iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** XII **Month of publication:** December 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XII December 2017- Available at www.ijraset.com

A Standalone Single Stage Switched Capacitor Inverter with Maximum Power Point Tracking

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Abstract: A DC-AC inverter containing no inductors or transformers is presented. In the transformer less photovoltaic (PV) system, the common mode ground leakage current may appear due to the galvanic connection between the PV array and the ground, which causes the safety issues and reduces the efficiency. To solve this problem, a novel inverter topology with switched capacitors is used in this work. To enable integration with the PV module, efficiency and compactness are maximized with a single stage topology that tracks the MPP of the PV source. Furthermore, a modified unipolar sinusoidal pulse width modulation (SPWM) strategy is used to reduce the pulsating current caused by the charging and discharging operations of the switched capacitors. This leads to simpler filtering to remove the unwanted noise in the signal. The advantages of this inverter are: power efficiency, no use of bulky inductors and capacitors and a cost effective low profile design. The Modified Perturb and Observe algorithm is used for maximum power point tracking. The circuit is simulated by using the PLECS software and more than 95% efficiency is obtained from the simulation result.

Keywords: Inverter,Maximum Power Point Tracking, Switched Capacitor,SPWM,PLECS.

I. INTRODUCTION

Switched capacitor (SC) power conditioners achieve power conversion by electronically switching capacitors between the input power source and the load. SC power conditioners are extensively used for dc-dc conversions. A lot of literature dealing with analysis, control methods, topologies efficiency issues and applications of SC dc-dc converters are available. The most distinguishing feature of SC dc-dc converters is the absence of inductors and transformers for handling power, leading to higher power densities compared to conventional dc-dc converters. The simulation results show that the stand alone switched capacitor inverter with maximum power point tracking. There are several MPPT techniques are available. In this paper, Modified Perturb and Observe algorithms are used to track the maximum power point. The advantages of SC dc-dc converters are efficiency over 95% under certain operating conditions for a wide range of load variation, amenability for mass production and cost effectiveness, ruggedness and compactness due to the absence of magnetic components, easy thermal management by heat steering techniques and a wide spectrum of output power ranging from a few milli-watts for single chip power solutions to over a kilowatt of output power.A switched capacitor (SC) based inverter that tracks the maximum power point (MPP) of a photovoltaic (PV) source and generates a pure sine output is presented in [1]. A DC-AC inverter containing no inductors or transformers is presented in [2]. The role of the magnetic devices is played by a switched-capacitor (SC) circuit, formed by two sub circuits. In [3], using CMOS-TG as a bidirectional switch, the various topologies can be integrated in the same configuration for achieving two functions: boosting and alternating; boosting for getting a sinusoidal output in which the peak is the result of a many times step-up of the input; alternating to realize the positive/negative half sinusoidal of the outputA closed-loop multistage (n -stage) multiphase (p -phase) switched-capacitor boost dc-ac inverter (MPSCI) is used in [4] by combining a variable-phase control (VPC) and sinusoidal pulse width-modulation (SPWM) technique for low-power step-up inversion/regulation. In [5], several modular converter topologies based on a switched-capacitor-cell concept are introduced for high-power applications. Two types of switched-capacitor cells, including the full cell and the half-cell, are discussed in [5]. A new type DC-AC converter using a voltage equational type switched capacitor transformer is presented in [6]. A test circuit which converts DC voltage (160 V) to an AC voltage (100 V/60 Hz) was built.[7] introduces a new transformer-less multilevel topology for PV arrays systems. The 7-levels structure ensembles the best characteristics of three basic topologies to obtain a step-up DC-AC converter with only a single DC input and nine power switches. [8] Proposes a switched-capacitor approach to generate a high voltage sinusoid at a frequency of few hundred Hertz for driving a highly capacitive load. The need for such a driver stemmed from an ITS (intelligent transportation systems) project that requires efficient inverters for driving electroluminescent (EL)

