

## A NOVEL MULTILEVEL INVERTER'S DESIGN AND IMPLEMENTATION BASED ON PHOTOVOLTAIC SYSTEMS

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**Keywords:** incremental conductance; inverter three phase; maximum power point tracking; photovoltaic; pulse width modulation; space vector pulse width modulation.

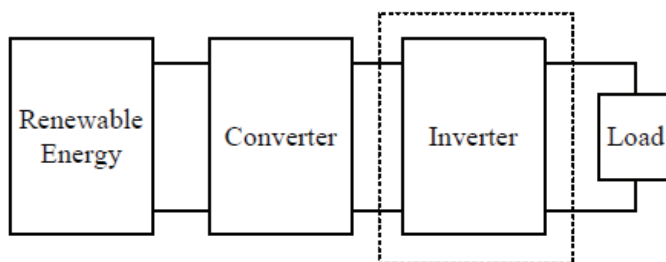
**Abstract:** Inverter and rectifier controllers frequently employ the space vector pulse width modulation (SVPWM) approach. The space vector pulse width modulation is more suitable for digital implementation than sinusoidal pulse width modulation (SPWM) and can enhance the achievable maximum output voltage, with maximum line voltage nearing 70.7 % of the DC link voltage (compared to 61.2 % for SPWM) in the linear modulation range. It can also achieve a lower voltage total harmonic distortion factor. In this work, we apply these two methods to photovoltaic systems based on technical dependence MPPT INC to improve the output voltage of the photovoltaic panel.

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### 1. Introduction

The demand for electric power and its quality has increased as a result of rapid technological advancement. The specification of power devices and power conversion techniques is being advocated as semiconductors develop. An inverter is one of the power converters that can convert DC to AC. An inverter is an electrical device that distributes electricity to other electrical devices such as an uninterruptible power supply, servo motor, air-conditioning system, and smart grid made out of renewable energy, as shown in Fig. 1. The output frequency and voltage must alter with varied loads to meet different needs and characteristics [1].

Due to a wide range of attributes like as abundance in nature, cheap maintenance, and high-power density, photovoltaic (PV) energy has become one of the most desired sources over all other renewable sources in the last decade [2]. The efficiency of the inverter, PV modules, and maximum power point tracking (MPPT) algorithms, on the other hand, has a significant impact on the efficiency of PV systems.



**Fig. 1. Block diagram of renewable system**

The greatest efficiency of commercially available PV inverters is 98 %. The efficiency of PV modules is being improved and is being studied extensively, although it is dependent on complex production processes. Instead, enhancing the MPPT's efficiency with various control strategies could be an option [3].

A variety of MPPT algorithms have been proposed including fractional open circuit voltage, fractional short circuit current, perturb and observe (**P&O**) [4], incremental conductance (**INC**), and artificial-intelligence-based algorithms. These algorithms vary in their complexity, efficiency, cost, and potential applications. One of very popular hill-climbing MPPT algorithm is the INC algorithm. This maximum power point tracking algorithm is based on the fact that the power-voltage curve of a PV generator at constant solar irradiance and cell temperature levels has normally only one MPPT [5].

This paper gives a complete experimental evaluation of the INC algorithm's performance characteristics by applying this methodology to two techniques of regulating the inverter and comparing the results.

## 2. The photoelectric effect governs the operation of PV panels

2.1. *Photovoltaic Cell Equivalent Circuit.* The solar array is constructed by connecting solar cells in series and parallel. When a solar cell is exposed to sunlight, it produces *dc* voltage. The analogous circuit model for a solar cell. Solar cells are a type of nonlinear current source. Its generated current is affected by material properties, solar cell age, irradiance, and cell temperature.

The current produced by the solar cell is equal to the current produced by the current source, minus the current that passes through the diode, minus the current that flows through the shunt resistor, as shown in the equivalent circuit [7, 8]

$$I = I_{ph} - I_D - I_{SH}, \quad (1)$$

where  $I$  is output current, A;  $I_{ph}$  is photo generated current, A;  $I_D$  is diode current, A;  $I_{SH}$  is shunt current, A.

