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Research Article

OPTIMAL DESIGN OF A MULTI-LEVEL VOLTAGE SOURCE INVERTER FOR SOLAR CELLS TO INCREASE OUTPUT POWER WITHOUT NEW SPENDING

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ABSTRACT
Photovoltaic systems convert solar energy directly into electrical energy and do not cause environmental pollution compared with conventional systems of energy production. Therefore, photovoltaic systems are also called “green" or "clean” energy sources. Along with the increasing problems of environmental pollution and the reduction of fossil energy reserves, the use of photovoltaic systems has increased in recent years. Historically, due to their high costs, photovoltaic systems were generally used to provide the required electric power for satellites. But with the growth of the semiconductor industry in recent years and lower costs in the production of semiconductor devices, nowadays, solar arrays have found extensive applications one of which is grid-connected photovoltaic systems. In photovoltaic systems connected to the grid, the inverter is an important part of the system components whose optimal design is of high importance and there are various methods of modulation for it. A common method for the design of multi-level inverter is PWM modulation technique of stairs. In this paper, a new method is proposed through which the switching angles in a multilevel and multi-story inverter modulation step connected photovoltaic systems are calculated. Derived mathematically prove that the proposed algorithm is reduced by THD. To prove that THD is reduced by the proposed algorithm and the output power of solar cells is increased, the mathematical derivation is given. Compared with other methods, it is seen that the obtained THD in this method is the least of all and inverters have improved performances in converting the output voltage of the solar cell. Most importantly, the level of computational process is so low that the calculations can be performed in real time without a lookup table. The proposed method does not require any new spending.

Keywords: *Solar Cell, Multi-level Inverter, Step Modulation*

INTRODUCTION
In recent years much attention has been attracted to multilevel inverter and numerous articles has published on this topic, in (Surin and Leon, 2011; Farid *et al.*, 2010; Rodriguez *et al.*, 2001) references, more background of this research has been presented. Also, many methods for the modulation and control of multilevel inverter have been proposed including, - the method based on sinusoidal bandwidth modulation technique with (Surin and Leon, 2011; Rodriguez *et al.*, 2001) carrier. In this method, the optimal displacement of angle technique has been used for reducing output voltage harmonics of multilevel inverter. In the multilevel inverters, switching point detection can be achieved by a microprocessor or by a digital signal processor (DSP) in real time. Vector PWM modulation technique is also common in the industry Surin and Leon (2011) and Rodriguez *et al.*, (2004) to estimate the time of diagnosis for space vector PWM method is more complex compared to SPWM switching, however, this procedure can also be performed by a microprocessor Rodriguez *et al.*, (2004) and Tolbert *et al.*, (1999). Another optimal modulation technique for multilevel inverters is PWM optimization procedure that includes a modulation step and a few other methods Tolbert *et al.*, (1999) and Rech and Pinheiro (2007). In (Li *et al.*, 2000) the optimal PWM method is presented by using multilevel selective harmonic elimination. This method was introduced in 1999 and is based PWM. Harmonics are removes selectively in this method. This method is rather simple, but more optimal results is needed for some applications. In

optimal PWM method with respect to the Fourier analysis, the total equations whose variables are switching angles are solved in order to provide a specific purpose, such as reducing harmonics distortions optimally. Generally, these equations are non-linear. Newton Rap son method and the method based on the theory of symmetric polynomials and the resultant are among the methods of solving this equation (Chiasson *et al.*, 2005). The genetic algorithm has been proposed for solving the sum of equations whose variables are switching angles (Ozpineci *et al.*, 2005). Other similar articles on the use of genetic algorithms in reducing the harmonics of multilevel inverter have been delivered. Moreover, other articles about harmonics distortions reduction in multilevel inverters, especially in photovoltaic and energy applications, in recent years have been presented (Ert *et al.*, 2002; Beig *et al.*, 2004) of other methods of control and modulation of multilevel inverters is the optimized SVPWM technique is (Karthikeyan and Chenthur, 2011). Other methods have also been proposed including the use of neural networks to optimize and reduce the harmonics of multilevel inverters (Govindaraju and Baskaran, 2009; Malarvizhi and Baskaran; Bambang *et al.*, 2010; Abdalla *et al.*,).

2. Solar Cells and Photovoltaic System and its Types

Photovoltaic systems convert solar energy directly into electrical energy and do not cause environmental pollution compared with conventional systems of energy production. Therefore, photovoltaic systems are also called “green" or "clean” energy sources. Along with the increasing problems of environmental pollution and the reduction of fossil energy reserves, the use of photovoltaic systems has increased in recent years. There are three types of crystalline cells: Polycrystalline, single crystal and amorphous silicon.

Single Crystal Cells: (with approximate thickness of 2/1 to 3/1 mm) has been formed of a large single crystal fragment a temperature around 1400 ° C and this process is very costly. Silicon must be pure and has a perfectly crystal structure. This process guarantees a production with a high level output.

Polycrystalline Cells: Polycrystalline films are prepared by a casting process. Molten silicon is poured into a mold and is allowed to crystallize. Polycrystalline films made by the cast are just generally are less expensive and have a lower efficiency (Due to defects in the crystal structure resulting from the casting process).

Amorphous Silicon: If a silicon layer is put on glass or other material it is known to be an amorphous or thin layer cell. This layer has a thickness of less than one micrometer (thickness of a human hair: 50 to 100 micrometers). Therefore, the production of these cells and their costs are lower. However, the yield of amorphous cells is very lower than that of the two other cells. This is why, basically, they have been used in low-power devices.

Silicon has special chemical properties, especially in its crystal structure. A silicon atom has 14 electrons which are superimposed in three various shells. The first two layers, closest to the center, have been completely filled. But the outer layer having four electrons is half full. So that the silicon atom is always looking for ways to fill the last layer (in order to get the 8 electrons completely). To do this, these electrons would be shared with four silicon atoms of its neighbors. Each atom tends to maintain its position with its neighbor atoms, just in this case, every atom is connected to its 4 neighbors from 4 directions. This is the crystal structure and the creation of these structures is important for this type of PV cell. We defined a pure crystalline silicon. Pure silicon is a weak electrical conductor, because none of its electrons move around like the electrons in good conductors such as copper. Instead, the electrons are arranged in the crystal structure which is fully locked. Silicon in a solar cell is changed slightly; since it will act as a solar cell. Solar cell has silicon with impurities (by changing the ways in which a particle acts, other atoms are mixed with silicon atoms). Usually we assume that the impurities are undesirable things. But here there the cell does not work without impurities! These impurities are added to a special goal. Consider silicon with a phosphorus atom on each side; perhaps out of every one million phosphorous silicon atoms, there are five electrons in its foreign layer rather than four. It is always linked with its neighboring silicon atoms, but in a sense that none of the phosphor electrons are not connected to anything. A part of a link is not formed, but one positive proton in the phosphorous nucleus pinches it to somewhere.

When energy is added to pure silicon (such as in the form of heat) can cause the bond of some electrons to be broken and to leave their atoms. A hole in each sample has been released. Then these electrons are scattered randomly around the crystal lattice and search other holes within which they may fall. The electrons are called "carrier free" and can move electric current. So, there are a few of them in pure silicon (although they are not very useful). Impure silicon combined with phosphorous atoms has a different scenario. Much less energy is spent on knocking one of loose "extra" phosphor electrons; because they have not been fixed in a bound (their neighbors have not blocked them). This process of adding impurities is called "doping". Due to free electrons, the resulting silicon is called "type N» (Negative). Doped silicon type N is a much better conductor compared with pure silicon. In fact, only a portion of the solar cell is N-type. Other parts are doped with "B" that has only three electrons, instead of 4 electrons, in its outer layer; thus, silicon becomes the p-type. Type P silicon, (Positive) has free holes Instead of free electrons. In fact, the holes represent only the absence of electron. So they carry symmetric (+) charge. They just move around electrons with the same performance. The interesting part begins when the P-type silicon is applied with N-type silicon. Note that each PV cell has ultimately one electric field. The cell will not work without an electric field, and this field arises when the P-type silicon and N-type silicon are in contact. Free electrons in N-side look for a hole to fall into it and detect free holes in the P-side and fill them with a sudden rush.

