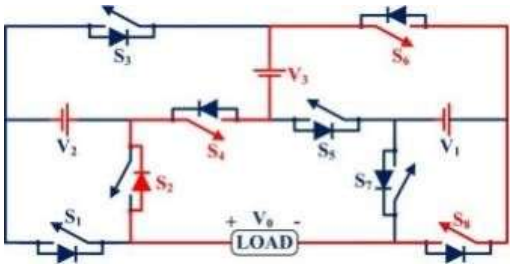


FIGURE18.Case-13forthe15MLI.

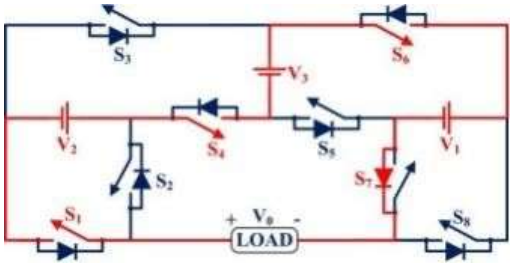


FIGURE19.Casee-14forthe15MLI.

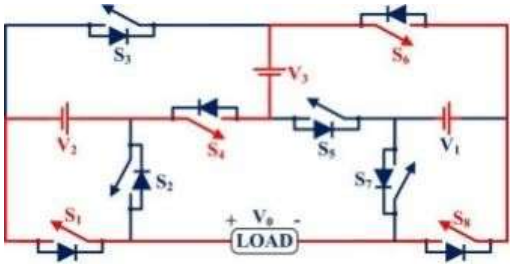


FIGURE20.Casee-15forthe15MLI.

$V_{OP}=\left(\frac{2^{3+1}-2}{2}\right)*57.15=400.05$V. The proposed inverter was implemented using two basic modules (k=2) to generate a 29-output voltage level.

B. RESULTS ANALYSIS

Using MATLAB/Simulink simulation and the dSPACE RTI1104 Controller for experimental validation, the suggested inverter was verified as shown in Fig. 34. The output waveforms and THD of the simulation are displayed in Figures 22–27. The high power CM75DU-

12HIGBTswithin600V&75Aratingsareusedfortheexperiment,alongwiththePVsimulator5kW&8Asources.ThedSPACEcontrollergeneratesgate pulsesby employingtheTLP250driver techniqueof the staircasePWM.

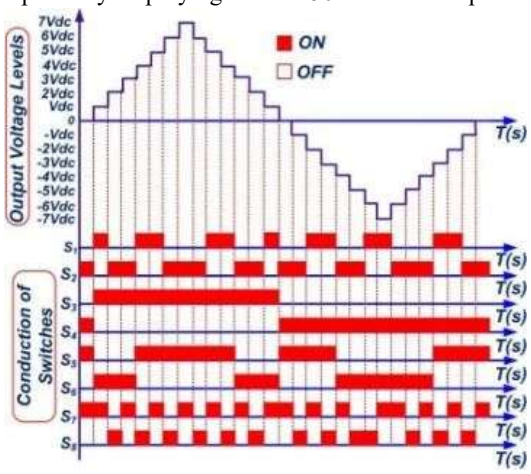


FIGURE21.Thepredicted15MLIwaveform.

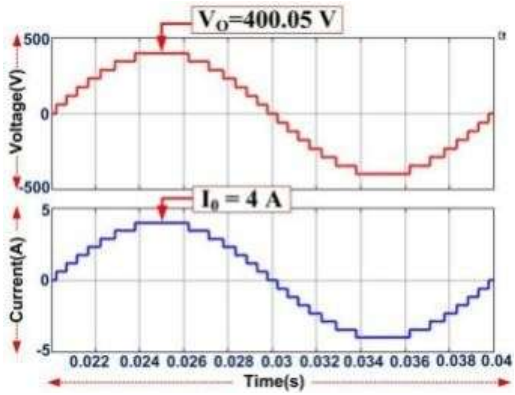


FIGURE22.The15MLI'ssingle-cycleoutputwaveform.

Single-phase loads with a resistance of 100 ohms, 175 mh, and 0.5 HP and a power factor of 0.75 were utilized for the simulation andexperiment, respectively. The source voltages used are Vdc = V1 = 57.15V, V2 = 114.3V, and V3 = 285.75V in order to obtain the maximumpeak outputvoltageVo=400.05V.The robustnessoftheproposed 15-level inverter isanalysed with linear and non-linearloads.