The voltage across these components controls the current that flows through them

$$V_j = V + IR_s, \quad (2)$$

where  $V_j$  is voltage across both diode and resistor  $R_{SH}$ , V;  $V$  is voltage across the output terminals, V;  $R_s$  is series resistance,  $\Omega$ .

The current redirected via the diode, according to the Shockley diode equation, is

$$I_D = I_0 \left\{ e^{\frac{qV_j}{nkT}} - 1 \right\}, \quad (3)$$

where  $I_0$  is reverse saturation current, A;  $n$  is diode ideality factor (1 for an ideal diode);  $q$  is elementary charge;  $k$  is the Boltzmann's constant;  $T$  is absolute temperature at 25 °C,  $kT/q \approx 0.0259$  V.

The current redirected via the shunt resistor, according to Ohm's law, is

$$I_{SH} = \frac{V_j}{R_{SH}}, \quad (4)$$

where  $R_{SH}$  is shunt resistance,  $\Omega$ .

The characteristic equation of a solar cell, which connects solar cell characteristics to output current and voltage, is obtained by substituting them into the first equation

$$I = I_{ph} - I_0 \left\{ e^{\frac{q(V+IR_s)}{nkT}} - 1 \right\} - \frac{V + IR_s}{R_{SH}}. \quad (5)$$

2.2. *Incremental conductance method.* The P-V characteristic curve was used to construct the incremental conductance. This method was created in 1993 to address some of the shortcomings of the P&O algorithm. On a broad irradiation changes environment, IC seeks to enhance the tracking time and create more energy. Using the relationship between  $dI/dV$  and  $-I/V$ , the MPP may be determined.

If  $dP/dV$  is negative, MPPT is on the right side of the recent position, but if MPP is positive, MPPT is on the left side. The IC method's equation is [9]:

$$\frac{dP}{dV} = \frac{d(V, I)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV}; \quad (6)$$

$$\frac{dP}{dV} = I + V \frac{dI}{dV}, \quad (7)$$

when  $dP/dV = 0$ , MPP is attained.

$$\frac{dI}{dV} = -\frac{I}{V}; \quad (8)$$

$$\frac{dP}{dV} > 0, \text{ then } V_p < V_{mpp}; \quad (9)$$

$$\frac{dP}{dV} = 0, \text{ then } V_p = V_{mpp}; \quad (10)$$

$$\frac{dP}{dV} < 0, \text{ then } V_p > V_{mpp}. \quad (11)$$

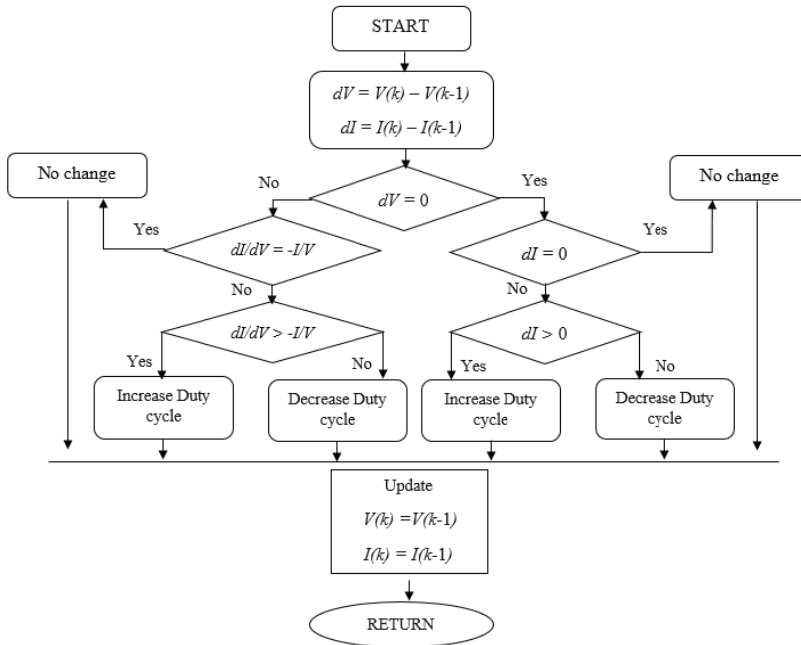


Fig. 2. Flow chart of Incremental Conductance algorithm

If the MPP is on the right side,  $dI/dV$  and  $-I/V$  must be used to reduce the PV voltage to reach the MPP [10]. The MPP may be found using IC approaches, which can also be utilized to enhance PV efficiency, minimize power loss, and lower system costs. When compared to P&O, the implementation of IC on a microcontroller yielded more steady results. In exchange for its implementation complexity, the oscillation around the MPP region may also be prevented. Because the voltage increment and decrement were chosen manually by trial and error, the tracking time was still slow. Figure 2 depicts the IC algorithm.

