DESIGN AND SIMULATION OF A SOLAR PV INTEGRATED 9-LEVEL FLYING CAPACITOR MULTILEVEL INVERTER USING SVPWM FOR HOUSEHOLD APPLICATIONS

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Abstract - *This study presents the design and simulation of a solar photovoltaic (PV)-based energy conversion system. A 12 kW PV array is modeled under varying sunlight and temperature conditions. A DC–DC boost converter regulates the PV output and maintains a 500 V DC link. A nine-level flying capacitor multilevel inverter (FCMLI) converts DC to AC using space vector PWM (SVPWM).The inverter delivers low-distortion AC power with balanced capacitor voltages. The system supplies both household loads and a 60 V, 50 Ah EV battery charger. The EV charger operates under a constant current–constant voltage (CC–CV) profile. MATLAB/Simulink simulations confirm efficient energy conversion and stability.*

***Key Words*: Maximum power point tracking (MPPT), Flying capacitor multilevel inverter (FCMLI), Space vector pulse width modulation, MATLAB/Simulink.**

1.INTRODUCTION

Renewable Energy and the Role of Solar Photovoltaics, The global energy demand has been steadily rising due to rapid industrialization, population growth, and the increasing reliance on electricity in daily life. Conventional energy sources such as coal, oil, and natural gas are not only limited but also responsible for severe environmental issues like greenhouse gas emissions and climate change. As a result, renewable energy has become a cornerstone of modern energy policies, with solar photovoltaic (PV) technology emerging as one of the most promising solutions [1]. Solar PV technology directly converts sunlight into electricity through semiconductor materials. The simplicity, scalability, and declining costs of solar panels have made them attractive for applications ranging from small household systems to large-scale solar farms. A PV module generates direct current (DC) electricity, which is suitable for charging batteries but not directly compatible with most appliances and power distribution systems that operate on alternating current (AC) [2]. The boost converter is a key power electronic interface that steps up the lower DC voltage from the PV system to a higher and more stable level. This higher voltage is necessary not only for efficient operation of the inverter but also to meet the charging requirements of modern EV batteries, which typically demand voltages in the range of 350–500 V[3]. The principle of operation of a boost converter is based on energy storage in an inductor during the ON state of a switching device (such as an IGBT or MOSFET) and releasing that energy to the load during the OFF state. When the switch is closed, current flows through the inductor, causing it to store energy as a magnetic field. When the switch is opened, the inductor attempts to maintain current flow by releasing energy, which adds to the input supply and raises the voltage across the output capacitor and the load. [4].

The control strategy used in an inverter plays a significant role in determining its efficiency, harmonic performance, and output voltage quality. Traditional sinusoidal PWM techniques, though simple, have drawbacks such as limited DC bus utilization and higher harmonic distortion. Space Vector Pulse Width Modulation (SVPWM) addresses these issues and is considered one of the most advanced modulation techniques for multilevel inverters. [5].

For a 9-level inverter, SVPWM generates optimized switching pulses for the 16 IGBTs in such a way that the output voltage waveform closely follows a sinusoidal reference. This results in smoother voltage, improved power quality, and better performance for sensitive loads like EV chargers [6]. PV-based pumping system with an induction motor drive and vector control to achieve efficient operation under varying solar irradiance [7]. Simulation results demonstrate that the proposed control method maintains stable motor performance and consistent water discharge[8].

The heart is the 9-level Flying Capacitor Multilevel Inverter (FCMLI) controlled using SVPWM. Multilevel inverters generate stepped output voltages by combining multiple voltage levels from capacitors or isolated DC sources. [9]. These capacitors help in distributing voltage stress evenly across the switches and also provide inherent voltage balancing. The output of a 9-level inverter ranges from -4Vdc to +4Vdc, producing nine distinct levels. With SVPWM, the switching is optimized to ensure capacitor voltages remain balanced, the output waveform is nearly sinusoidal, and THD is minimized. The inverter converts the 740 V DC link voltage from the boost converter into 240 V AC, which is used to power household loads and charge the EV battery simultaneously.[10]. The performance of the suggested system is assessed in several environmental scenarios using MATLAB/Simulink simulation.