Anatomy of a Cell: Previously, silicon was strictly neutral in terms of electricity. Excess electrons are out of balance by additional phosphorus protons. Missed electrons (holes) with B lost protons disturb the balance. When electrons and holes are combined at the junction between silicon-type N, P, however the neutral state is lost. Do the free electrons fill all the free holes? No! If they do so, then this complete order will be of no use. But right at the junction, they are mixed and create a fence. With making it harder and harder for N-type electrons that cross P. Finally, equilibrium is set and we have a separate bilateral electrical field.

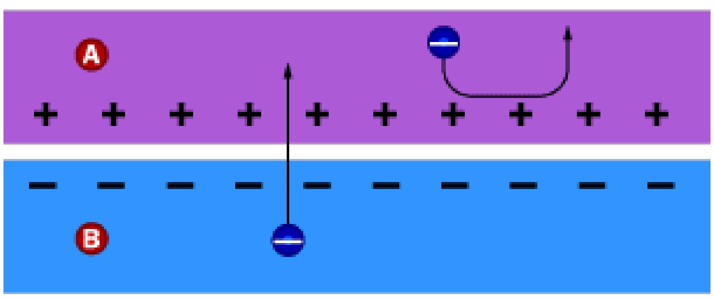


Figure 1: (A) N-type silicon and (B) P-type silicon

3. The Effect of Electric Field on Photovoltaic Cells

This electric field acts like a diode by pushing the electrons to flow from the p-type and N-type but by no any other way. This mode is similar to a mass (electrons can flow easily to the masses, but they cannot climb it). Thus we have obtained an active electric field; like a diode in which electrons can only move in one direction.

When the light, in the form of photons, collides the solar cells, their energy releases electron - hole couple. Each photon with enough energy will normally free one electron completely and result in one free hole.

If this event is close enough to the electric field, or if the free electron and the free hole deviation event occur within its impact range, will send this field towards N-side and P-side of the hole. Mostly, this results from the completion of electrical neutrality and if we create a surface flow path, electrons flow, throughout the path, in their main direction (the P) in order to join the holes which have been sent to there to perform electric field work. Electron motion produces the current and the cell field creates voltage.

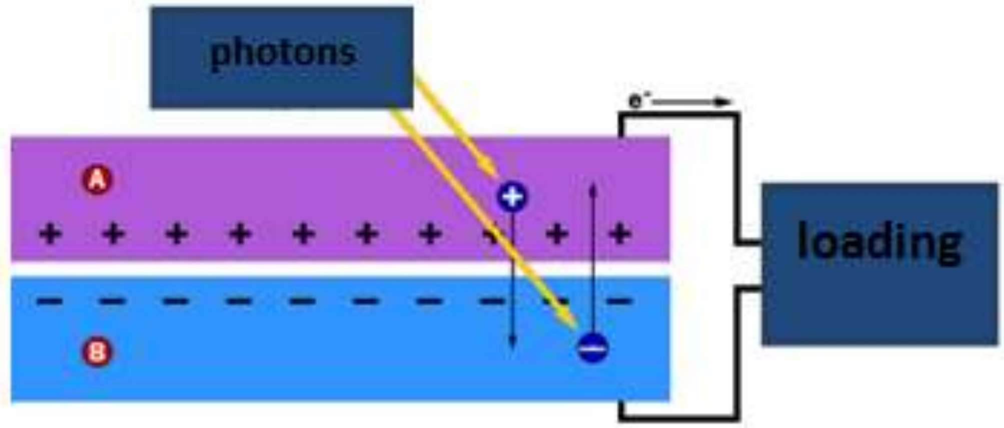
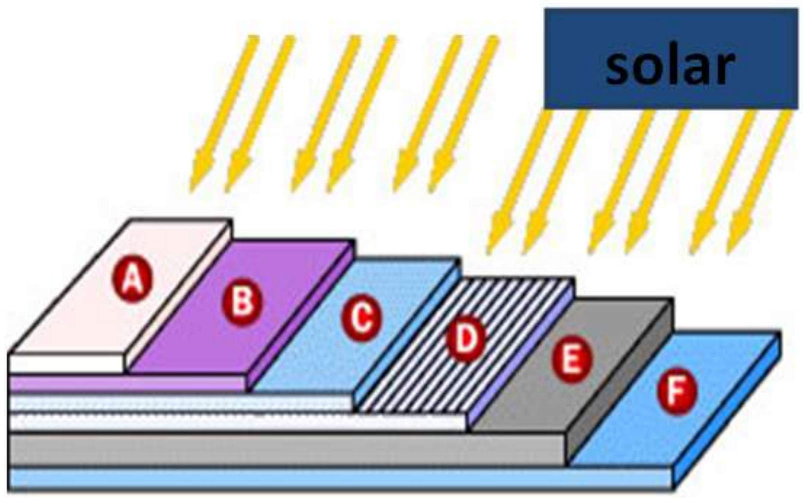


Figure 2: (A) N-type silicon, and (B) P-type silicon

Performance of Photovoltaic Cell



A:surface glass; B:antireflection coating; C:network segment(part); F:rear segment(part)

Figure 3: the structure of a silicon PV cell generator

In the photovoltaic system, an inverter is a device that converts dc voltage, generated by the solar panels, to ac voltage. The output voltage can be single-phase or three-phase. Power electronics devices are used in the structure of an inverter. Among the main features of an inverter is the capability of changing the amplitude and the frequency of output voltage with low distortion. Inverters have various structures. Multi-level and multi-layer inverters are important types of inverters that are widely used in photovoltaic systems.

4. Multilevel Inverters with Step Modulation

A very important group of design techniques and the modulation of multi-level and multi-layer inverters connected to the solar cells is optimal PWM modulation. The representative of this group is step modulation. An example of Cascade multilevel inverter class is shown in Figure 4. As shown in Figure 4, v_HI represents the i th output voltage of H (HB) formed bridge. F_i switching function for communication between V_dc and v_HI is used as follows:

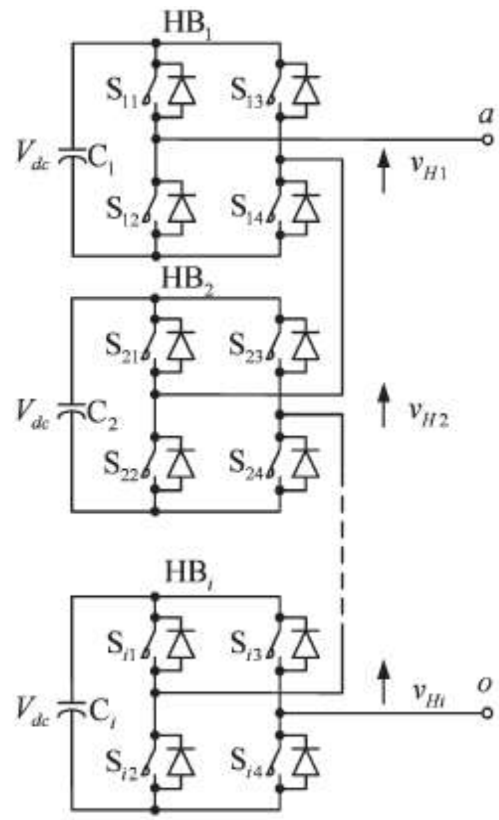


Figure 4: Multi-level Inverter Cascade (Cascade)