As per Figs. 28 and 29, the experimentally obtained output power, output voltage, and output current for the proposed inverter withlinearloads are Po=782.55W, Vo=400.05V,Io=4A,Vrms=277.5V,andIrms=2.82A.InFig. 30, the inverter's performance andeffectivenessareconfirmedwithamotorload(non-linear)usingtheoutputvoltageandcurrent(Vo=400.05V,Io=6.5A).Thedynamicloadisusedtotestand incorporate swaps from linear to nonlinear. The suggested inverter achieves the maximum system peak output voltage of 400V andkeeps a stable output during dynamic load changes, as shown in Figs. 31 and 32. According to IEEE standards, the efficiency is 95.237%,and theexperimentalTHDis4.41%. Toenhancepower quality,theproposedinverter canbelinked to thegridand FACTS.

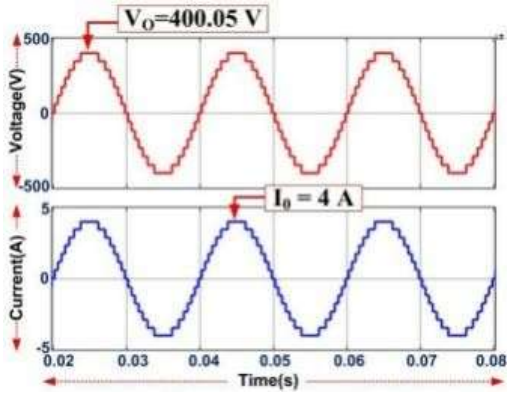


FIGURE23:The15MLI'stwo-cycleoutput waveform.

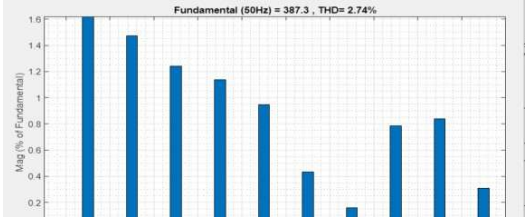


FIGURE24.The 15MLITHD simulation

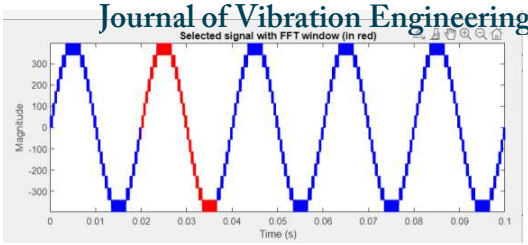


FIGURE25.Waveformofthe15MLIexperiment

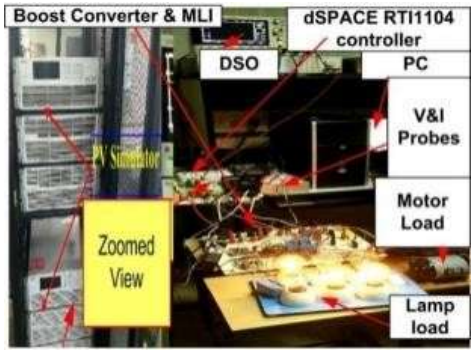


FIGURE26.Prototypemodelof15MLI.

TABLE3.Levels vsModulationindex.

MI (Modulation Index)	L (Number of Levels)
0.14	3
0.29	5
0.43	7
0.57	9
0.71	11
0.86	13
1.00	15

FIGURE27.Levels vsMIof15MLI.

1. CONCLUSION

Thispaperproposesanewtypeof15-levelinverterforuseinsolarPVsystems.ItusesaboostconvertertogenerateanACoutputvoltage.The proposed inverter has fewer components and low total harmonic distortion.A proposed inverter uses eight insulated-gating bipolartransistors,whicharetriggeredbyapulse-widthmeasurementtechniqueknownasthestaircasemodulationtechnique.Ithashighefficiency,lowerlosses,andlowharmonicdistortion.Comparedtomultilevelmodels,thisdesignofferssignificantreductionincomplexityandstress.The design of the proposed inverter was tested with different types of load conditions, such as non-linear and linear loads. It was able tomaintain stable performanceunder dynamic conditions, whichmakesitsuitable forapplications.

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