1.1 Objective

- Design and model a solar PV system with a DC–DC boost converter and nine-level FCMLI.
- Implement SVPWM control for efficient inverter operation.
- Integrate the system for residential AC supply and EV CC–CV charging.
- Evaluate performance in MATLAB/Simulink for efficiency, waveform quality, THD, and charging effectiveness.

1.2 Proposed Methodology

The system comprises a solar photovoltaic (PV) array, a DC–DC boost converter, a 9-level flying capacitor multilevel inverter (FCMLI) controlled by Space Vector Pulse Width Modulation (SVPWM), and an electric vehicle (EV) charging interface. The methodology ensures that each subsystem is carefully modeled and integrated to validate the overall system performance in MATLAB/Simulink.

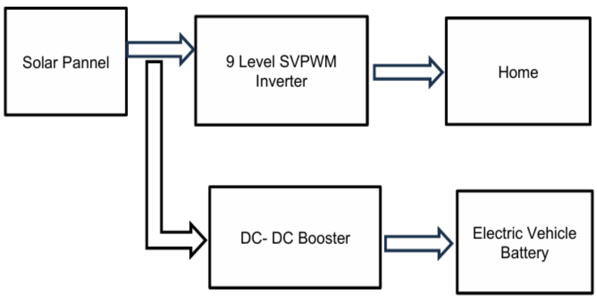

Fig 1.2: Block Diagram

9-level flying capacitor multilevel inverter using svpwm for solar powered EV charging Applications.

The diagram of the proposed system clearly shows the flow of energy from the solar source to the end applications while highlighting the role of each subsystem. Solar PV Array is the primary renewable source, consisting of 40 series-connected modules of 300 W each, delivering nearly 12 kW. It provides a variable DC voltage (350–500 V) depending on solar irradiation and temperature. Since the PV output fluctuates, a DC–DC Boost Converter is connected next to step up and stabilize the voltage to around 400 V DC, suitable for inverter operation. The boost converter also implements Maximum Power Point Tracking (MPPT) by dynamically adjusting its duty ratio so that the PV array always operates at its peak power point. The regulated high-voltage DC from the boost converter forms the input to the 9-Level SVPWM Flying Capacitor Multilevel Inverter (FCMLI). The inverter employs 28 flying capacitors, 8 DC bus capacitors, and 16 IGBTs, configured to generate multiple discrete voltage levels. Each capacitor charges and discharges in a controlled manner, producing a stepped output that approximates a sinusoidal waveform. The inverter is controlled using Space Vector Pulse Width Modulation (SVPWM), which optimizes the switching states, enhances DC bus utilization, and reduces total harmonic distortion (THD). By applying SVPWM, the inverter synthesizes nine distinct voltage levels ranging from −370 V to +370 V, which correspond to a clean AC output of about 240 V RMS. The AC output from the inverter is supplied directly to residential loads, enabling the use of solar energy for household appliances. Simultaneously, part of the generated energy is routed to an EV charging unit, designed to charge a 60 V, 50 Ah battery pack (3 kWh). The EV charger uses a buck-type DC–DC converter to step down the 400V DC link voltage to a safe 60 V charging voltage. The charging process follows a CC–CV (Constant Current–Constant Voltage) profile, ensuring safe and efficient battery charging. A central controller supervises the entire system, continuously monitoring PV voltage/current, DC link voltage, and inverter output. The controller generates PWM pulses for the boost converter and SVPWM switching signals for the inverter. It also ensures capacitor voltage balancing in the FCMLI, which is essential for stable multilevel operation. Protection functions are integrated into the controller to handle over voltage, over-current, and temperature variations. The combination of PV, boost converter, inverter, and control unit ensures a high-quality AC output with minimal harmonics. The block diagram also represents bidirectional power flow capability for EV charging/discharging in future upgrades. The modular structure of the blocks makes the system scalable, allowing for higher power levels or additional loads. Overall, the block diagram demonstrates a complete renewable-powered system that provides reliable AC power for household use and clean DC power for EV charging, optimized by advanced control techniques.

2. MODELLING OF 9-LEVEL FLYING CAPACITOR MULTILEVEL INVERTER USING SVPWM FOR HOUSEHOLD APPLICATIONS.

The integrated system was simulated in MATLAB/Simulink to validate the design and performance of each subsystem: Solar PV, DC–DC Boost Converter, 9-Level SVPWM Flying Capacitor Inverter, and the load/EV battery charging unit.