(1) $v_{HI} = F_i.V_{dc}$

The value of Fi can be any of 1 or -1 or 0 values. For value of 1, the keys S_{i1} and S_{i4} are needed to be on. For the value of -1, the key S_{i2} and S_{i3} are needed to be on. For the value of 0, the keys S_{i1} and S_{i3} or S_{i2} and S_{i4} are required to be on. The output voltage of Inverter,v_{ao}, is the sum of the output voltages of HBs. The output voltage of a cascade multilevel inverter with the S-layer is as follows:

(2) $v_{ao} = \sum_{i=1}^{s} v_{Hi} = \sum_{i=1}^{s} F_i.V_{dc}$

Figure 5 shows the total output voltage waveforms and HB voltages for multi-level inverter with seven layers through step modulation. θ_1 ,θ_2 and θ_3 are switching angles which show on or off moments of the key in HBs.

By using Fourier analysis for a cascaded multilevel inverter with S layers from HBs, the harmonic range of Nth v_{ao} voltage is expressed by the following equation:

(3) $v_n = \frac{4}{n\pi}\sum_{i=1}^{s}[v_{dc}\cos(n\theta_k)]$

Where n, is odd-order harmonics and θ_k is Kth switching angle. Amplitude is zero for all even harmonics. Modulation index M is defined as follows:

(4) $m = \frac{4}{\pi}\frac{V_1}{V_{max}} = \frac{4}{\pi}\frac{V_1}{sV_{dc}}$

V_{max} , is the maximum obtainable value of voltage from the output of the inverter. For the seven-layer inverter, S is equal to three and, V_{max} is equal to $3V_{dc}$.

5. Applications of Optimization of the Output Voltage and Computing the Switching Angles

Minimization or elimination of harmonics in multilevel inverters occurs in various application scenarios

1. Minimizing the inverter output voltage THD, for many applications, including the photovoltaic systems and energy

2. Eliminating the low-order odd harmonic of load voltage, such as the third, fifth and seventh harmonics, for applications with appropriate filters.
3. Minimizing THD regardless of multiple of three harmonics that can be applied in specific three-phase systems.
4. Eliminating low-order odd harmonics regardless of multiple of three harmonics.

This article will focus on the first goal which is optimization of voltage to solar cells. The amplitude of each odd nth harmonic of v_{ao} voltage was shown in (3). Thus, the voltage THD is expressed as follows:

(5) $$\text{THD} = \sqrt{\frac{\sum_{n=3,5,7,\ldots} v_n^2}{v_1^2}}$$

It seems that it is difficult to obtain the minimum THD as straightforward, since the numerator of equation (5) is infinite. A solution in this case can be removing only the finite number of harmonics. Generally, a number of low-order harmonics that make up the bulk of THD can be deleted. Consider a seven-level inverter, the third- and the fifth-order harmonics can be eliminated as follows:

(6) $$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) = 3.m$$

(7) $$\cos(3\theta_1) + \cos(3\theta_2) + \cos(3\theta_3) = 0$$

(8) $$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0.$$

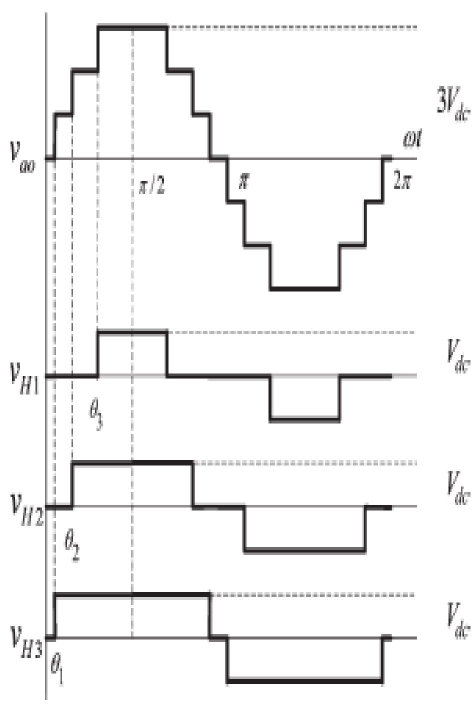


Figure 5: The total output voltage waveforms and HB voltages for a multilevel inverter with step modulation

Several methods such as Newton - Rap son iterative method, methods based on the theory of symmetric polynomials and outcomes, and methods based on genetic algorithms have been proposed for solving all nonlinear non algebraic equations (6). However, calculations based on the above method are so time consuming that they cannot be solved in a real time by a microprocessor or DSP. Switching times can be calculated only with an offline computer. Switching angles obtained in an offline mode, should be stored in a lookup table (search) in a microprocessor or DSP. In addition, the above method does not give any guarantees to minimize THD in voltage. In a cascaded multilevel inverter with S numbers of HB in relation to step modulation, if more than (S^{-1}) harmonic is considered to minimize the THD consider, these harmonics cannot be removed because the number of variables (unknowns) are greater than the number of equations in equation set. Minimizing THD in this case has not been investigated so far.

6. The Proposed Algorithm for Computing the Switching Angles

In this section, to compute the switching angles in multilevel inverters connected to the solar cells a new algorithm is presented in the step modulation. This algorithm has two unique features. First, THD voltage is surely minimized. Secondly, the calculation takes so little time that a conventional microprocessor or DSP can perform calculations in real time. There are two steps in this algorithm.

Step One: We obtain ρ by solving the equation.

$$\sum_{k=1}^{s}\sqrt{1-\left(\frac{k-1/2}{s-1/2}\cdot\rho\right)^{2}}=m\cdot s \tag{7}$$

Where, as we mentioned earlier, m is a given modulation index and s is the number of given HB in a cascaded multilevel inverter.

Second step: We obtain the switching angles by evaluating the following equation.

$$\theta_k=\arcsin\left(\frac{k-1/2}{s-1/2}.\rho\right), k=1,2,\ldots s \tag{8}$$

Since (7) includes a ρ variable, it can be rapidly solved by using Newton - Rap son method with fewer repetitions. In practice, if the initial value is selected appropriately, only one repetition gives an exact and acceptable value of ρ. The computational complexity of the given algorithm is analyzed. Newton - Rap son method is used to solve equation (7). From (7) we have:

$$f(\rho)=\sum_{k=1}^{s}\sqrt{1-\left(\frac{k-1/2}{s-1/2}\cdot\rho\right)^{2}}-m\cdot s$$

(8)

$$f^{/}(p)=\sum_{k=1}^{s}\frac{-\left(\frac{k-1/2}{s-1/2}\right)^{2}.\rho}{\sqrt{1-\left(\frac{k-1/2}{s-1/2}.\rho\right)^{2}}} \tag{10}$$

The value of ρ after the j th iteration can be expressed as follows: (11)

$$pj=p_{j-1}-\frac{f(p)}{f^{/}(p)}$$

In most cases, the system is stable and m will change very slowly. We assume that m changes linearly from 0.64 to 0.93 at 58 msec. Sampling frequency of the DSP program is placed on KHz10. Thus, m increases about 0.0005 in the next calculation of the next sample. For the first calculation, m is 0.64. In this calculation, the initial value of ρ for the iteration is equal to 0.99. To obtain the exact value of ρ form, 0, 64 is used in four iterations which will be explained later.