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displays. [9] presented to propose a new inverter topology for a multilevel voltage output. This topology is designed based on a switched capacitor (SC) technique, and the number of output levels is determined by the number of SC cells. novel switched-capacitor-based cascaded multilevel inverter is proposed in [10], which is constructed by a switched-capacitor frontend and H-Bridge backend. Through the conversion of series and parallel connections, the switched-capacitor frontend increases the number of voltage levels. A novel switched-capacitor inverter is used in [11]. The inverter outputs larger voltage than the input voltage by switching the capacitors in series and in parallel. In [12], SunShot aims to make solar energy a low-cost electricity source for all Americans through research and development efforts in collaboration with public and private partners. In [13], Boundary conduction mode (BCM) and discontinuous conduction mode (DCM) control strategies are widely used for the flyback micro inverter. The BCM and DCM control strategies are investigated for the interleaved flyback micro inverter concentrating on the loss analysis under different load conditions. Switched capacitor multilevel output DC-DC converters are evaluated as panel integrated modules in a solar maximum power point tracking system [14]. The recommended system includes a central input current-controlled ripple port inverter. The use of a switched capacitor (SC) dc-dc converter for tracking the maximum power point (MPP) of a photovoltaic (PV) array with the possibility of partial shading is described in [15]. The SC converter topology can be reconfigured to maximize conversion efficiency depending on the solar radiation and load.

A. Switched Capacitor Benefits

The common inverter always contains the magnetic elements, and so it results in the electromagnetic interference (EMI) problem. For avoiding the EMI effect, it is a quite excellent choice to adopt a switched capacitor circuit scheme, containing only capacitors and switches. Although the circuit lead to efficiency problem, it is the most excellent one of their advantages that the SC circuits do not require any magnetic elements (inductor/transformer), so the IC fabrication is not only promising but the EMI problem is also improved [3].

B. Single stage conversion

In a single stage operation, the DC supplied by the solar cell is directly converted into AC by employing inverters.

Under two stage operations, the DC output of PV cell is boost up by employing DC-DC converters and then this DC is inverted into *AC by using inverters.* When Comparing between two stage and single stage conversion, the dc output from the PV source is increased or decreased by the converter and it is inverted by using the inverter. The two stage conversion has an overall efficiency of $\eta 1 * \eta 2$. In the single stage conversion the dc output from the PV module is directly converted into ac by employing inverters. A single stage is not only more efficient but is also cost effective due to lower component.

II. SYSTEM OVERVIEW

This section describes the block diagram of the switched capacitor based inverter using in standalone operation. The capacitor charging and discharging operations are controlled by the switches. The PV source is produced the electrical energy and is stored in the source capacitance $C_{PV.}$ The source capacitance acts like a definite source. The switched capacitor blocks are connected across the PV source. Diode is used for the freewheeling operation. The LC filter is used to remove the unwanted signals. The output of LC filter is a unipolar waveform. This waveform is converted into bipolar waveform by using the single phase H-bridge inverter. Unified Sinusoidal Pulse Width Modulation is used to turn on and turn off the switches. Maximum Power Point Tracking tracks the MPP and given the duty cycle as the output.