### 3. Different pulse width modulation techniques

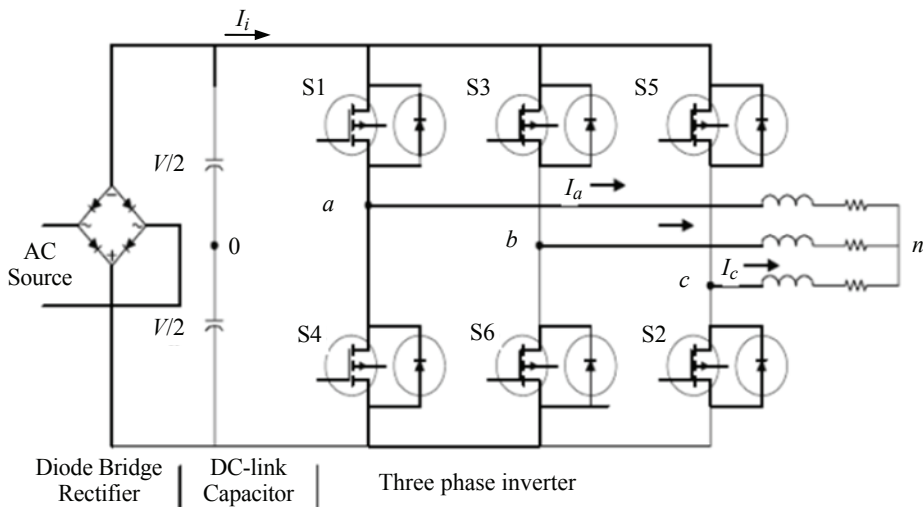
3.1. *Sinusoidal pulse width modulation*. Rather than keeping the same pulse width across all pulses as in multiple pulse width modulation, the width of each pulse is altered in proportion to the amplitude of a sine wave measured at the pulse's center. The distortion factor as well as lower order harmonics are greatly decreased. A sinusoidal reference signal is compared to a triangular carrier wave of frequency to generate the gating signals. The inverter output frequency and peak amplitude are determined by the frequency of the reference signal, which also influences the modulation index and the output voltage. The carrier frequency determines the number of pulses each half cycle.

Inverters that use PWM switching techniques have a constant input voltage that is usually constant in magnitude. The inverters job is to take this input voltage and output ac where the magnitude and frequency may be regulated. There are many various ways that pulse-width modulation can be done to shape the output to be alternating power. A typical approach termed sinusoidal PWM will be explained. In order to output a sinusoidal waveform at a certain frequency a sinusoidal control signal at the required frequency is compared with a triangle waveform. The inverter then utilizes the frequency of the triangle wave as the switching frequency. This is normally kept constant [10].

3.2. *Space vector pulse width modulation (SVPWM) algorithm*. For three phase inverters, Space Vector Modulation (SVM) was first devised as a vector approach to Pulse Width Modulation (PWM). It's a more advanced sine wave generation approach that delivers a higher voltage to the motor while reducing total harmonic distortion. Any modulation technique's main goal is to produce varied output with a maximum fundamental component and few harmonics. The Space Vector PWM approach is a sophisticated, computation-intensive PWM technique that is one of the best for variable frequency driving applications.