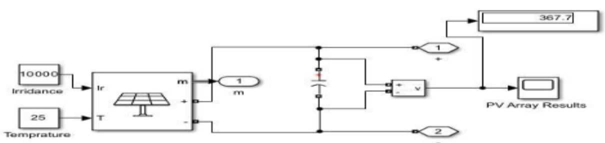

Fig 2: Simulation of the Solar Panel

The simulation shows a PV module model (Sim scape Electrical / Sim Power Systems has a PV Array block). If you don't have that toolbox, implement the single-diode model using sources, diode, Rs, Rsh or use user-contributed PV model from MathWorks File Exchange. Configure module electrical specs per parameters. m: Isc ≈ 9.5 A, Voc ≈ 37.67 V, Imp ≈ 10 A, Vmp ≈ 32 V. Connect 20 modules in series inside the PV block (string of series PV modules) so that

Vmp_total ~ 640 V. Add measurement points: PV voltage (V_pv), PV current (I_pv), PV power (P_pv = V_pv * I_pv).
➢**Optional:** add irradiance and temperature inputs so you can sweep irradiation (1000 → 600 W/m²) or temp (25 → 45 °C) during tests.

2.1 DC–DC boost converter (PV → Vdc)

The boost converter raises the PV array DC (~400V) to the DC-link (740V) used by the inverter and charging interface. The following design equations and worked examples show how to select duty ratio, inductor and capacitor. **Basic boost relation and duty ratio** Assuming ideal boost converter, continuous conduction mode (CCM), steady state:

$$V_{out} = \frac{V_{in}}{1-D}$$

Solve for duty ratio D :

$$D = 1 - \frac{V_{in}}{V_{out}}.$$

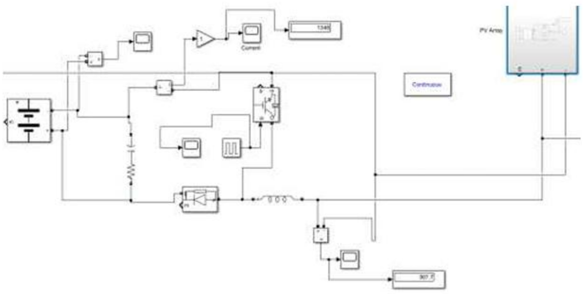

Fig 2.1: Simulation of the DC/DC Booster

2.2 Design and simulation of 9-level SVPWM of flying capacitor:

For a 9-level FCMLI you can implement multilevel SVPWM (space vector extension) or use synthesized SVPWM per phase that maps to multilevel states. The high-level steps:
➢ Convert three-phase reference to α–β (Clarke transform) if doing three-phase; for single phase you can synthesize a two-level reference as well.
➢ Determine the sector in the extended space vector diagram (multilevel maps to many more vectors).
➢ Compute the time durations for adjacent switching vectors to synthesize the reference vector (vector decomposition).
➢ Translate vector time durations into gating timings for the 16 IGBTs (there are redundant switching states to help balance flying caps).
If this is complex, you may implement a multi-carrier or phase-shifted carrier approach adapted to flying-capacitor levels, but you stated you used SVPWM — implement the extended SVPWM algorithm for multilevel (there are MATLAB examples and literature).