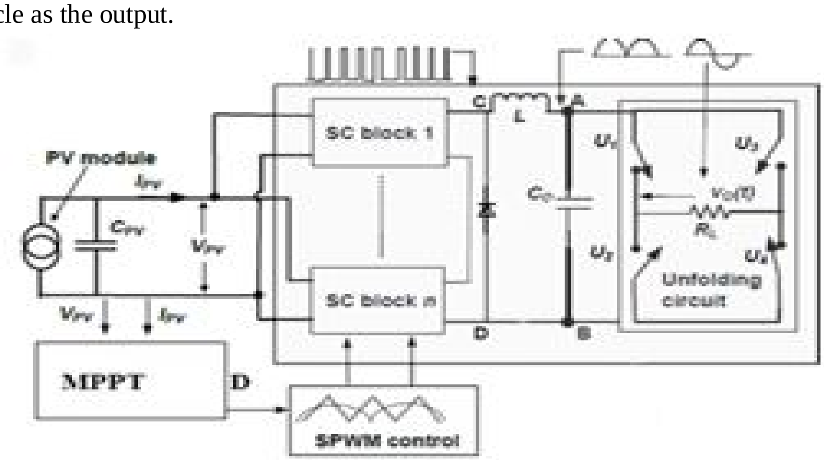

Fig.1 Overall configuration of PV module integrated single stage SC inverter

A. Switched Capacitor Block

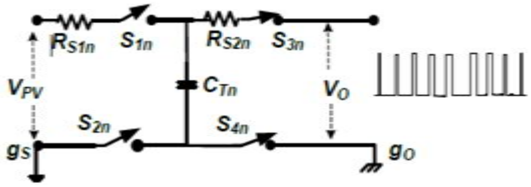

Fig. 2 n^{th} basic SC building block of the inverter

The SC converter is shown in figure2. The S1 and S2 represent the input switches. The S3 and S4 represent the output switches. The switches are turned ON and OFF by using the SPWM. When S1 and S2 are closed, the capacitor $C_{Tn}$is charging. Then there is a dead time when all switches are opened. When S3 and S4 are closed, $C_{Tn}$is discharging into the load. Thus this topology generates a floating output voltage with respect the source $V_{PV.}$ By connecting the inputs of multiple basic SC blocks in parallel across the input source V_{PV} and their floating output in series, the topology can be used as a buck.

B. LC Filter

During the buck mode, the input current can be treated as the input filter's inductor's current, whose ripple is much reduced from the filtering effect. Thus the input inductor is designed based on the current ripple in boost mode.

III. DESIGN PROCEDURE FOR THE SC INVERTER

A. Selecting C_{PV}

A constant voltage must be presented to the input of the SC inverter. A capacitor C_{PV} is connected across the PV module's output for this purpose where [16]

$$C_{PV}=\frac{Ppv}{4\Pi foVpv\ \Delta Vpv} \longrightarrow (1)$$

Here $P_{pv}$is the maximum power that the PV array can deliver and ΔV_{PV} is the maximum allowed ripple on the PV voltage.

Design of L L is designed to always operate in discontinuous conduction mode to minimize its size. Let $I_{L\text{-}peak}$ be the peak value of $i_L(t)$. It is assumed that $I_{L\text{-}peak} = 4I_{0\text{-}peak.}$[1]

$$L= V_{0peak}.dt/di \longrightarrow (2)$$

Selecting C_0

C_0 affects the average output ripple $\Delta V.R_L$ is supported by L and C_0 when all switches are off.Thus C_0 is given by,

$$C_0=\frac{-0.5Ts}{R*\ln\{{}^{Vo\text{-}peak-\Delta V}/_{Vo\text{-}peak}\}} (3) \longrightarrow$$

Components Selection

Components	Values
C_{PV}	10µF
Rs_1	0.4Ω
Rs_2	1.6Ω
C_T	10µF
C_0	0.47µF
L	850µH
R_L	180Ω

Table.1

B. Sinusoidal Pulse width Modulation

In SPWM (Sinusoidal Pulse Width Modulation) two signals are compared. The Modulating reference signal is sinusoidal and the carrier wave is triangular. Gating pulses are produce by comparing the two signals and the width of each pulse is varied is proportion to the amplitude of the sine wave. The frequency of the reference signal determines the inverter output frequency and the reference peak amplitude controls the modulation index and the RMS value of the output voltage. In this paper unipolar sinusoidal pulse width modulation is used. The positive half cycle is considered to produce the pulses.

The frequency of triangular wave will be greater than the frequency of sine reference wave. So that let f_s= 70KHz and f_0= 100Hz.

