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Design and Performance Evaluation of a 17-Level Reduced-Switch Single-Source Multilevel Inverter for Enhanced Grid Power Quality

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***Abstract*—** Modern multilevel conversion techniques seek to obtain superior excellent periodic voltage while avoiding the excessive hardware complexity associated with conventional converter structures. The key challenge lies in achieving a numerous voltage tier without increasing the number of semiconductor devices, gate-driving circuits. Excessive component count not only enlarges converter size but also introduces additional switching losses, electrical strain, control complexity, and care specifications Therefore, developing a compact converter capable of generating top notch output with simplified hardware remains an important research objective. This work presents the design and performance evaluation of a seventeen-level minimized change unitary supply switched-capacitor multilevel inverter. Reckon configuration utilizes a switched-capacitor voltage boosting mechanism to synthesize multiple voltage levels from a standalone regulated DC source while requiring considerably fewer semiconductor switches than more stepped wave inverter. Appropriate expending and releasing sequences enable electro condensing device self-balancing, eliminating the need for additional balancing circuits and improving converter reliability. Simplified design contributes to lower conduction losses, simplified gate-drive implementation, and enhanced operational efficiency. To achieve stable operation, an INC algorithm regulates the input energy extraction, The coordinated operation of these control strategies produces a symmetrical multilevel output waveform with reduced harmonic components and ameliorate voltage quality. The deliberate switching methodology also distributes device stress effectively and maintains satisfactory capacitor voltage regulation throughout the operating cycle.

KEYWORDS: Switched-capacitor multilevel inverter (SCMLI), Seventeen-level inverter, Reduced switch count, Self-balancing capacitor, Voltage boosting, Incremental conductance (INC), Total harmonic distortion (THD), Power quality.

1. INTRODUCTION

The growing worldwide request on behalf of electrical power, together with the rapid penetration of renewable energy resources, has created the requirement for highly streamlined and secure power transformation systems. Solar technology is currently one of the best options for renewable power because it is clean, sustainable, environmentally friendly, and readily available. However, powered sun energy is the form of direct current, whereas maximum domestic, industrial, and utility applications require alternating current. Therefore, efficient DC-to-AC power conversion, a necessary requirement for non-conventional power integration.

Power electronic converters play a crucial part in converting the D.C electricity produced with sustainable energy origins towards high-quality alternating power. Among various converter technologies, stepped waveform inverters have appeared as a useful strategy because they are capable of producing staircase-shaped output voltage waveforms which nearly resemble time varying waveforms. Contrasted with traditional two step inverters, stepped wave form presents numerous benefits, containing lower harmonic distortion, diminished potential strain on semiconductor appliances, lower electromagnetic interference, optimized performance, reduced constraints. Those characteristics build them appropriate grid-connected green power systems, e mobility infrastructure charging stations, power electronic systems, and medium-voltage industrial applications.

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Conventional core family inverters configuration, such as Neutral Point Clamped, Flying Capacitor, Cascaded H-Bridge power converters, were extensively investigated for high power applications. Although these arrangements provide excellent output waveform quality, they also suffer from several practical limitations. Neutral-Point Clamped inverters require a large diode count in light of the growing output voltage escalating. Flying-Capacitor inverters demand numerous E-condensers and complex emf balancing techniques. Cascaded H. Bridge converters necessitate multiple floating DC channels, increasing system cost also implementation complexity. These drawbacks have motivated researchers to develop reduced-component and reduced-switch multilevel inverter configurations.

Recent advancements in switched-capacitor multilevel inverter technology have demonstrated that high voltage gain can be achieved using unipolar significantly reducing the quantity of semiconductor knobs. Switched capacitor layouts also provide automatic capacitor voltage balancing, lower switching losses, and improved voltage boosting capability without requiring multiple isolated power supplies. Consequently, these converters have become attractive candidates for photovoltaic energy conversion systems.

In photovoltaic applications, extracting peak available power from the PV output is equally important. As Diurnal cycle variates round the clock, the working point of p-v array as well changes. Maximum power point tracking methods therefore employed to guarantee optimal energy removal varying surroundings. Among various mppt methods, the incremental conductance algorithm provides accurate and fast ppt with minimal steady state oscillations, making it right for practical clean power implementations

Switching strategy adopted for a multilevel inverter has a significant influence on output waveform quality and harmonic performance. Level Shifted Pulse length Modulation widespread because of its simple implementation, reduced computational complexity, and ability to generate balanced gate pulses for multilevel converters. This modulation approach intensifies harmonic mitigation while maintaining stable operation of the inverter.