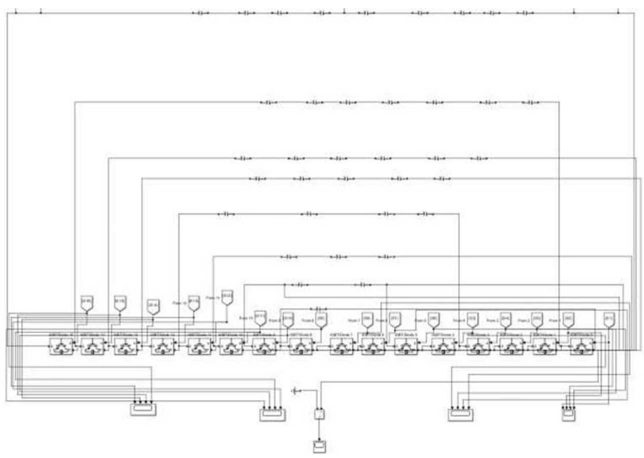

Fig 2.2: Simulation of 9-level SVPWM of flying capacitor

2.3 Simulation setup-step-by-step (exact,reproducible): key design numbers used throughout

Create a new Simulink model folder and a MATLAB script parameters. that defines all global numeric constants (PV panel specs, Vdc, fs, L, C, D, E, number of caps, load power, battery voltage, etc.). This makes tuning and re-running easy. In Simulink: File → Model Properties → Callback you can call parameters. at model start.

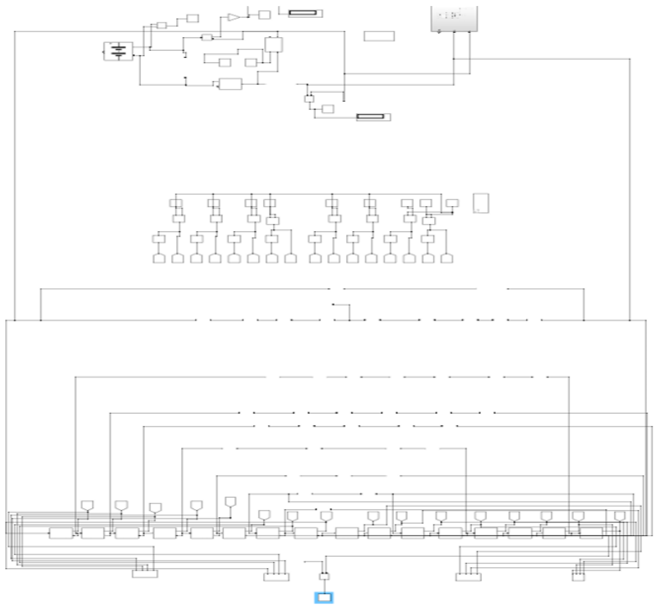

Fig 2.3: Simulation Model of 9-level flying capacitor multilevel inverter using SVPWM for Household applications.

The following sections describe the results in detail.

➢ PV array: 40× 300 W modules → 12 kW. Typical Vmp per module ≈ 32 V, so Vmp_total ≈ 640–660 V, Imp ≈ 10 A.

➢ Boost target (DC link): Vdc = 400 V. ➢ Boost duty ratio (ideal): D ≈ 0.3243.

➢ Boost output current (approx): Iout ≈ 9–9.5 A.

➢ Switching frequency (suggested): fs = 10 kHz (you may increase to reduce L/C size; watch switching losses).

➢ 9-level FCMLI: n = 9 → Nbc = 28 flying caps, Nc = 8 DC bus caps, Nsd = 16 IGBTs.

➢ Step voltage E = Vdc / 8 = 92.5 V → levels ±4E (±370 V). ➢ Load: 2 kW resistive at 240 V AC (I ≈ 8.33 A RMS).

➢ EV battery: 60 V, 50 Ah (3 kWh); charging power ~2 kW → I ≈ 33.3 A.

2.4: MPPT & converter interaction: The DC–DC boost converter should operate in a way that the PV array is maintained at its MPP. Implement MPPT (e.g. Perturb & Observe or Incremental Conductance) to adjust the converter duty cycle so that PV works at Vmp,total . The converter may also need to handle partial shading or varying irradiation, and must be rated to accept the PV open circuit voltage (Voc_total ≈ 20 × Voc_p ≈ 20 × 37.67 ≈ 753.4 V) — hence all PV side components should withstand Voc_total plus margin.