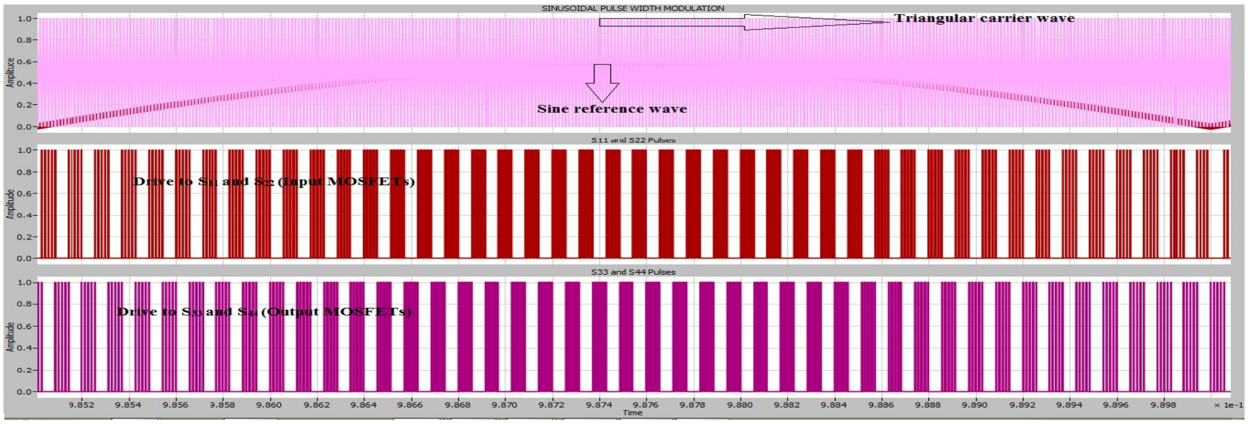

Fig.3. Sinusoidal Pulse width Modulation

IV. MAXIMUM POWER POINT TRACKING

Various MPPT techniques are described inthe literatures. The Perturb and Observe (P & O) algorithm is the most popular. This method is widely used in commercial PV inverter using reduced instruction set micro processors. Even though, this method is simple and reliable, it has three main demerits, when the maximum power point (Vm) is reached, the P & O algorithm will fluctuate around it resulting in a loss of PV power. This is especially true in cases of constant or slowly varying atmospheric conditions (steady state variations). Next demerit is that it cannot cope with the sudden or dynamic change in their radiance and the operating point could not converge to the MPP locus. This also results in energy loss. Finally, it is seen that for small perturbation steps, the tracking is slow but the variations in PV reference voltage is minimal. For large perturbations, faster tracking is realized with increased variations in the output of the MPPT. These are some of the major disadvantages of this method. The above de-merits are clearly addressed in the Modified P & O technique (MP & O).

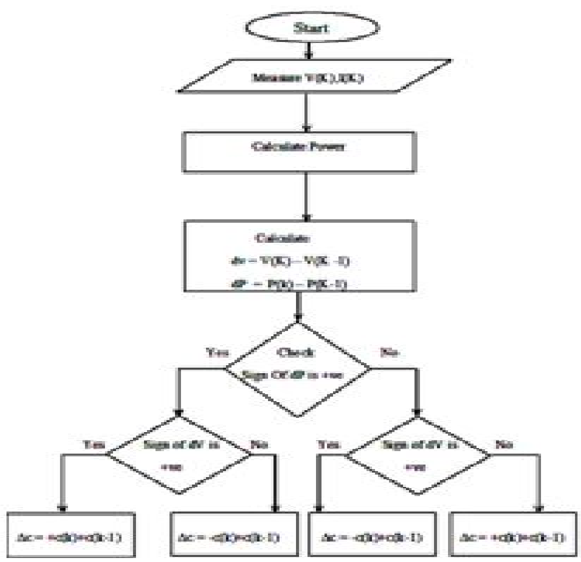

Fig.4 Flow chart of Modified P&O algorithm

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XII December 2017- Available at www.ijraset.com

A modified P & O technique is therefore used that can overcome the limitation of hill climbing P & O method. The flow chart of the MP &O method is given in Fig.4. This modified method uses sign of the change in power and voltage. Here, when the magnitude of power change Δp is increasing, the sign of perturbation c(k) is positive. But, when the power decreases/increases rapidly after an increase/decrease, caused by change in atmospheric conditions, the sign of the change in voltage Δv and power Δp multiplied together changes accordingly and sign of perturbation c(k) changes in such a direction to make the sum Δc =0 for one instant. Next instant, when the change in power continues to become positive/negative, the algorithm follows the hill climbing method.

A. Behaviour of Modified P and O algorithm

ΔP	ΔV	C(K-1)	Signof C(K)= sign of(ΔP*ΔV)	ΔC= C(K-1)+ΔC	V_{ref}= V(K-1)+ΔC
+	+	+0.003	+0.003	+0.006	↑
-	+	+0.003	-0.003	0	constant
+	-	-0.003	-0.003	-0.006	↓
-	-	-0.003	+0.003	0	constant

Table.2

B. Unfolder Circuit

The unfolder circuit is similar to the single phase half bridge inverter. It consist of four switches (U1,U2,U3,U4).When U1 and U4 are turned ON by the positive pulse and U2 and U3 are turned ON by the negative pulse. The switching frequency is designed as 100Hz.