The present work focuses on seven-teen level SC MLI integrated by a solar photo-voltaic system. The proposed configuration utilizes a reduced number of semiconductor switches while maintaining automatic capacitor voltage balancing and producing a high-quality output waveform. An incremental conductance solar charge controller regulates the PV output before supplying the inverter. The inverter is controlled using Level Shifted PWM to generate a staircase output voltage with reduced harmonic distortion.

Simulation studies carried out in MATLAB & simulink demonstrate which proposed IBR a 17-degree amplitude. Total Harmonic Distortion of 2.81%, whatever complies the IEEE-519 harmonic standards. The structure also reduces switching losses, minimizes component count, improves converter efficiency, and enhances overall power quality, making it a viable remedy future ecofriendly based wattage conversion system.

2. LITERATURE SURVEY

Instead of evaluating sellers at the seller level, the current method in e-commerce platforms mostly concentrates on product-level suggestions. To make product recommendations to consumers, the majority of recommendation systems rely on numerical ratings, popularity measures, and simple review analysis. Users usually manually compare pricing and star ratings when there are several merchants offering the same goods. This procedure can be difficult, time-consuming, and inconsistent. If sentiment analysis is used on many platforms, it is attribute-based, which means it assesses aspects of the product including durability, pricing, design, and quality. These methods, however, are ineffective at differentiating between several vendors selling the same goods. Seller-specific elements including customer service, authenticity, refund processing, and delivery dependability are frequently not thoroughly examined. Furthermore, reviews are typically categorized by traditional methods into straightforward groups like neutral, negative, and favorable. Contextual meanings, conflicting emotions, sarcasm, and comparative feedback are all missed. Customers may be misled while choosing a merchant due to this restriction,

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which also lowers the accuracy of recommendations. The absence of integration between quantitative metrics like pricing trends, seller response time, and performance history and qualitative review insights is another significant flaw. Customers are therefore forced to rely on information that is dispersed over product pages. The current system lacks a thorough seller-focused analysis process, albeit offering rudimentary suggestion support. It does not make full use of cutting-edge AI methods to enhance multi-seller marketplace decision-making.

3. PROPOSED PV ARRAY

Fig 1 represents equivalent circuit of a PV cell model. It has a current source for sunlight-generated current, a diode for the p-n junction, a parallel connect resistance (Rp) for leakage loss, and a series connected resistance (Rs) for internal losses. This model analyses proposed PV cell performance.

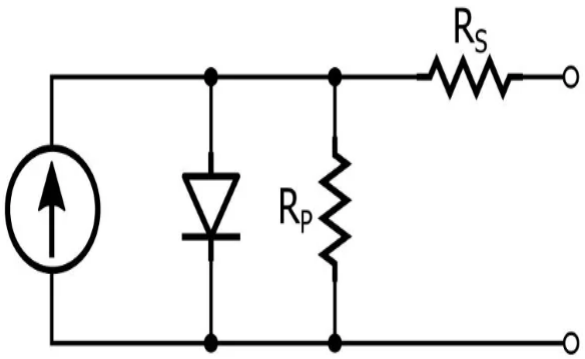

Fig 1. equivalent circuit of a PV cell

Fig 2 represents the voltage-current (V-I) characteristics of a photovoltaic (PV) cell are non-linear and change depending on sunlight radiation (W/m2). It is important to monitor and extract the maximum power from the PV array by using some techniques. To get, the Maximum Power Point Tracking (MPPT) controller adjusts the operation of the boost converter for level up input voltage from solar PV. It considering several inputs such as open-circuit voltage (Voc), short-circuit current (Isc), solar radiation, temperature, and the output voltage of the DC link.