For next calculation, m is equal to 0.6405. The initial value of ρ in this iteration is set the value obtained in the calculation of m to 0.64. Note that only one iteration is used to calculate ρ per m equal to 0.6405. Similarly, for 0641 m, the initial value of ρ for this iteration is put the obtained ρ for 0.6405 m, and only

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one iteration is applies to obtain ρ for 0641 m. By following this method, we can calculate all the values of ρ for, 0.6405, 0.641, 0, 6415 ... and 0.93 m. In short, in calculating a sampling period, the values of ρ is calculated by using Newton - Rap son method. Note that the initial value of ρ is placed the value obtained in the last sampling. Thus, only one iteration is sufficient to obtain precise value of ρ. The obtained value of ρ from the above method is inserted in (7) so as to achieve a new index of $m^/$ modulation. The difference between m and $m^/$ is considered as the error of m which represents the accuracy of the calculation. As it is shown Figure 3, with the above method, this error of m is very low. In a dynamic process, m changes quickly. Through this method, an acceptable value of ρ can also be obtained in dynamic processes. Suppose that in 5.8 milliseconds, m changes from 0.64 to 0.93 linearly and sampling frequency is still KHz10. With this method, the error of m is less than 0.0008. As it is shown in Figure 7.

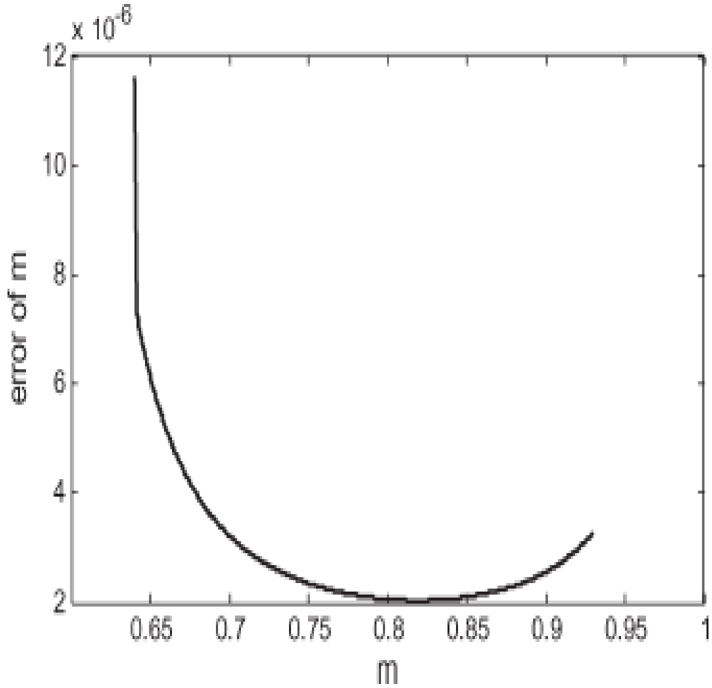

Figure 6

Computational complexity is analyzed according to the above method, in which only one iteration is necessary. Only the operation of multiplication, division, square root and arc sine are considered because they require a lot of computational time. Values))s-1/2) / (k-1/2 و ((($((s-1/2)/(k-1/2))^2$ in (9) and (10) are stored in a microprocessor or DSP. The time taken for one iteration is expressed as follows:

(12)

$$T_{iteration} = (3+s).T_{multiplication} + T_{rootsquare} + (s+1)T_{division}$$

Where T_multiplication and T_rootsquare and T_iteration are the timeline used for multiplication and square root and division operations, respectively. Therefore, the computational details of all the algorithm is as follows: (13)

$$T_{iteration} = (3+2s).T_{multiplication} + T_{rootsquare} + (s+1)T_{division} + sT_{arcsin}$$

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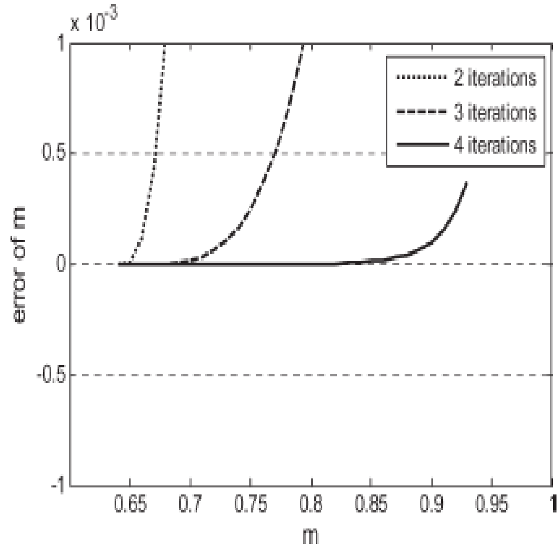

Figure 7:

Where $T_{arcsin}$is the consumed time for the arcsin function. In case of the seven-level inverter, s is three. Computational details of the operation are only 9 multiplications, 4 divisions, one square root, and 3 arc sine. Such computational details can be performed simply with a microprocessor or DSP.
In some special situations, m can have a quick change, or even have a stepped change. For example, m may have a stepped change when the whole system operation changes. If there is a rapid change or stepped change in m, the initial value of ρ can be obtained after four iterations. As shown in Figure 5, the error of m is less than 0.0005 after four iterations. So sudden changes or a stepped change of m whose calculation details are shown in (14) can be used by a microprocessor or DSP in real-time.

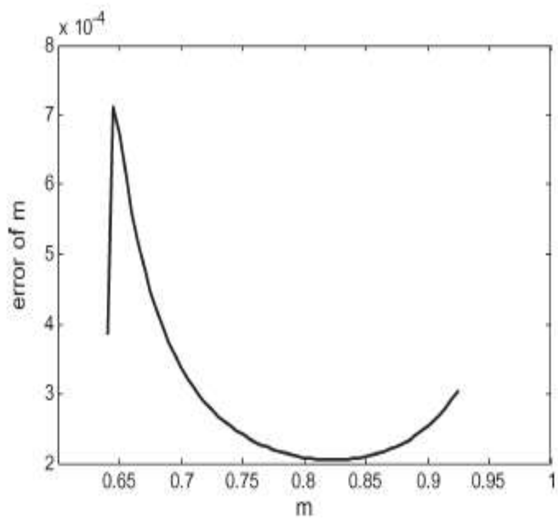

Figure 8

$$T_{solve} = (12 + 8s).\,T_{multiplication} + {}^{4}T_{rootsquare} + (4s + 4)T_{division} + sT_{arcsin} \quad (14)$$

The above analysis is applied for the user in which all calculations are performed by a microprocessor or DSP without a lookup table. The advantage of this implementation is very accurate solutions with

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minimal memory usage. An alternative application is to store the offline values of ρ, solved by the proposed algorithm, in a lookup table suggested by an unknown reviewer. Therefore, the switching angles which are calculated by (8) and computational details are only s mutilation and s arc sine.

7. Comparison with Existing Methods

In this section, for a seven-level inverter with step modulation, four THD voltages are compared with different methods. Switching angles obtained with the proposed algorithm are shown in Figure 9. In this figure, THD of the proposed method is compared with other methods. According to this figure, the proposed algorithm performs better than the previous methods. As shown in Figure 10, THD has the lowest value when the modulation index is about 0.84.