Figure 3 depicts the circuit model of a typical three phase voltage source PWM inverter. The six power switches that shape the output are a, a', b, b', c, and c', and are controlled by the switching variables a, a', b, b', c, and c'. When an upper switch is turned on, i.e., when a, b, or c is 1, the matching bottom transistor, i.e., when a', b', or c' is 0, is turned off. As a result, the output voltage can be determined by the on and off states of the higher switches S1, S3, and S5. The Space vector pulse width modulation differs from PWM modulation in that it is based on a space vector representation of the voltages in the plane. Clark's transformation uncovers the components. A particular switching sequence of the upper three power transistors of a three phase power inverter is referred to as SVPWM. It has been demonstrated to produce less harmonic distortion in the output voltages and/or currents applied to the phases of an AC motor and to make better use of the dc input voltage. It has become increasingly popular in recent years as a result of its exceptional performance qualities.

The inverter output voltage is modulated using the space vector idea, which is obtained from the spinning field of an induction motor. The three phase values can be converted to their equal two phase quantity in either a synchronously moving frame (or)



**Fig. 3. Three phase voltage source inverters**

a stationary frame using this modulation technique. The magnitude of the reference vector can be determined from these two phase components and utilized to modulate the inverter output. In the following section, we will look at how to get the rotating space vector using a stationary reference frame. Let the three phase sinusoidal voltage component in the stationary reference frame be,

$$V_a = V_m \sin \omega t; \quad (12)$$

$$V_b = V_m \sin \left( \omega t - \frac{2\pi}{3} \right); \quad (13)$$

$$V_c = V_m \sin \left( \omega t - \frac{4\pi}{3} \right). \quad (14)$$

When this three phase voltage is given to an AC machine, it causes a spinning flux in the machine's air gap. A single rotating voltage vector can be used to represent the rotating resultant flux. In the stationary reference frame, Clark's Transformation can be used to determine the magnitude and angle of the rotating vector. The voltage equations in the  $abc$  reference frame can be translated into the stationary dq reference frame, which comprises of the horizontal  $d$  and vertical  $q$  axes, as shown in Fig. 4, to implement space vector PWM. The relationship between these two reference frames can be seen in Fig. 4.

$$f_{dq0} = K_s f_{abc}. \quad (15)$$

$$K_s = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}, \quad f_{dq0} = [f_d f_q f_0]^T, \quad f_{abc} = [f_a f_b f_c]^T, \quad \text{and } f \text{ denotes}$$

either a voltage or a current variable.

Figure 4 shows how it's done. In a three-dimensional coordinate system, this transformation is identical to an orthogonal projection of  $[a \ b \ c]t$  onto the two-dimensional perpendicular to the vector  $[1 \ 1 \ 1]t$  (the analogous  $d$ - $q$  plane). As a result, there are six non-zero vectors and two zero vectors. Figure 5 shows how six non-zero vectors ( $V_1 \dots V_6$ ) shape the axes of a hexagonal and supply power to the load.

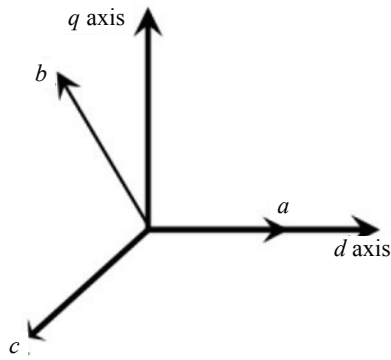


Fig. 4. The relationship of *abc* reference frame and stationary *d-q* reference frame