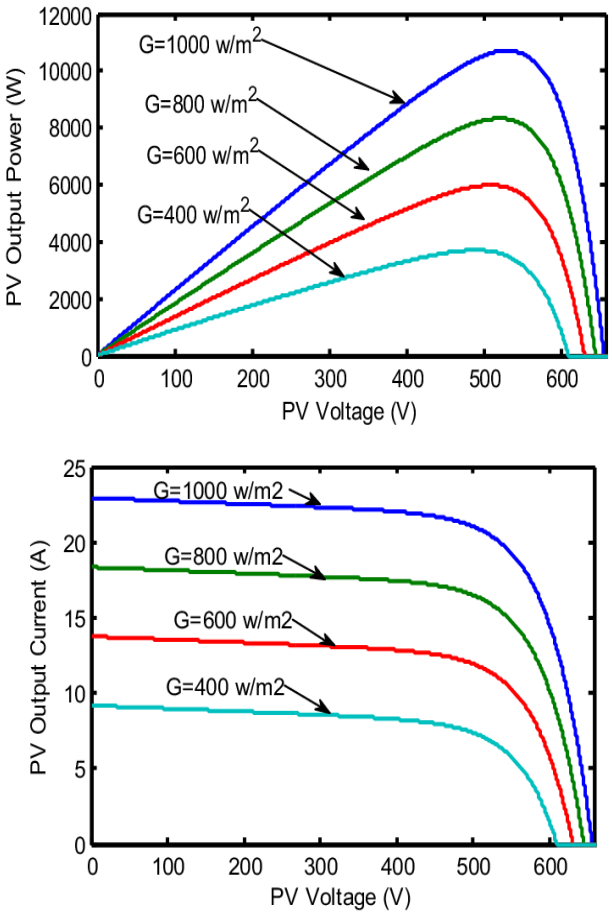

Fig 2 voltage-current (V-I) characteristics (PV) cell.

Under conditions were irradiance changes rapidly, conventional Incremental Conductance (INC) MPPT methods may not good fit for effective for proposed system. To overcome this, an Enhanced Incremental Conductance (EINC) MPPT method has been introduced to proposed system. This improved technique adjusts the duty cycle(D) of the boost converter to achieve efficient power extraction from the PV array.

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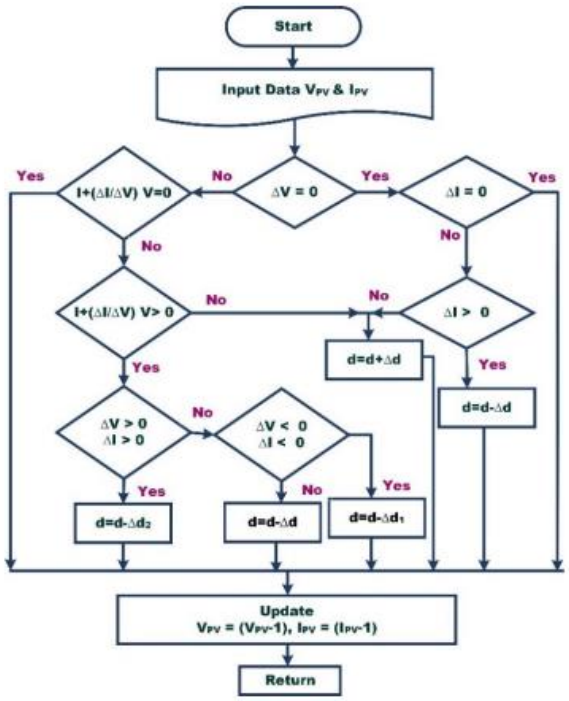

Fig 3. EINC

Fig 3 represents, The EINC MPPT technique, in this proposed system, the DC-DC boost converter receives input from the PV array and delivers its output to the DC bus of the Hybrid Active Power Filter (HAPF) inverters. The PV array initially generated a voltage of 30 V, which is stepped up to 75 V by the converter. The diode and load currents of the PV module are described by Equations (1) and (2).

$$i_d = i_{sat}\left(e^{\frac{QVoc}{AKT}} - 1\right) \qquad (1)$$

$$i = i_L - i_{sat}\left(e^{\frac{QVoc}{AKT}} - 1\right) - \frac{V_{oc}}{R_{sh}} \qquad (2)$$

4. PROPOSED SIMO MULTILEVEL CONVERTER

The increasing assimilation of Renewable Energy assets into off grid solar systems has created growing demand to efficient, compact, economical power electronic converters. Conventional multilevel inverter topologies namely Neutral Point Clamped, Flying Capacitor and Cascaded H-Bridge inverters capable of producing high-quality out-put voltage with lessened harmonic distortion. Nevertheless, these topologies require a myriad semiconductor switches, gate driver circuits, isolated DC sources, and passive constituents, causing an uptick in converter sophistication, implementation cost, switching losses.