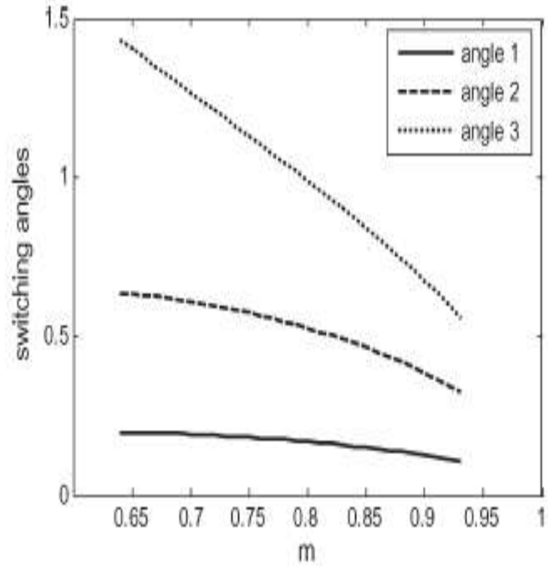

Figure 9

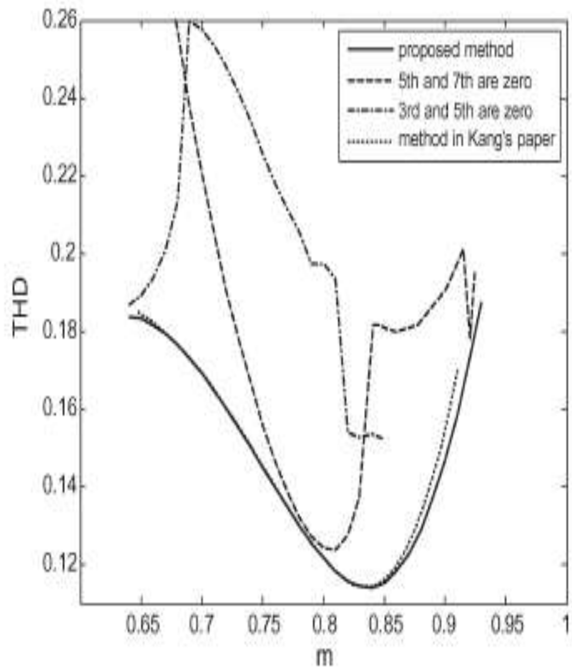

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Figure 10: Comparison of the proposed method THD with other methods

Which implies that the modulation index in normal operations can be designed in 0.84.

8. Mathematical Proof of the Proposed Algorithm

In this section, the proposed algorithm is proved mathematically. THD is expressed as (5). To simplify, THD is represented by d. With the shown values in (4), we can minimize d^2 instead of d, which is simple and the result is the same as that one. With respect to Lagrange multiplier method, we obtain a set of the following equations:

(15) $$\frac{\partial}{\partial \theta_k} d^2 = \lambda \frac{\partial}{\partial \theta_k}\left(\frac{\pi}{4}\frac{V1}{s.V_{dc}} - m\right)$$

The Nth harmonic of Vn voltage is shown in the form of (3). Note that:

(16) $$RHS = \lambda \frac{\partial}{\partial \theta_k}\frac{\pi}{4_s}V1 = \lambda \frac{\pi}{4sV_{dc}}\frac{4}{\pi}(-V_{dc}\sin\theta_k) = -\frac{\lambda}{s}\sin\theta_k$$

Also, LHS can be obtained using (17), which is calculated as follows:

(17)

$$RHS = \frac{\partial}{\partial \theta_k}\left(\frac{\underset{n=1,3,000}{\Sigma V_n^2}}{V_1^2} - 1\right) = \frac{\left(\frac{\partial}{\partial \theta_k}\left(\underset{n=1,3,000}{\Sigma V_n^2}\right)\right)(V_1^2) - \left(\underset{n=1,3,000}{\Sigma V_n^2}\right)\left(\frac{\partial}{\partial \theta_k}V_1^2\right)}{V_1^4}$$

$$= \frac{\underset{n=1,3,000}{\Sigma}(2V_n V_{dc}(-n\sin n\theta_k))(V_1^2) - \left(\underset{n=1,3,000}{\Sigma V_n^2}\right)\left(2V1V_{dc}\frac{4}{\pi}(-\sin\theta_k)\right)}{V_1^4}$$

$$= \frac{-\underset{n=1,3,000}{\Sigma}(V_n \sin n\theta_k) + \sin\theta_k \frac{1}{V_1}\underset{n1,3,000}{\Sigma V_n^2}}{\frac{\pi}{8}V_1^2}V_{dc}$$

$$v_{ao}(\theta) = \sum_{n=1,3,5,\ldots} V_n \sin n\theta. \quad (18)$$

$$\sum_{n=1,3,5,\ldots} V_n \sin n\theta_k = v_{ao}(\theta_k)$$

(19)

$$= \frac{\lim_{\theta\to\theta_{k-}} v_{ao}(\theta) + \lim_{\theta\to\theta_{k+}} v_{ao}(\theta)}{2}$$

$$= (k - 1/2)V_{dc}.$$

(20)

$$\text{LHS} = \frac{-\left(k-\frac{1}{2}\right)V_{dc} + \sin\theta_k \frac{1}{V_1}\sum_{n=1,3,\ldots} V_n^2}{\frac{\pi}{8}V_1^2}V_{dc}.$$

With equivalent of the LHS and RHS, we have

(21)

$$\frac{-\left(k-\frac{1}{2}\right)V_{dc} + \sin\theta_k \frac{1}{V_1}\underset{n1,3,000}{\Sigma V_n^2}}{\frac{\pi}{8}V_1^2}V_{dc} = -\frac{\lambda}{s}\sin\theta_k$$

$$\frac{\frac{1}{V_1}\sum_{n=1,3,000} V_n^2 + \frac{\lambda}{s}\frac{\pi}{8}\frac{V_1^2}{V_{dc}}}{V_{dc}}\sin\theta_k = k-\frac{1}{2}$$

So,

$$\sin\theta_k = \frac{k-1/2}{s-1/2}.p \tag{22}$$

That,

$$\rho = \frac{(s-1/2)V_{dc}}{\frac{1}{V_1}\sum_{n=1,3,\ldots} V_n^2 + \frac{\lambda}{s}\frac{\pi}{8}\frac{V_1^2}{V_{dc}}}. \tag{23}$$

From (3) and (4) we can obtain:

$$m.s = \frac{\pi}{4}\frac{V1}{s.V_{dc}}s = \frac{\pi}{4}\frac{V1}{s.V_{dc}}\frac{4}{\pi}\sum_{k=1}^{s}[V_{dc}\cos(\theta_k)] = \sum_{k=1}^{s}\cos(\theta_k) \tag{24}$$

According to (22) and (24), equation (7) is obtained

7. Simulation with MATLAB SIMULINK

The circuit and structure of the inverter simulated in MATLAB is shown in Figure 11. In the simulation, the solar cells are considered as a source of DC voltage.

