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Modelling of 3-Level Diode Clamped Inverter Using SPWM & SVPWM For Solar Application.

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Abstract — *This paper deals with utilizing the solar energy to feed AC loads. In this paper solar energy will be converted in to AC by means of Three-level diode clamped inverter in which DC is obtained by means of MPPT (Maximum power point tracking-Perturb & Observe method). In diode clamped inverter implementation of SPWM (sinusoidal pulse width modulation) as well as SVPWM (space vector pulse width modulation) techniques for pulse width modulation and generation of gate pulse to make switches ON and OFF is utilized. After that individual analysis of both the techniques by doing %THD (total harmonic distortion) analysis is done in which modelling and simulation is done through MATLAB/simulink.*

Keywords*- MPPT, Multilevel Inverter, Solar Energy, SPWM, SVPWM.*

I. INTRODUCTION

Demand of renewable energy sources is gradually increasing because of the high cost and limited conventional energy sources like oil, gas, coal and multilevel inverters are more reliable to interface with renewable energy sources than a conventional two-level inverter for a high power application in aspects of better power quality, [1]-[10], as well as multilevel Inverters have become more popular over the years in electric power application with the promise of less disturbances outputs and the possibility to function at higher switching frequencies than ordinary two-level inverter, [1].
There are three topologies for multilevel inverter, [1]:

1. Cascaded H-Bridge Multilevel inverter,
2. Flying Capacitor Multilevel inverter and
3. Diode Clamped Multilevel inverter.

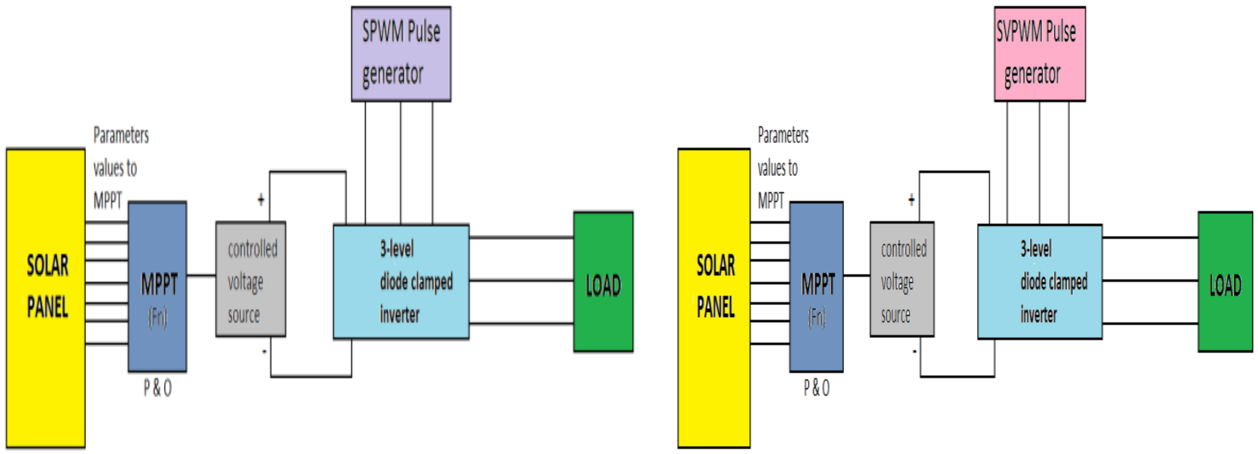
In this work diode clamped topology has been used. To control multilevel inverters, different types of pulse width modulation (PWM) techniques are used, [1]-[3]:

1. SPWM
2. SVPWM

In Sinusoidal Pulse width modulation (SPWM) the gating signals generated by comparing sinusoidal reference signal with a triangular carrier wave, [4]. In Space Vector pulse width Modulation (SVPWM) rotating phase is obtained by adding all the three voltages, [3]-[7]. SVPWM technique is mostly used for multilevel inverters compared to SPWM, [3]. SVPWM technique was originally developed as a vector approach to PWM for three phase inverters. It is an advanced and computation method and it is quite different from other PWM methods.

V max =Vdc\2 : For Sinusoidal PWM
V max =Vdc\√3 : For Space vector PWM

It shows that SVPWM can produce about 15% higher output voltage than SPWM.



(A) **(B)**

Fig.1: Block diagram arrangement of the entire system along with (A)SPWM technique (B)SVPWM technique.

II. PV Cell

The energy of solar radiation is directly converted in mainly two forms:

1. Direct conversion into electricity that takes place in solar cells.
2. Heat accumulation in solar collectors.

The direct conversion of solar radiation into electricity is often known as a photo-voltaic (PV) energy conversion, [8]. So, the PV effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The whole process of solar energy conversion into electricity is therefore denoted as the "photo-voltaic".