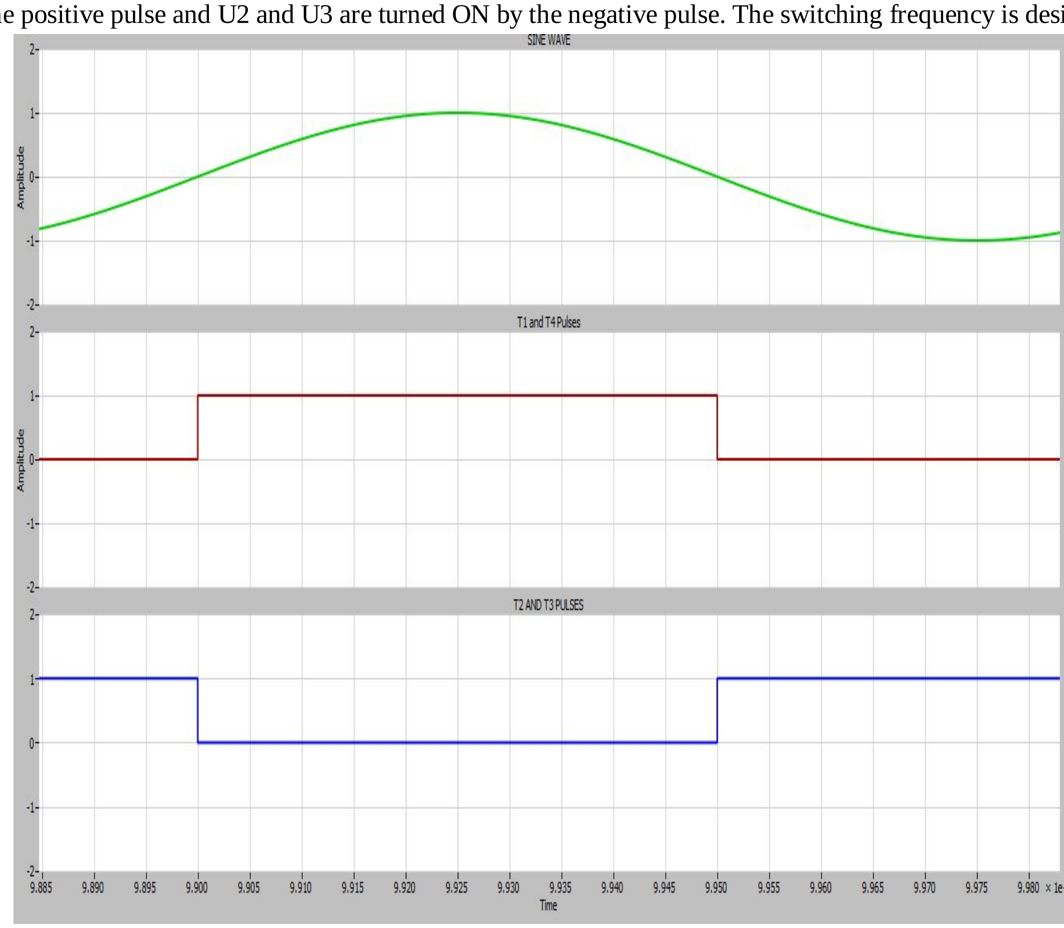

Fig.5. Switching pulses of Unfolder Circuit

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V. SIMULATION RESULTS

The circuit is simulated using PLECS software as shown in Fig.6.