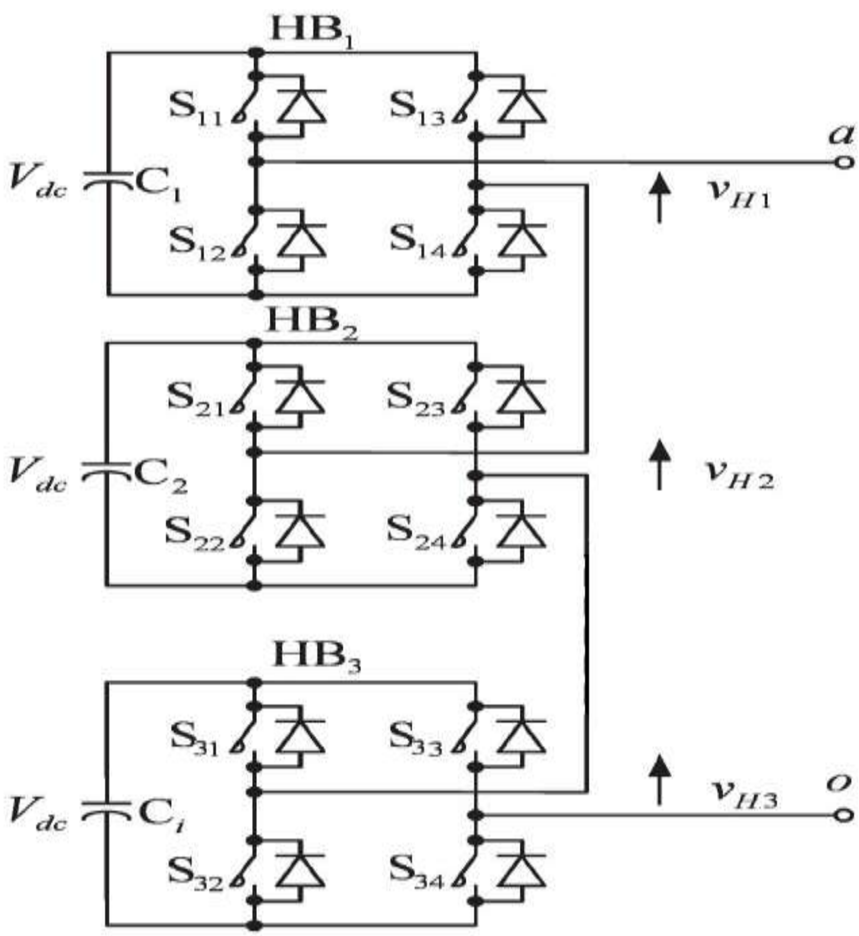

Figure 11: Structure of 7-level inverter

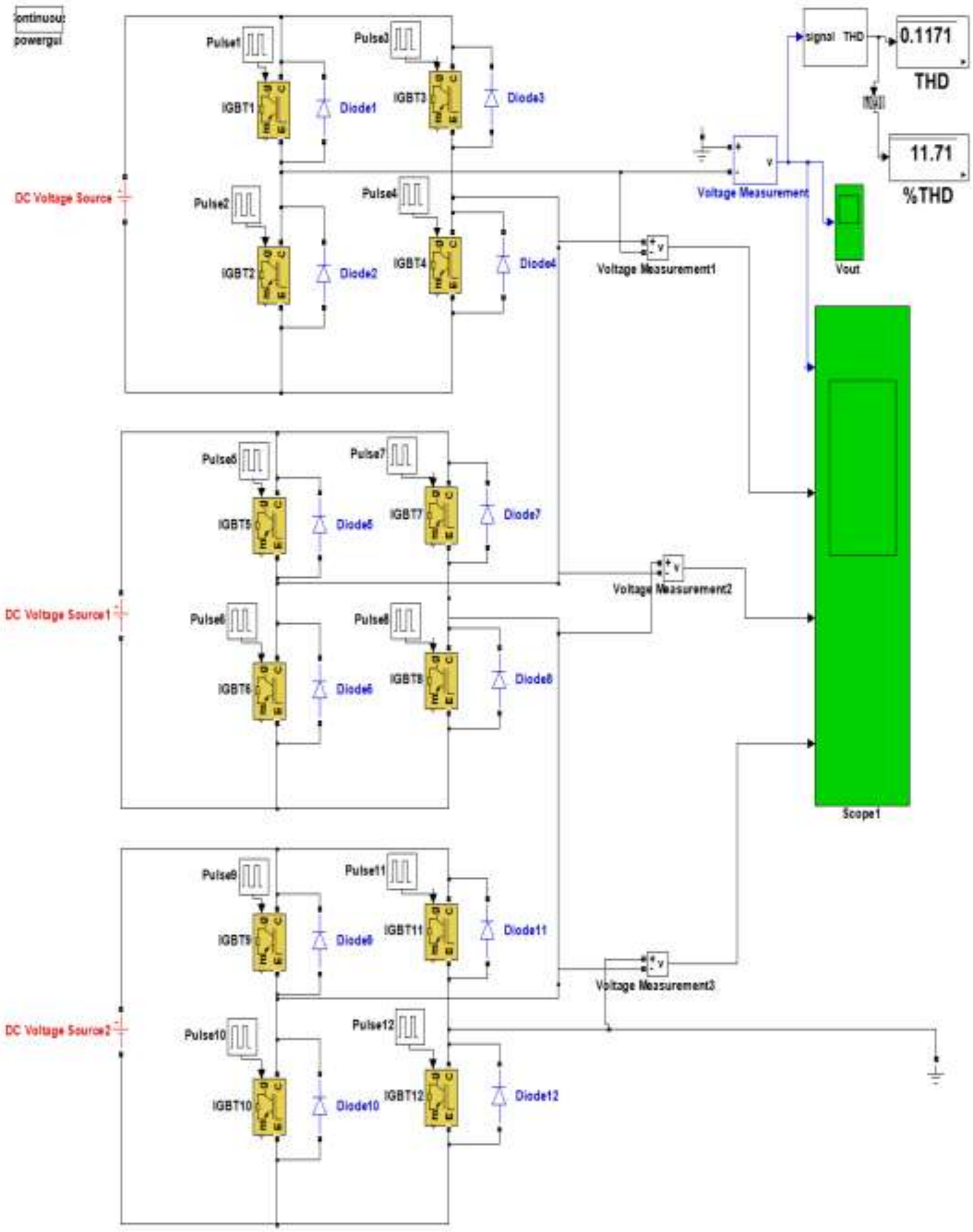

Figure 12: Simulated circuit of inverter in MATLAB SIMULINK setting

Table 1: The value of THD resulting from the simulation of four indices of different modulation

The value of THD Based on percentage	Modulation index
17	0.7
12.9	0.8
11.7	0.84
14.8	0.9

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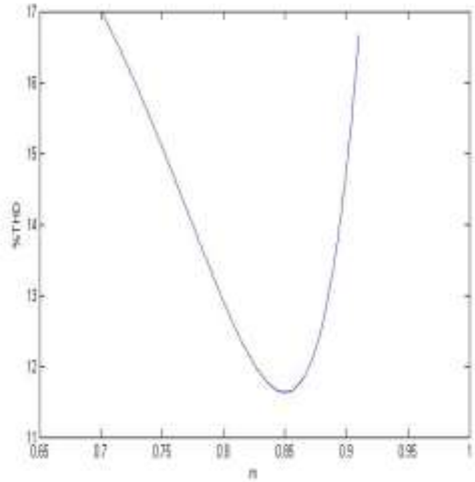

Figure 13: Diagram of the percent of THD based on modulation index - plotted with MATLAB