To overcome these limitations, this work presents a dropped-switch single-source multilevel inverter designed to improve grid power quality while belittling the several semiconductor devices. Reduced Switch topology employs a one DC source together with switched-capacitor cells to create multiple voltage levels near the output. Lower component count without compromising voltage quality, the proposed configuration offers a simple, efficient, and cost-effective solution for renewable energy implementation.

The Reduced Switch inverter operates using a controlled charging and discharging mechanism of switched capacitors. During capacitor charging, energy is stored from the DC input source, whereas during capacitor discharging, the stored energy is combined with the input source to generate higher output voltage levels. Appropriate switching sequences are generated using L.S P.W.M, ensuring proper capacitor voltage balancing, smooth output voltage generation, and reduced switching losses.

The core focus of the streamlined Switch inverter is to trigger staircase output Voltage wave-form carefully resembles a sinusoidal waveform. The rising of voltage levels significantly attenuated (THD), improves power quality, minimizes electromagnetic interference, and decreases the higher order configurations.

Furthermore, the reduced number of semiconductor switches lowers conduction losses, simplifies the gate driver circuitry, and enhances converter reliability.

The complete system is patterned and analyzed utilizing MATLAB simulink to test its behavior under steady-state operating conditions. Simulation studies include output voltage analysis, output current analysis, harmonic spectrum analysis applying Fast Fourier Transform , comparison of power quality performance. The obtained results demonstrate that reduced-switch single-source multilevel inverter provides improved efficiency, minimalistic harmonic distortion, and superior grid compatibility compared with conventional multilevel inverter topologies. This chapter presents the detailed circuit configuration, operating

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principle, switching sequence, modulation strategy, mathematical analysis, and performance characteristics of the alleviated Switch Inverter developed in this work.

Reduced Switch converter is a 17-level single-source switched-capacitor multilevel inverter Reduced Switch for renewable energy applications. The topology serves to produce a towering-quality AC output voltage while limiting the quantity of semiconductor switches, gate-driver circuits, by means of passive components. Unlike conventional multilevel inverter configurations that require multiple isolated DC sources or a countless switching device, the proposed hybrid designs operate using alone regulated direct current source obtained from a solar photovoltaic system.

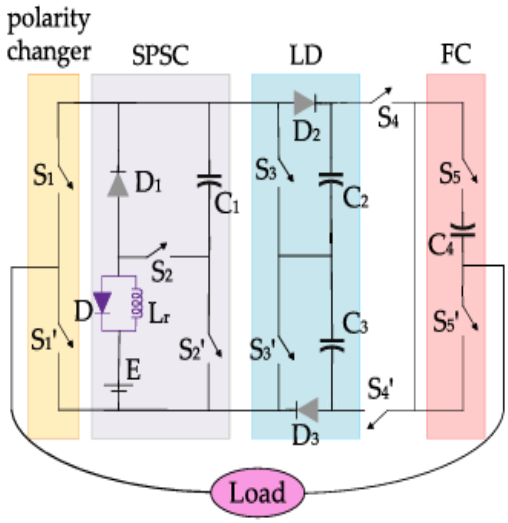

Fig.4 Reduced Switch Inverter

The proposed converter consists of a single DC source, a switched-capacitor network, power semiconductor switches, charging diodes, and a load. The switched-capacitor network operates as a voltage-boosting stage by charging and discharging capacitors, enabling the generation of multiple output voltage levels without additional DC sources or transformers. The inverter is controlled using Level-Shifted Pulse Width Modulation (LS-PWM), which generates the required gate signals to produce a staircase output waveform that closely approximates a sinusoidal waveform, thereby reducing harmonic distortion and improving power quality.

The reduced-switch single-source multilevel inverter employs controlled capacitor charging and discharging to synthesize multiple voltage levels while minimizing the number of semiconductor switches. This simplified topology reduces switching and conduction losses, lowers implementation cost, decreases control complexity, and enhances overall efficiency and reliability. During operation, the capacitors are initially charged from the DC source and are subsequently connected individually or in series with the source to generate the required positive and negative voltage levels, while maintaining capacitor voltage self-balancing.

The proposed topology is validated in MATLAB/Simulink under steady-state operating conditions. Simulation results, including output voltage, output current, capacitor voltages, and FFT analysis, demonstrate that the inverter produces a high-quality multilevel AC output with low Total Harmonic Distortion (THD).