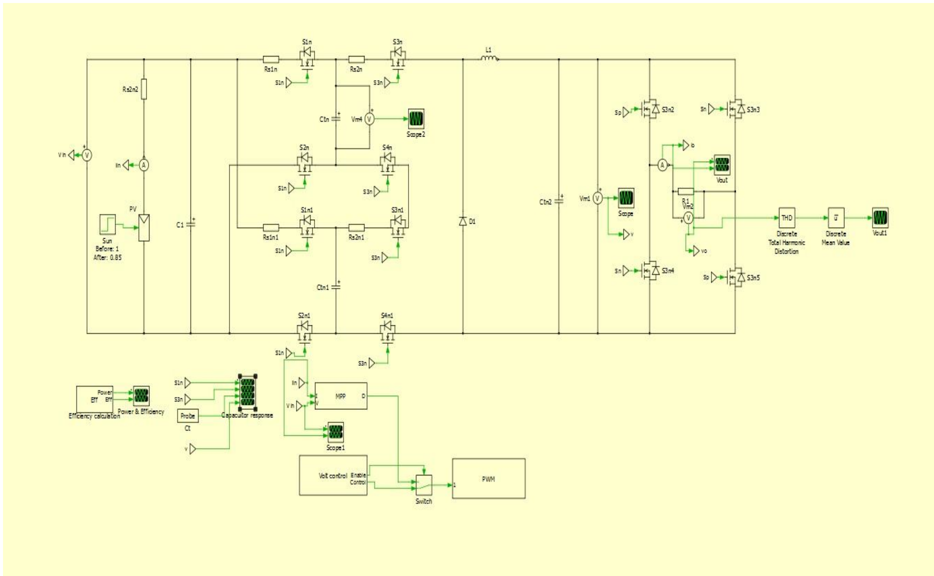

Fig.6 Simulation circuit

A. Output Of Lc Filter

The below simulation result shows that the output of LC filter. LC filter is used to remove unwanted signals. The LC filter is used to attenuate the high frequency signals.

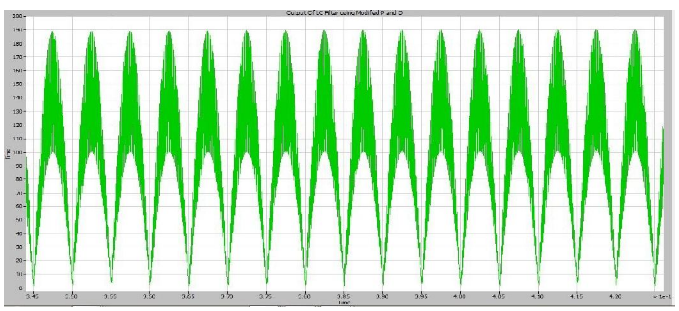

Fig.7. Output of LC Filter

B. Output Voltage And Current Waveform

The below Simulation result shows that the output voltage and current waveform. When the input voltage is 160V , the corresponding output voltage is 190$V_{peak\text{-}peak}$.

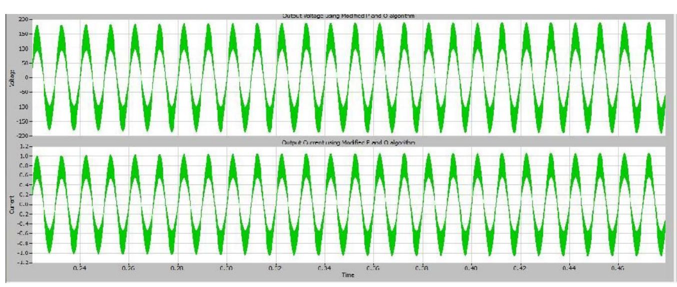

Fig.8.Output Voltage and Current

C. Efficiency

The below simulation shows that the curves of input power and output power of PV module. From the simulation it is observed that the efficiency is reached more than 95%

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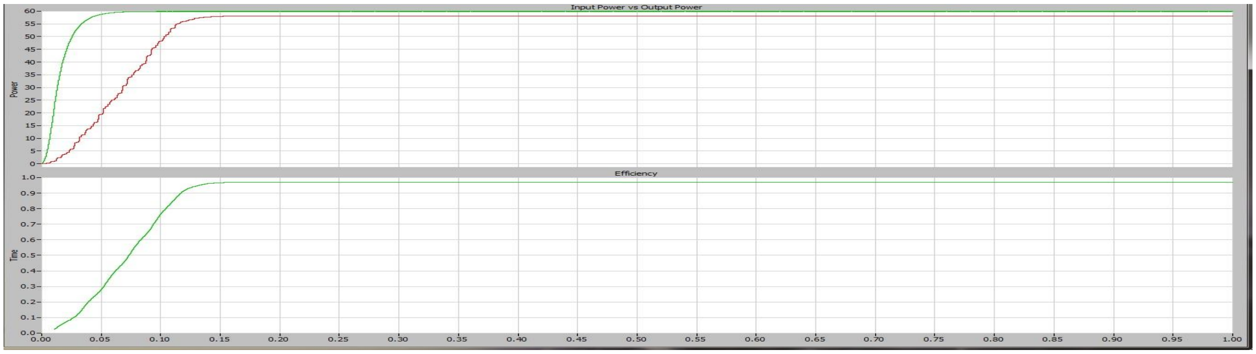

Fig,9 Efficiency of the Inverter

VI. CONCLUSION

This paper has discussed a switched capacitor based dc-ac inverter with the following features. (a) The inverter is fed from a PV module; (b) It's a single stage topology for PV module's MPP tracking, step down the input voltage and inversion resulting in high efficiency. (c) It has scope for integration with the PV module due to inherent features of SC inverter like compactness, ruggedness, and light weight. This Project is simulated by using the PLECS software. The Maximum Power Point tracking is implemented by using the Modified Perturb and Observe algorithm. The Performance of the MPPT algorithm is analyzed. The modified unipolar sinusoidal pulse width modulation is used to control the switched capacitor switches. The inversion efficiency is greater than 95% is achieved based on the simulation result.