2.5 EV Battery — Capacity, Charging Profile & Converter Interfacing

Battery capacity and stored energy
Given battery specification:
• Nominal voltage Vbatt=60 V.
•Capacity Cbatt=50Ah
Stored energy: Ebatt=Vbatt×Cbatt=60 V×50 Ah=3000 Wh=3.0 kWh.
This matches the paper's reported 3000 Wp (3 kWh). (Note: Wp is usually used for PV; for battery we use Wh or kWh.)
Charging power & current
If CCS2 charger and the simulation use 2 kW charging power:
• Charging current at battery:
Icharge=PchargeVbatt=2000 W60 V=33.3333 A.
Thus a 2 kW charger will supply about 33.33 A at 60 V.
Time to charge from 0% to 100% in ideal conditions: tcharge=EbattPcharge=30002000=1.5 hours=90 minutes.
In practice, due to inefficiencies and CC–CV switching, real charge time will be longer (account for e.g. 85–95% charge efficiency).
Charging profile (CC–CV)
Lithium-ion charging commonly uses a CC–CV profile:
➢ **Constant Current (CC) phase:** battery is charged at a constant current (e.g., 33.33 A) until battery voltage reaches the target maximum (e.g., Vmax per pack).
➢ **Constant Voltage (CV) phase:** charger holds voltage at Vmax and charging current tapers down until a small end current threshold.
For a 60 V pack the charger must regulate to pack-specific max voltage (depends on cell chemistry and series count). If the pack is 60 V nominal, a typical maximum pack voltage during CV might be e.g. 63–67 V (depends on cell count and cell max voltage). The charger must be programmed with battery manufacturer recommended values.

Typical approach for output filter L and C:

1. Choose cutoff frequency fc safely below switching frequency but well above fundamental (e.g., fc≈fs/10 or design for e.g. 1–2 kHz with fs=10).

2. Ensure filter damping to avoid resonance with grid/load.

Parameter	Formula or basis	Numerical result
Inverter levels nn	given	9
Balancing caps NbcN_{bc}	(n−1)(n−2)/2	28
Switching devices NsdN_{sd}	2(n-1)	16
DC-bus caps NcN_c	n−1	8
DC link VdcV_{dc}	simulated/boosted	400V
Step EE	Vdc/8V	50 V
Max level 4E4E	4×E	200 V
Peak of 240 V RMS	240 Sqrt 2	339.41 V
Boost duty DD	1−Vin/Vout	0.3243
Inductor LL (example)	VinD/(ΔIfs)	8.66 mH (fs=10 kHz, ΔI=20%)
Output capacitor C	IoutD/(fsΔV))	8.21 µF (ΔV=5%)
PV total	20 × 330 W	6.6 kW
PV Vmp_total (assumed)	20 × 33 V	660 V
PV Imp	P/V	10:00 AM
EV battery energy	V × Ah	60 V × 50 Ah = 3 kWh
EV charging current	P / V	2000 W / 60 V = 33.33 A

Table 2.5: Overall Parameter values.

3.RESULTS

9-level SVPWM flying capacitor multilevel inverter which is connected with the PV array and the electric vehicle battery and the home. The total number of Kw is 12 kw system is simulated. The electric vehicle battery is also charged from the solar panel and solar system is also provides power to the household as simulated in the Matlab. Pv array is working in 10000 irradiation and 25 °C temperature.

The output of the PV array is 400v. that voltage will be supplied to the 9-level SVPWM flying capacitor multilevel inverter.

Dc voltage will be converter into the ac from the inverter. The solar panel feeds the power to the home and also to the EV charger to charge the battery. Dc/dc converter is connected between the EV vehicle and the solar panel.

Solar panel voltage is boosted for the EV vehicle to charge the battery. The output of the solar system is 400V. and from the dc/dc boost converter get the output voltage is 400V. and the current is 9.36 amps and the battery will charge from the solar panel. The final output of the 9-level SVPWM flying capacitor multilevel inverter of the PV array is half of the input voltage. The input of the 9-level SVPWM inverter from the PV array is 400v and the output voltage is 240 Voltage, This is the off-grid system. solar panel installed capacity is 12kw. total consumption of our home is 2kw. total and EV battery consumption is 3kw I can easily use the power of the solar to operate the home and battery with the 9-level flying capacitor multi-level inverter.