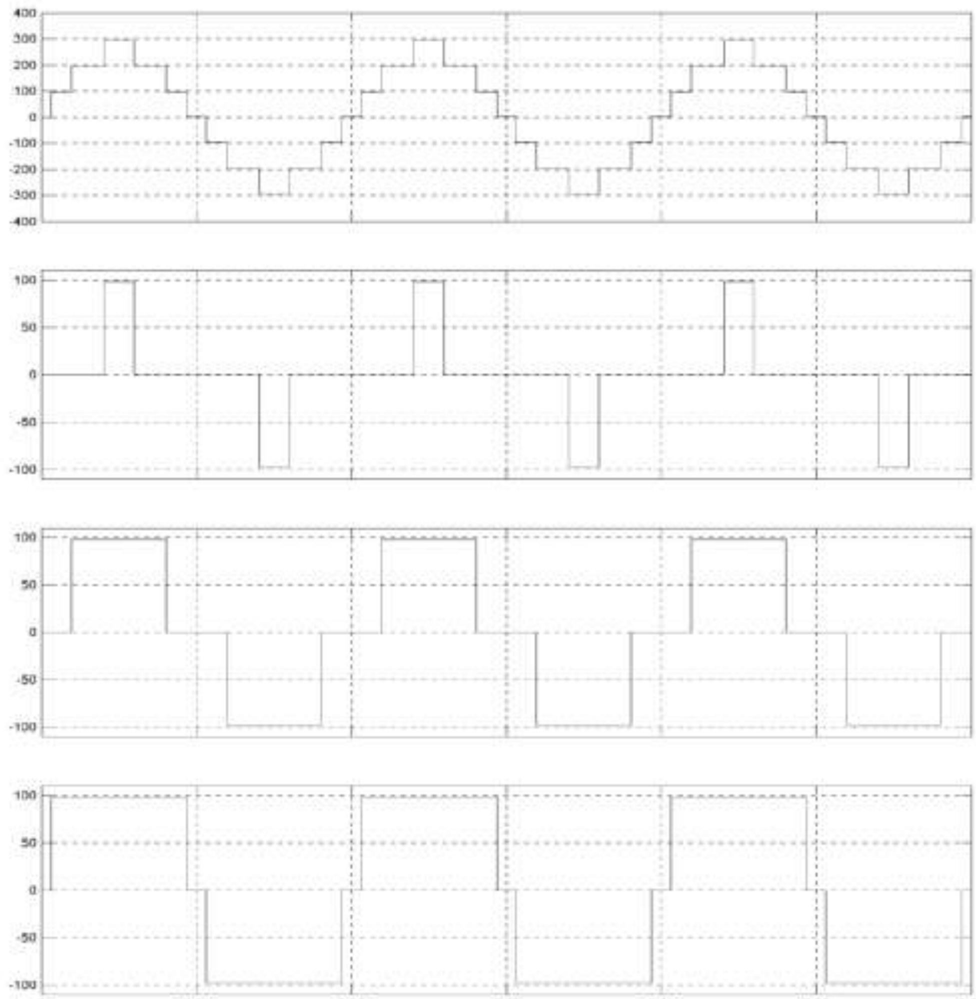

Figure 14: inverter output voltage (upper curve) and first, second and third floor voltages for m = 0.7

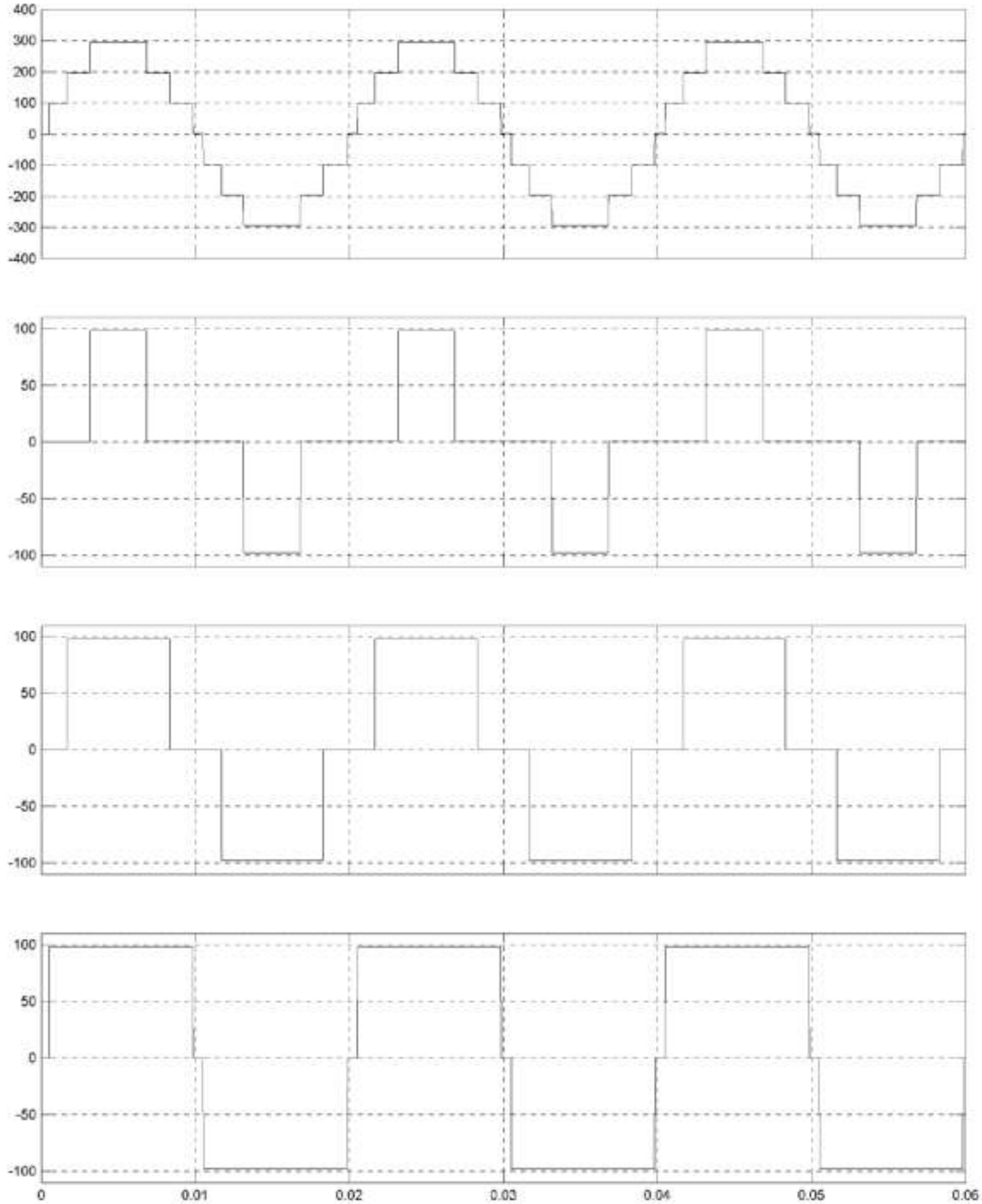

Figure 15: inverter output voltage (upper curve) and first, second and third floor voltages for m = 0.8

Table 1 shows the value of THD resulting from the simulation for four indices of different modulation. Moreover, the diagram of the percent of THD based on modulation index is provided in Figure 13.