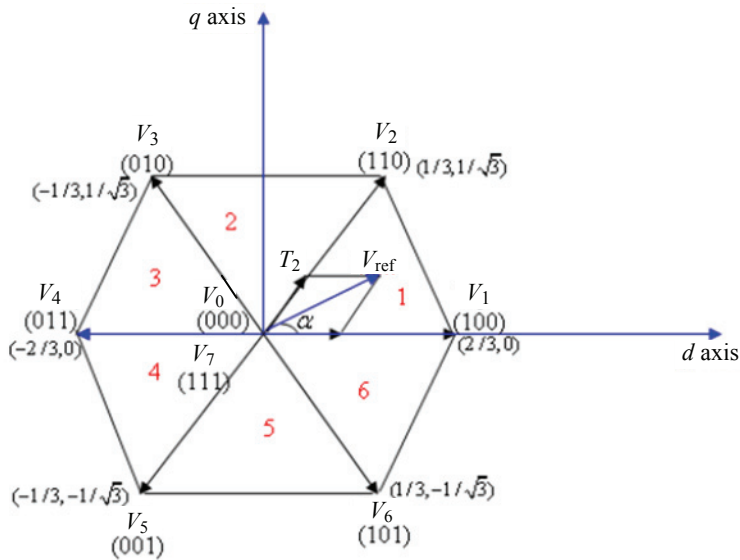


Fig. 5. Basic switching, vectors and sectors

Any two contiguous non-zero vectors form a 60-degree angle. Meanwhile, at the origin, two zero vectors ( $V_0$  and  $V_7$ ) apply zero voltage to the load. The fundamental space vectors are the eight vectors that are denoted by ( $V_0, \dots, V_7$ ). In the *d-q* plane, the same transformation can be applied to the desired output voltage to obtain the desired reference voltage vector  $V_{ref}$ . The goal of the SVPWM approach is to use the eight switching patterns to approximate the reference voltage vector  $V_{ref}$ . One straightforward approximation is to make the inverter's average output in a small period  $T$  equal to  $V_{ref}$  average output in the same period.

There are six switching states for 180° mode of operation, as well as two more states that turn on all three switches of either the upper or lower arms. Three bits are required to code these eight states in binary (one-zero format). Furthermore, because upper and lower switches are always commutated in a complimentary manner, representing the status of either upper or lower arm switches is sufficient. The status of the top bridge switches will be reflected in the next discussion, while the lower switches will be complimentary. Let's say "1" means the switch is on and "0" means it's off. Table 1 lists the various phase and line voltages for each of the eight states [11].

Switching patterns and output vectors

Voltage vectors	Switching vectors			Line to neutral voltage			Line to line voltage		
	<i>A</i>	<i>B</i>	<i>C</i>	$V_{an}$	$V_{bn}$	$V_{cn}$	$V_{ab}$	$V_{bc}$	$V_0$
$V_0$	0	0	0	0	0	0	0	0	0
$V_1$	1	0	0	2/3	-1/3	-1/3	1	0	-1
$V_2$	1	1	0	1/3	1/3	-2/3	0	1	-1
$V_3$	0	1	0	-1/3	2/3	-1/3	-1	1	0
$V_4$	0	1	1	-2/3	1/3	1/3	-1	0	1
$V_5$	0	0	1	-1/3	1/3	2/3	0	-1	1
$V_6$	1	0	1	1/3	-2/3	1/3	1	-1	0
$V_7$	1	1	1	0	0	0	0	0	0

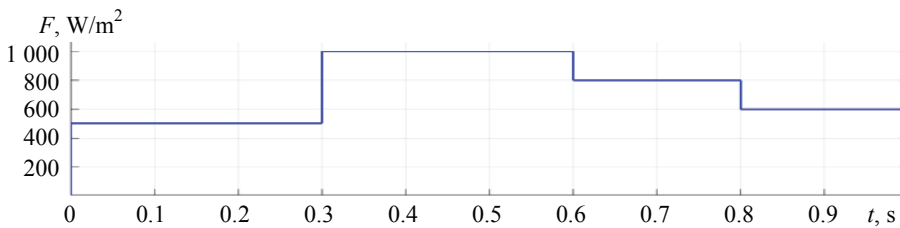
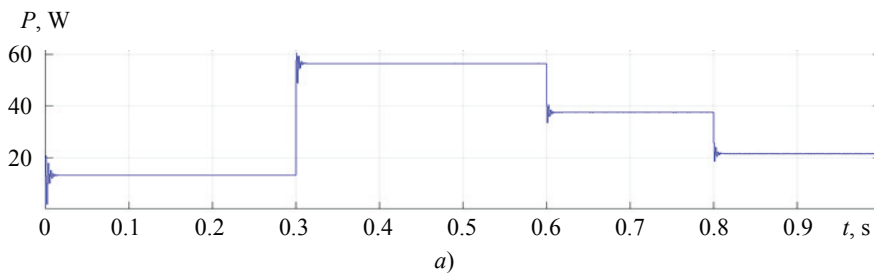
#### 4. Simulation results and discussion