The results confirm that the proposed reduced-switch switched-capacitor multilevel inverter is an efficient and cost-effective solution for power quality improvement and renewable energy integration. Fig.4 illustrates the output voltage waveform and capacitor charging/discharging pattern of the proposed 17-level switched-capacitor multilevel inverter over one fundamental cycle. The staircase output voltage is generated by sequentially increasing the voltage levels from 0to $+4E$during the positive half cycle and decreasing them symmetrically to 0. During the negative half cycle, the same switching sequence is repeated with reversed polarity, producing voltage levels from 0to $-4E$and back to zero. This symmetrical operation results in a near-sinusoidal output waveform with reduced harmonic distortion.

Fig.5 illustrates the output voltage waveform and capacitor charging/discharging pattern of the proposed 17-level switched-capacitor multilevel inverter over one fundamental cycle. The staircase output voltage is generated by sequentially increasing the voltage levels from 0to $+4E$during the positive half cycle and decreasing them symmetrically to 0. During the negative half cycle, the same switching sequence is repeated with

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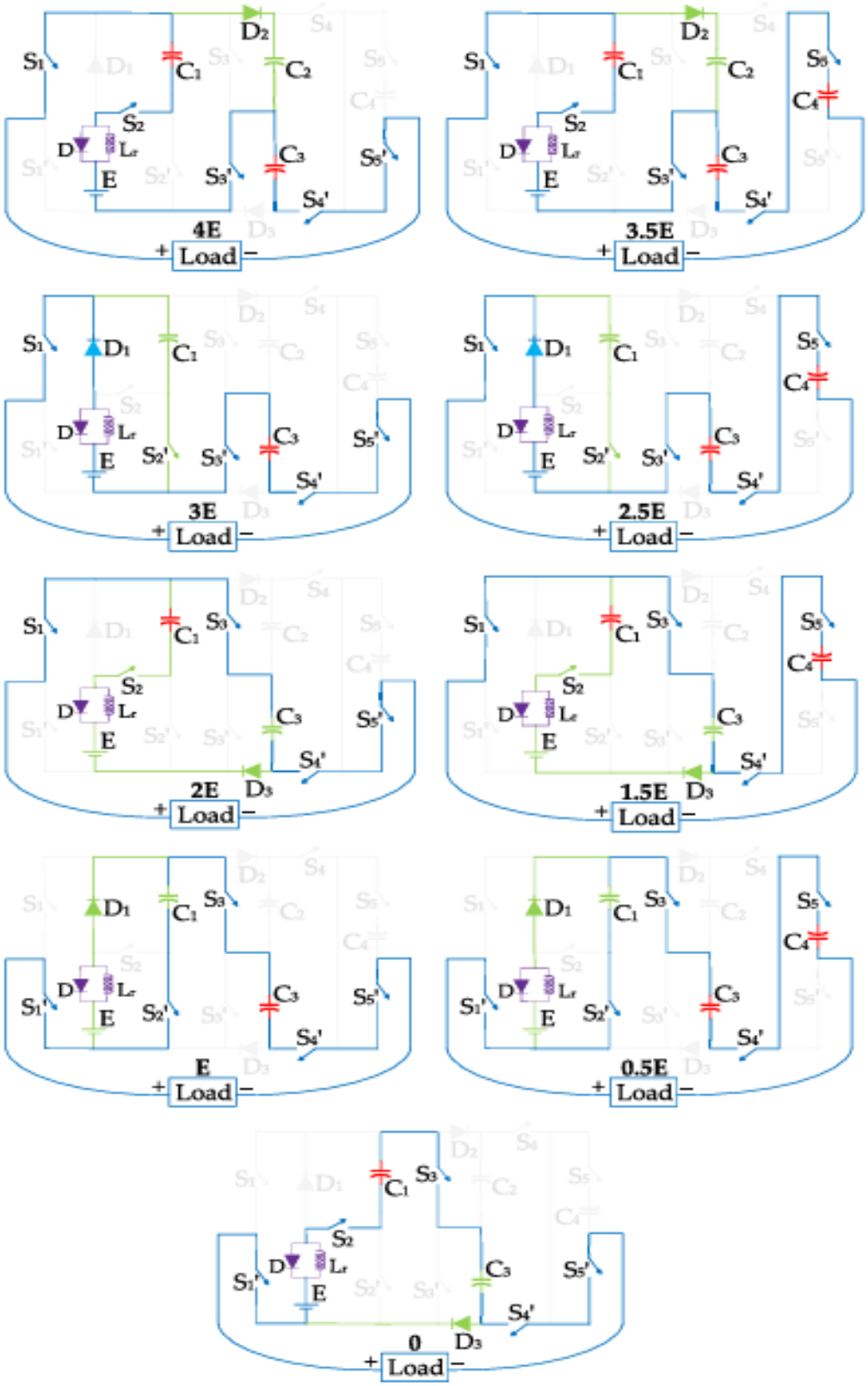

Fig.5 Working Principle

reversed polarity, producing voltage levels from 0to $-4E$and back to zero. This symmetrical operation results in a near-sinusoidal output waveform with reduced harmonic distortion.