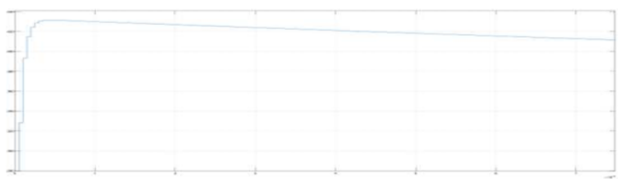

Fig 3.1: Output Voltage From the Pv Array

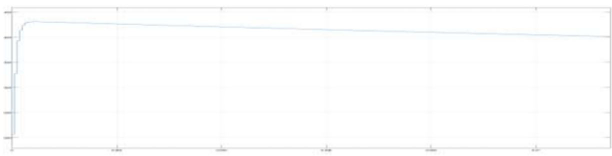

Fig 3.2: Boosted voltage (voltage and time)

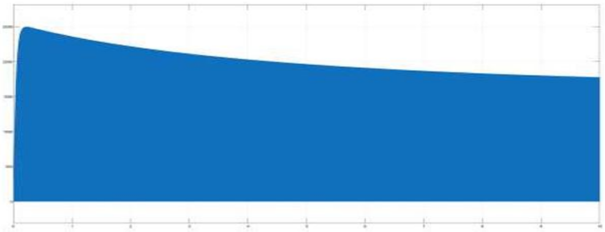

Fig 3.3: current from the solar system

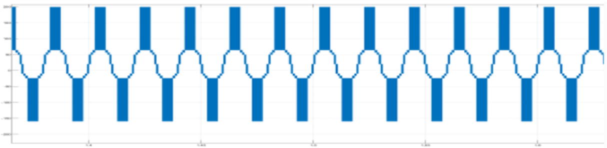

Fig 3.4: AC Output voltage – From load to House

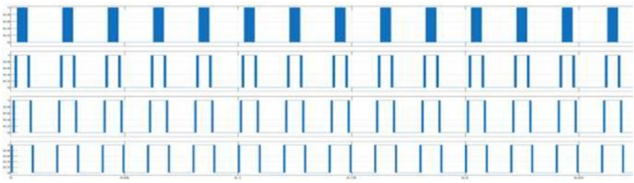

Fig 3.5: Switching pulse of S0,S1,S2,S3 from the inverter

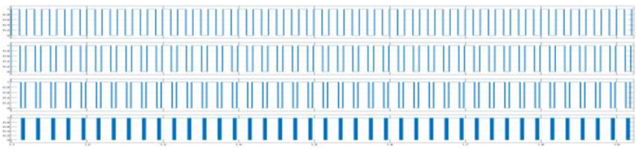

Fig 3.6: Switching pulse of S4,S5,S6,S7 from the inverter

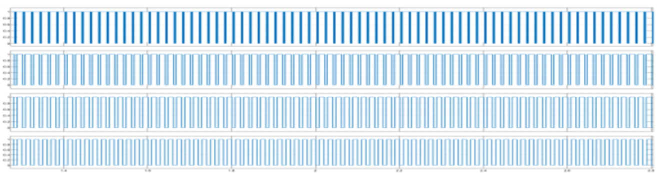

Fig3.7:Switching pulse of S8,S9,S10,S11 from the inverter

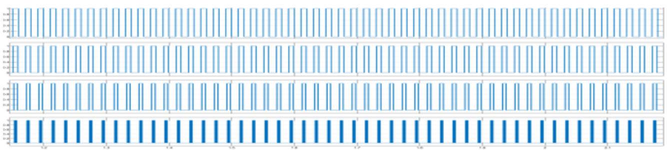

Fig 3.8: Switching pulse of S12,S13,S14,S15 from the inverter

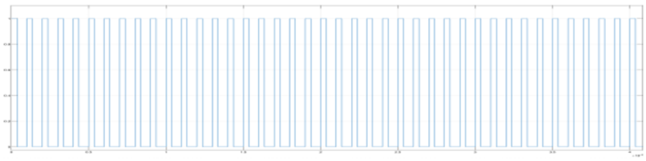

Fig 3.9 Switching pluse for dc-dc booster

Fig 3.10: EV battery Wave form

4. CONCLUSIONS

The study successfully developed a solar PV-integrated nine-level flying capacitor multilevel inverter controlled by SVPWM, offering high efficiency, low harmonic distortion, and stable operation. The system effectively supports dual applications—EV charging and residential power supply—while maintaining excellent power quality and DC-link regulation. With its modular design and superior performance, the proposed system proves feasible for real-world renewable energy integration. Future enhancements like grid connectivity, advanced MPPT, and wide bandgap devices can further optimize its efficiency and adaptability for sustainable power solutions.

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