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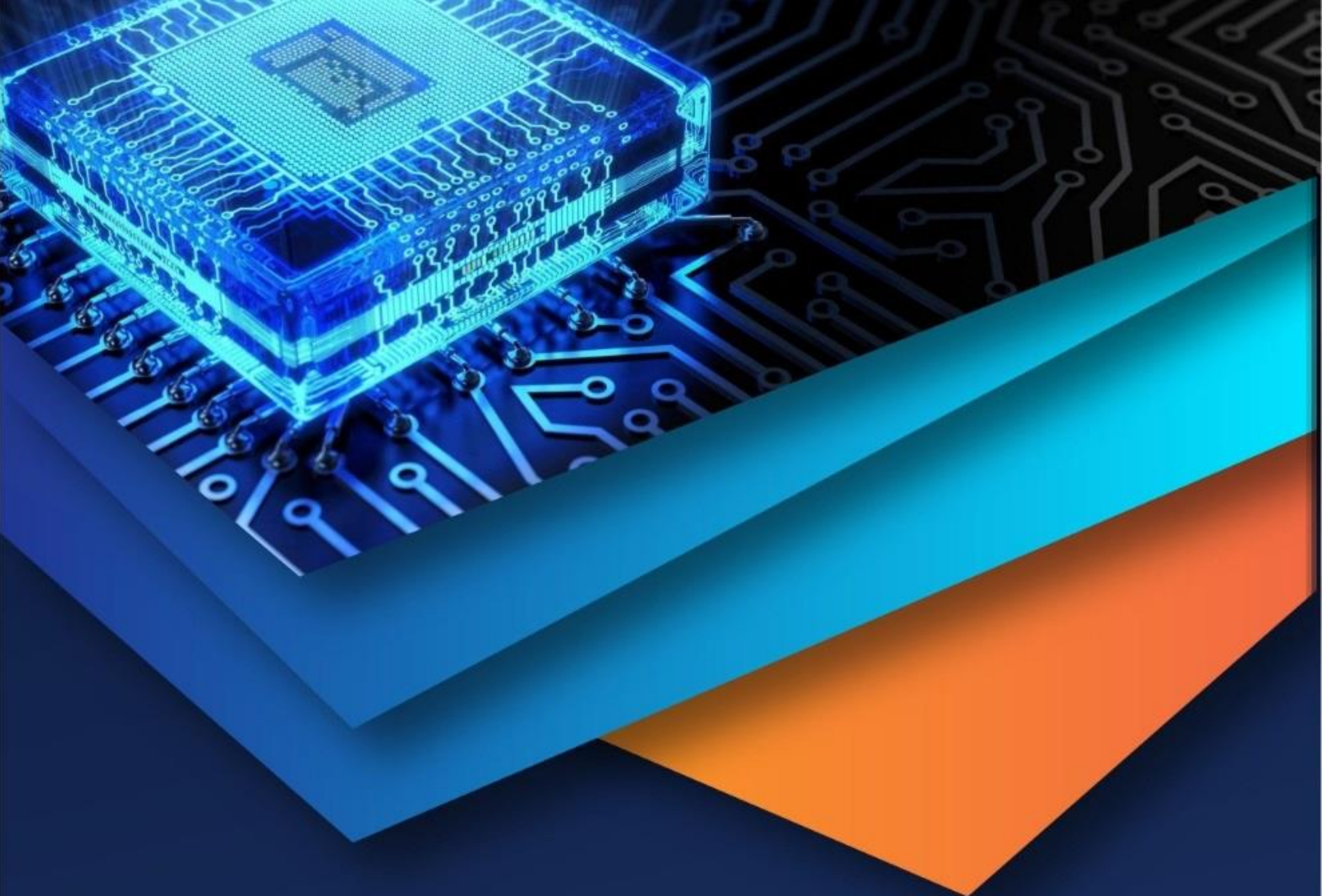

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