The lower section of the figure shows the operating states of capacitors C_1, C_2, C_3, and C_4. The green intervals represent capacitor charging, the red intervals indicate capacitor discharging, and the

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Gray intervals denote no charging or discharging activity. Capacitors are charged and discharged in a coordinated manner according to the selected switching states, ensuring self-voltage balancing without requiring additional balancing circuits. The labeled LDP (Longest Discharging Period) indicates the maximum continuous discharge interval for each capacitor. Specifically, C_1experiences the longest discharge period during the highest positive voltage level, C_2during the highest negative voltage level, C_3over the intermediate positive voltage levels, and C_4over the widest operating interval. These charging and discharging patterns maintain stable capacitor voltages while enabling efficient generation of all seventeen output voltage levels as shown in Fig 6.

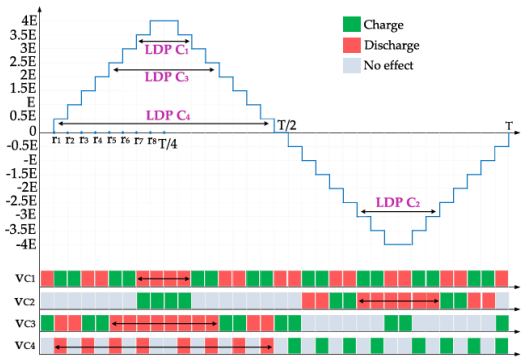

Fig 6. Charging and discharging

5.SIMULATION AND RESULTS

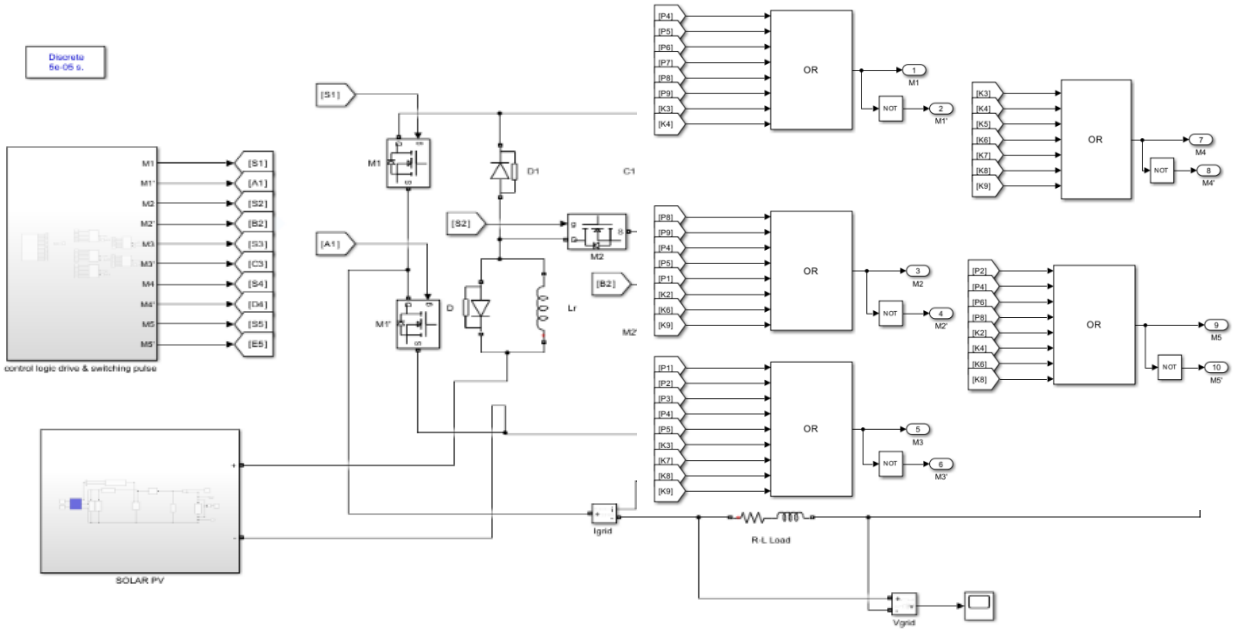

Fig.7 Reduced Switch Multilevel Inverter Simulation

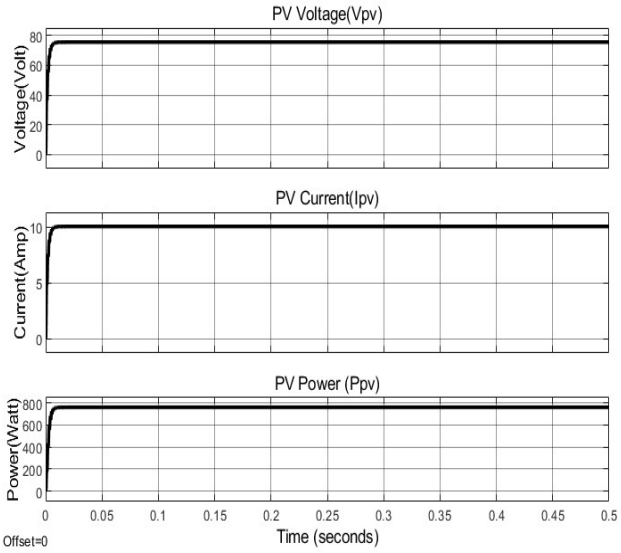

Fig.8. solar power, voltage and current

Using the MATLAB-Simulink tool, simulation modeling of the suggested system in which generated voltage (Vpv) from the solar PV is fed to a proposed 17-level multilevel inverter (M-LI) is displayed in Fig. 7. The input to the solar-PV for solar system modeling consists of all simulation parameters listed in the table, an irradiation of 1000W/m², and a temperature of 25Co. The INC-based procedure for optimal power point spoor and parameter seen in Table 1 is employed to maximize the potential difference precipitated per PV panel used for the single source proposed MLI.

The control pulses generated by this IC-MPPT technique are used to drive a boost-converter

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provide optimized power 750W, voltage 75V and current 10A Fig.8.