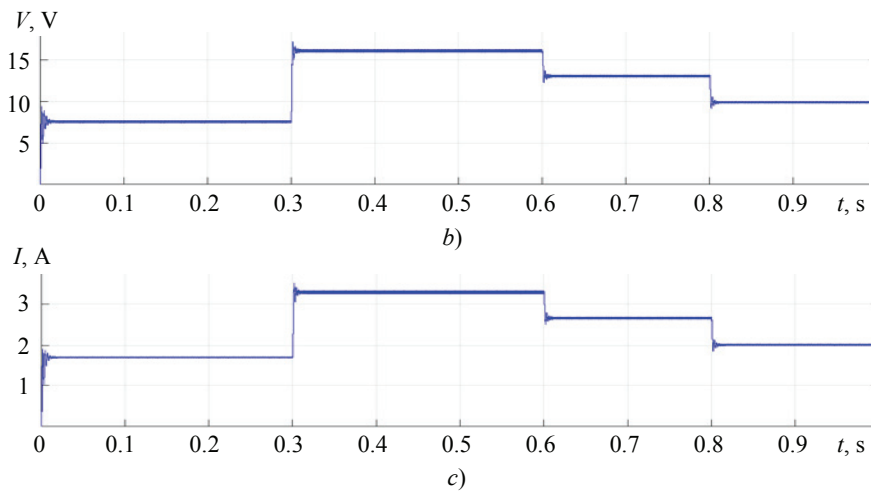
Figures 6 and 7 show the changes of irradiance and the follow of output of the converter DC-DC of the power and voltage and current respectively by Incremental Conductance algorithm.

The basic purpose of any modulation approach is to generate variable output with maximal fundamental component with fewest harmonics. The purpose of pulse width modulation approaches is augmentation of basic output voltage and decrease of harmonic content in three phase voltage source inverters. In this research several PWM approaches are examined in terms of Total Harmonic Distortion (THD).

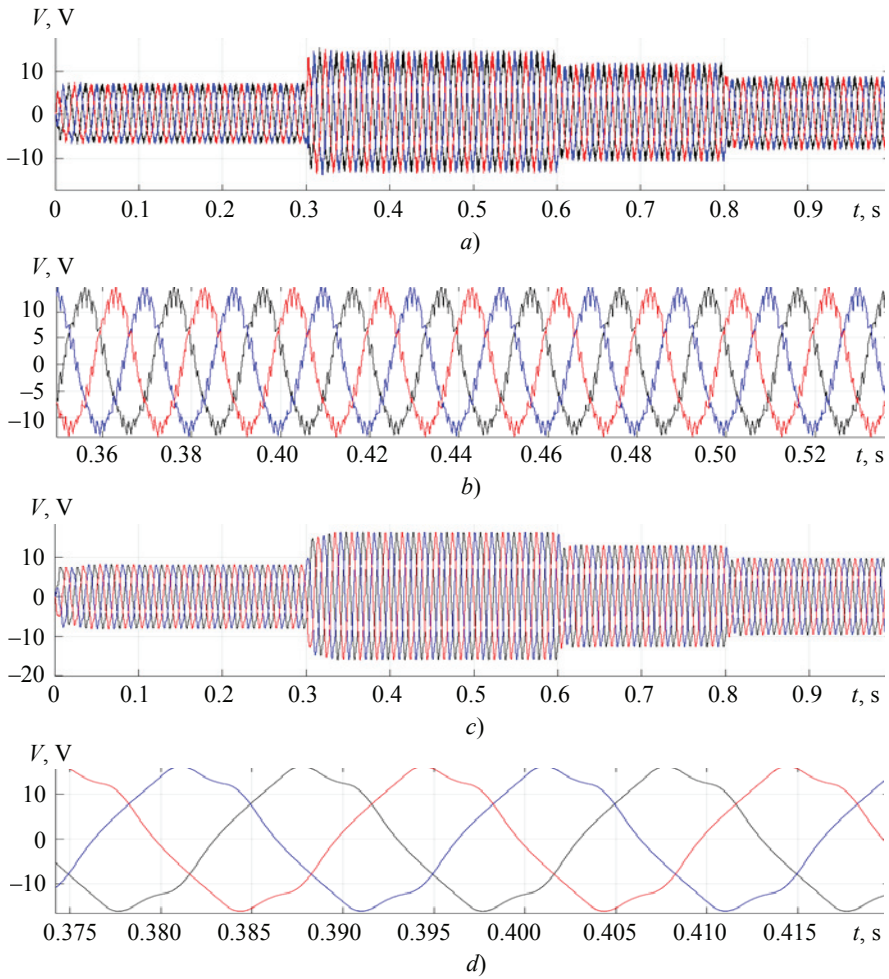
Simulink Models has been built for Sinusoidal PWM (SPWM), SVPWM, and space vector PWM switching patterns. Simulation work was undertaken in MATLAB/Simulink R2018a.