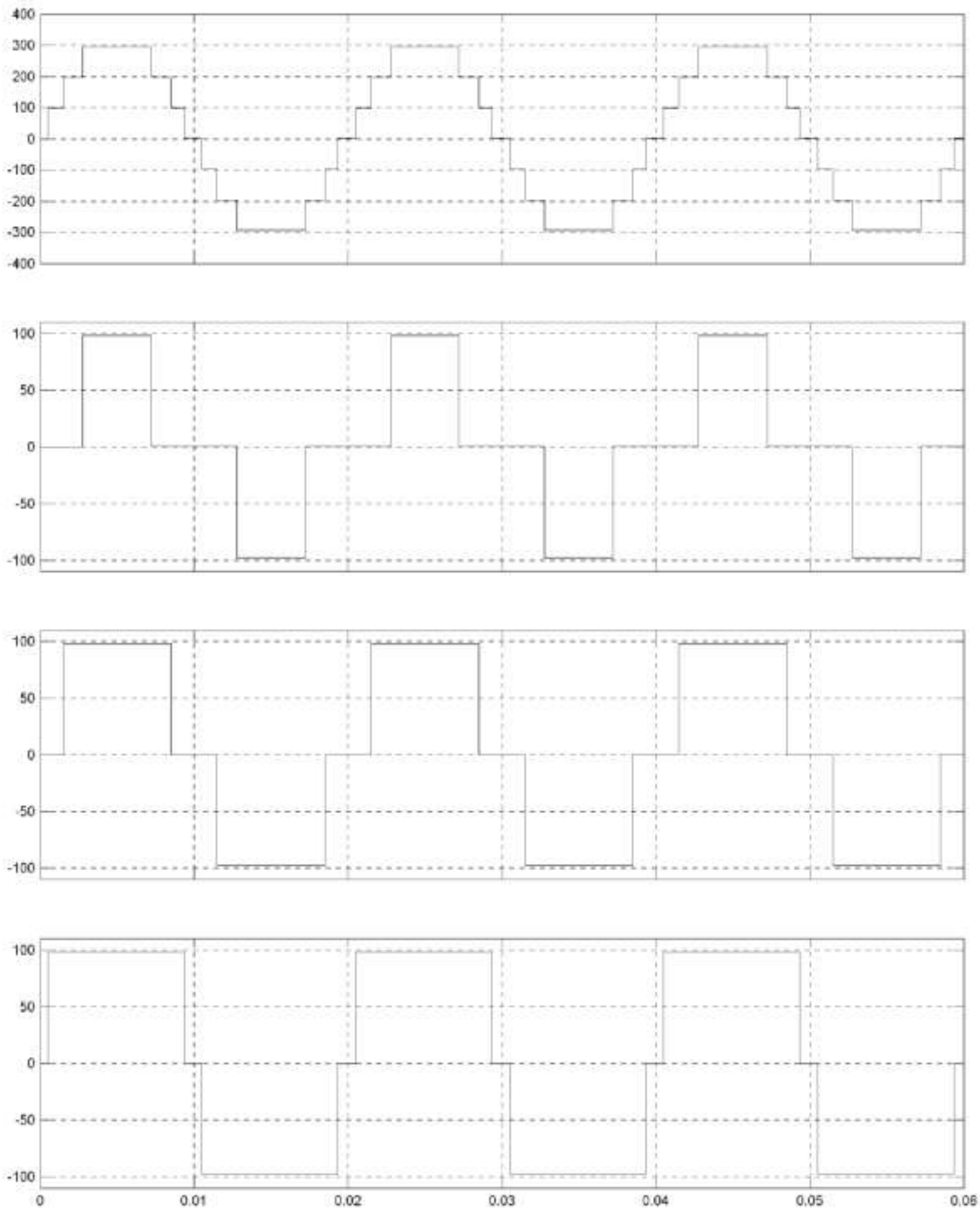

Figure 16: inverter output voltage (upper curve) and first, second and third floor voltages for m = 0.84

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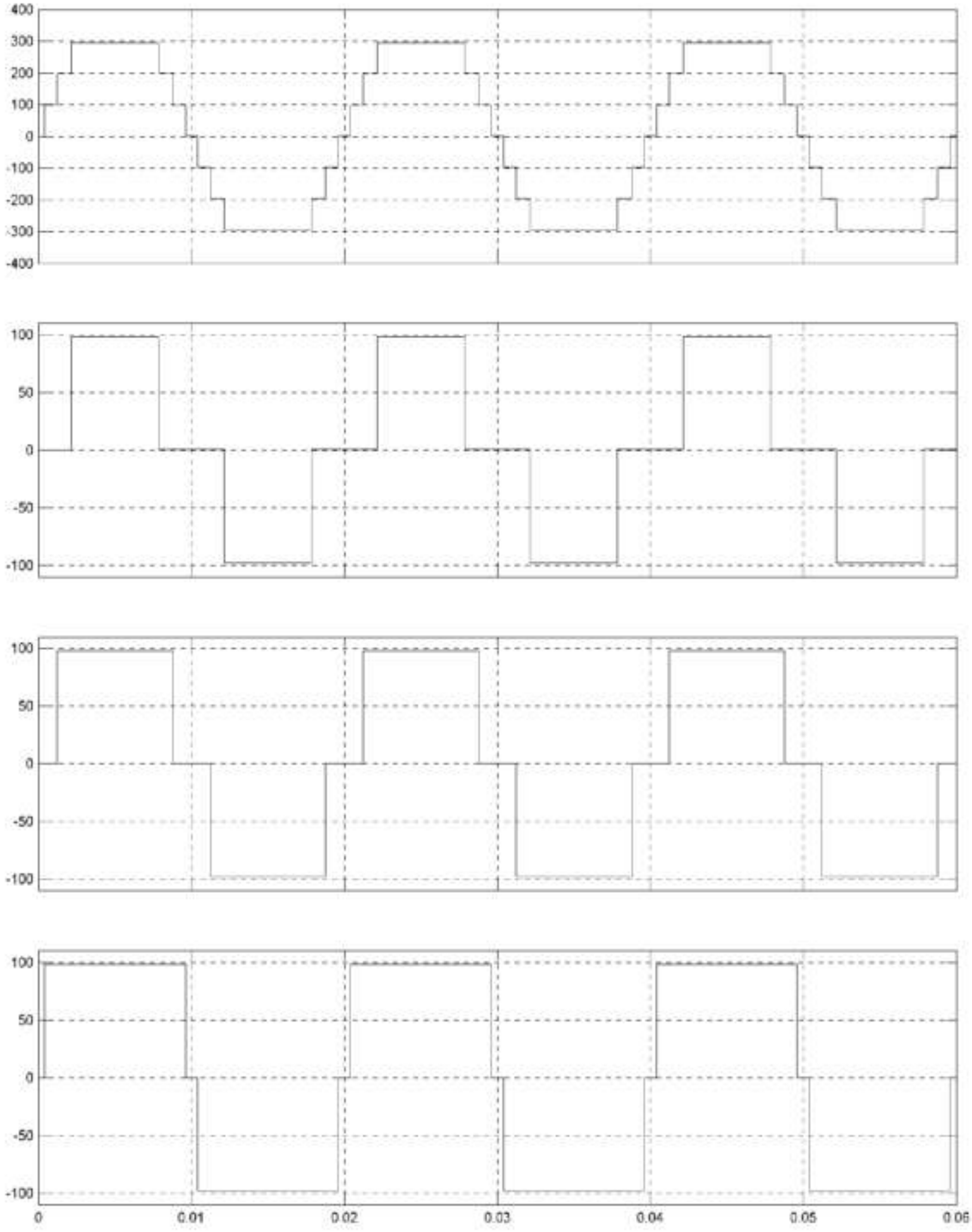

Figure 17: inverter output voltage (upper curve) and first, second and third floor voltages for m = 0.9

Due to these things, the value of minimum THD is equal to 11.7 percent, and occurs for m = .84. the diagram of inverter output voltage and the voltage of the first, second and third floors of the inverter for four modulation indices is presented in next figures.

Conclusion

In this paper, a new approach to optimize the output voltage of multi-level inverters connected to the solar cells was presented based on a stepped modulation. With this algorithm, THD voltage was minimized, so losses are reduced and more power is obtained from solar cells. Benefits and features of the proposed method in the design of inverter are as follows:

1 – Reduce harmonics distortions in the output of the photovoltaic system
2 - Increase the quality of the output power of photovoltaic system
3 - Reduce Losses
4 - Increase the output power of photovoltaic system
5 - No need for new spending considering the simultaneous technical and economic issues

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