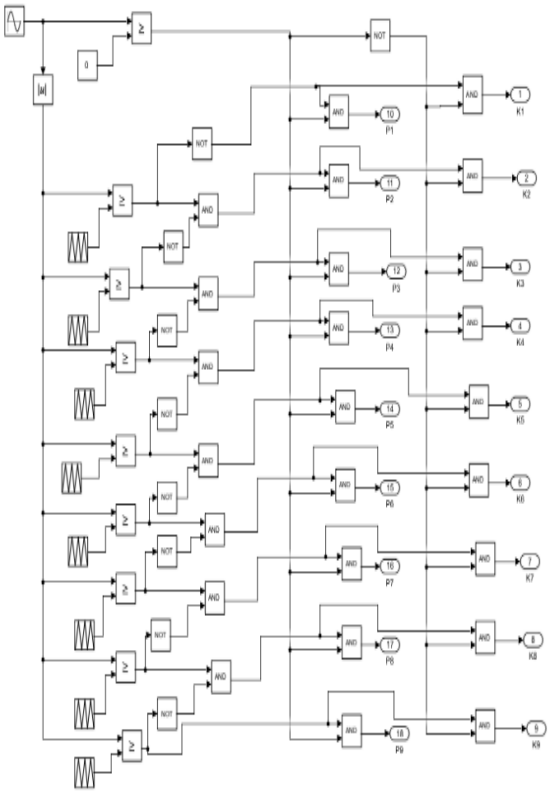


Fig.9. Control logic drive signal is generated using LS-PWM

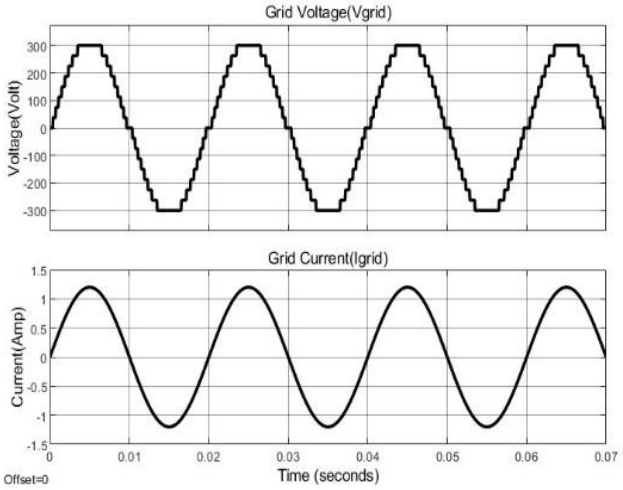
The control logic drive signal is generated using pulse generation approach. figure replicates control signals created for the gate driver. These signals are produced by reviewing basis response (Vrf) with modulating indication (Vr). Fig.9 illustrates the process of delivering gate pulses using the control signals provided to the gate driver. These control signals are then passed through OR gates, which producing shifting pulses for suggested voltage level conversion block switches M1, M2, M3, M4, and M5, as well as their complementary pulses M1', M2', M3', 4', and M5' as shown Fig.10.

That final result proposed system formulating the 17-level sinusoidal output voltage is 300V and current 1.2A waveform across the grid as shown Fig.11

Fig. 10 Switching pulses for shortened voltage level converter

Fig.11 Voltage (Vgrid) and current (Igrid)

evaluate the grid power-quality of the 17-level proposed multilevel converter system, Total-Harmonic Distortion (T-HD) is analysed. THD is a main performance that measures the distortion composition in the output voltage (Vgrid) pulse measured against fundamental frequency. A less THD value better waveform power quality in grid, improved power efficiency with less switching components in MLI and low switching Power losses making it crucial in sensitive grid applications. In this paper, the system achieved a THD of just 2.81%, Fig.12, which is lower than the IEEE-standard limit of 5% for voltage harmonics in power



systems.

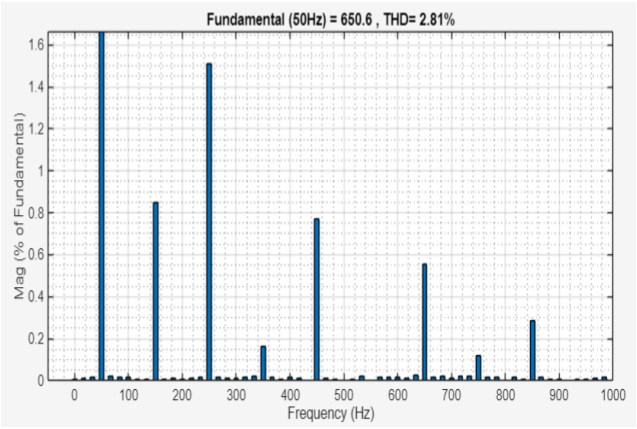


Fig.12 THD

Table-1 Simulation parameters

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Parameter Name	Range
PV array parameters	
Maximum power	305.226W