Figures 8, *a - d*, show the output voltage for SPWM and SVPWM respectively. The results found that the output voltage of the inverter is distorted while increasing the frequency of SPWM. By the contrary in the output voltage of SVPWM the switching losses is minimized and accurate while increasing the frequency.

Fig. 6. Insolation – illumination  $F$ Fig. 7. Graphs of the dependence of power  $P$  (*a*) (start)



**Fig. 7. Ending. Graphs of the dependence of voltage  $V$  (b) and the current  $I$  (c) from the time of solar illumination  $t$  obtained by the method of “Incremental Conductance”**



**Fig. 8. Output voltage for PWM (a), PWM (Zoom) (b), SVPWM (c), SVPWM (Zoom) (d)**

## 5. Conclusion

From the analysis on the current ripple created by employing various PWM techniques by photovoltaic applications with Incremental Conductance algorithm, we deduce that the Simulation study reveals that SVPWM gives more enhanced fundamental output with better quality i.e., lesser THD compared to SPWM.

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## Разработка и внедрение новых многоуровневых инверторов на основе фотоэлектрических систем

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**Ключевые слова:** инкрементальная проводимость; трехфазный инвертор; отслеживание точки максимальной мощности; фотогальванический; широтно-импульсная модуляция; пространственно-векторная широтно-импульсная модуляция.

**Аннотация:** В инверторных и выпрямительных контроллерах часто используется пространственно-векторная широтно-импульсная модуляция (SVPWM), которая более применима для цифровой реализации, чем синусоидальная широтно-импульсная модуляция (SPWM). Ее использование позволяет повысить выходное напряжение до 70,7 % вместо 61,2 % для линии постоянного тока в режиме линейной модуляции (SPWM) от максимально возможного. Рассмотрены два метода моделирования фотоэлектрических систем по технической зависимости MPPT INC с целью улучшения качества выходного напряжения фотоэлектрической панели.

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### **Entwicklung und Implementierung neuer mehrstufiger Wechselrichter auf Basis von photoelektrischen Systemen**

**Zusammenfassung:** In Wechselrichter- und Gleichrichtersteuerungen wird häufig die Raumvektor-Pulsweitenmodulation (SVPWM) verwendet, die für die digitale Implementierung besser geeignet ist als die sinusförmige Pulsweitenmodulation (SPWM). Durch ihre Verwendung kann man die Ausgangsspannung auf 70,7 % statt 61,2 % für eine DC-Leitung im linearen Modulationsmodus (SPWM) vom maximal möglichen erhöhen. Es sind zwei Methoden zur Modellierung von Photovoltaikanlagen gemäß der technischen Abhängigkeit von MPPT INC betrachtet, um die Qualität der Ausgangsspannung des Photovoltaikmoduls zu verbessern.

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### **Élaboration et mise en œuvre de nouveaux onduleurs à plusieurs niveaux basés sur des systèmes photovoltaïques**

**Résumé:** Les contrôleurs d'onduleur et de redresseur utilisent souvent la modulation de largeur et d'impulsion spatiale-vecteur (MLISV), qui est plus applicable à la mise en œuvre numérique que la modulation de largeur d'impulsion sinusoïdale (MLIS). Son utilisation permet d'augmenter la tension de sortie à 70,7 % au lieu de 61,2 % pour une ligne du courant continu en mode de modulation linéaire (MLIS) à partir du maximum possible. Sont examinées deux méthodes de simulation de systèmes photovoltaïques basées sur la dépendance technique de MPPT INC afin d'améliorer la qualité de la tension de sortie du panneau photovoltaïque.

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