Voltage at maximum power point ($Vmpp$)	54.7V
Open circuit voltage (Voc)	64.2V
Current at maximum power point ($Impp$)	5.8A
Short circuit current (Isc)	5.96A
Input DC voltage (V)	25V
Output voltage (Vpv)	75V
Duty cycle (D)	0.75
Switching frequency	50khz
Proposed MLI parameters	
Input voltage Vpv	75V
Capacitor C1, C3	$1600\mu F$
Capacitor C2	$2400\mu F$
Capacitor C4	$2000\mu F$
Inductor Lr	$660\mu F$
R-L Load	200Ω,100mH
Fundamental frequency	50Hz
Switching frequency	25khz

6.CONCLUSION

The proposed 17-level reduced-switch single-source switched-capacitor multilevel inverter (SCMLI) integrated with a solar PV system was successfully designed and simulated in MATLAB/Simulink. The system combines a PV array, an Incremental Conductance (INC) MPPT controller, a boost converter, and an LS-PWM-controlled switched-capacitor multilevel inverter to achieve high-quality power conversion with reduced hardware complexity. Using a single DC source and fewer semiconductor switches, the proposed topology provides voltage boosting, automatic capacitor voltage balancing, and lower switching losses without requiring additional balancing circuits. Simulation results demonstrate that the inverter generates a 17-level output voltage of approximately 300 V with a load current of 1.2 A and a THD of 2.81%, satisfying IEEE 519 harmonic standards. The INC-based MPPT effectively extracts maximum power from the PV array, while the boost converter maintains a stable DC-link voltage. Overall, the proposed inverter offers improved voltage gain, enhanced power quality, reduced component count, and high efficiency, making it a promising solution for standalone renewable energy systems, battery energy storage applications, residential power supplies, and future grid-connected converters.

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