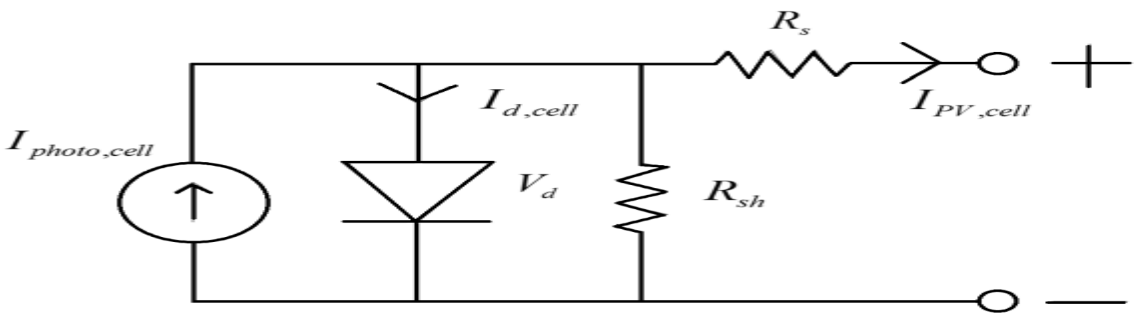


Fig.2: Circuit of PV Cell.

The basic equation from the theory of semiconductors of ideal photovoltaic cell is given below in **equation. (1),** [8]-[9].

$$I = Ipv,cell - Io,cell\,.\,[\exp\left(\frac{qV}{aKT}\right) - 1] \quad \text{……………………….(1)}$$

Where,
Ipv, cell=current generated by the incident light
q = charge of electron
K = Boltzmann constant
T = temperature of p-n junction
a = diode ideality factor
Id = Shotckey diode equation

The basic **equation. (1)** never represents the I-V characteristic of practical photovoltaic array. Practical array composed of several connected PV cells and the observation characteristic requires the inclusion of additional parameters to the basic **equation. (2),** [8]-[9] given below,

$$I = Ipv - Io\,.\left[\exp\left(\frac{V + RsI}{Vt\,.\,a}\right) - 1\right] - \left[\frac{V + RsI}{Rp}\right] \quad \text{……………….(2)}$$

Where,
Ipv and Io = photovoltaic and saturation current of array
Vt = thermal voltage of array with Ns cells connected in series
Rs = equivalent series resistance of the array
Rp = equivalent parallel resistance

This **equation. (2)** originates the I-V curve.

The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following **equation. (3),** [8]-[9].

$$Ipv = (Ipv,n + Kt\Delta T)\frac{G}{Gn}] \quad \text{…………………………………………….(3)}$$

Where,
Ipv,n = light generated current at nominal condition (at 25^{o}C and 100 W/m^{2}).
ΔT = T-Tn (T and Tn is the actual and nominal temperatures).
G = irradiation on the device surface.
Gn = nominal irradiation.

The diode saturation current Io and its dependence on the temperature can be expressed by **equation. (4),** [8]-[9]; given below,

$$Io = Io,n\,.\,(\frac{Tn}{T})^3 \exp\,[\frac{qEg}{aK}(\frac{1}{Tn} - \frac{1}{T})] \quad \text{………………………………..(4)}$$

Where,

Eg = Band-gap energy of semiconductor (Eg=1.12ev)

The nominal saturation current Io,n can be represent by **equation. (5)**, [8]-[9].

$$Io,n = \frac{Isc,n}{\exp\left(\frac{Voc,n}{a.Vt.n}\right) - 1} \quad \text{……………………………………………………….(5)}$$

III. MPPT (Maximum Power Point Tracking)

Solar energy constitutes a suitable choice for different kinds of applications as it converts directly solar energy into the electrical energy. But to utilize PV system is today still more expensive than electricity produced from traditional sources. So, to reduce the total cost of PV system, maximum power point tracking (MPPT) is considered. Maximum power point is achieved at single point in PV graph, tracking of maximum power point with continuously variations in radiation intensity and temperature is necessary to ensure the efficient operation of the solar cell array. MPPT enables an increase in the power delivered from the PV module to the inverter or load, as well as also increase the operating lifetime of the PV system, [11].

MPPT Methods:

There are two basic kinds of methods for MPPT:

1. Off line methods
   - open circuit voltage method
   - short circuit current method
2. On line methods
   - perturb & observe method
   - Incremental conductance Method

In this work perturb & observe method which is on line method has been used.

3.1. Perturb & Observe/Hill climbing method-

The Perturb and Observe algorithm given in **Fig. (3)** states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we are going in the direction of MPP and we will keep on perturbing in the same direction. If the ΔP is negative than we will go away from the direction of MPP and the sign of perturbation supplied has to be changed. **Fig. (3)** shows the flowchart of this algorithm, [11].

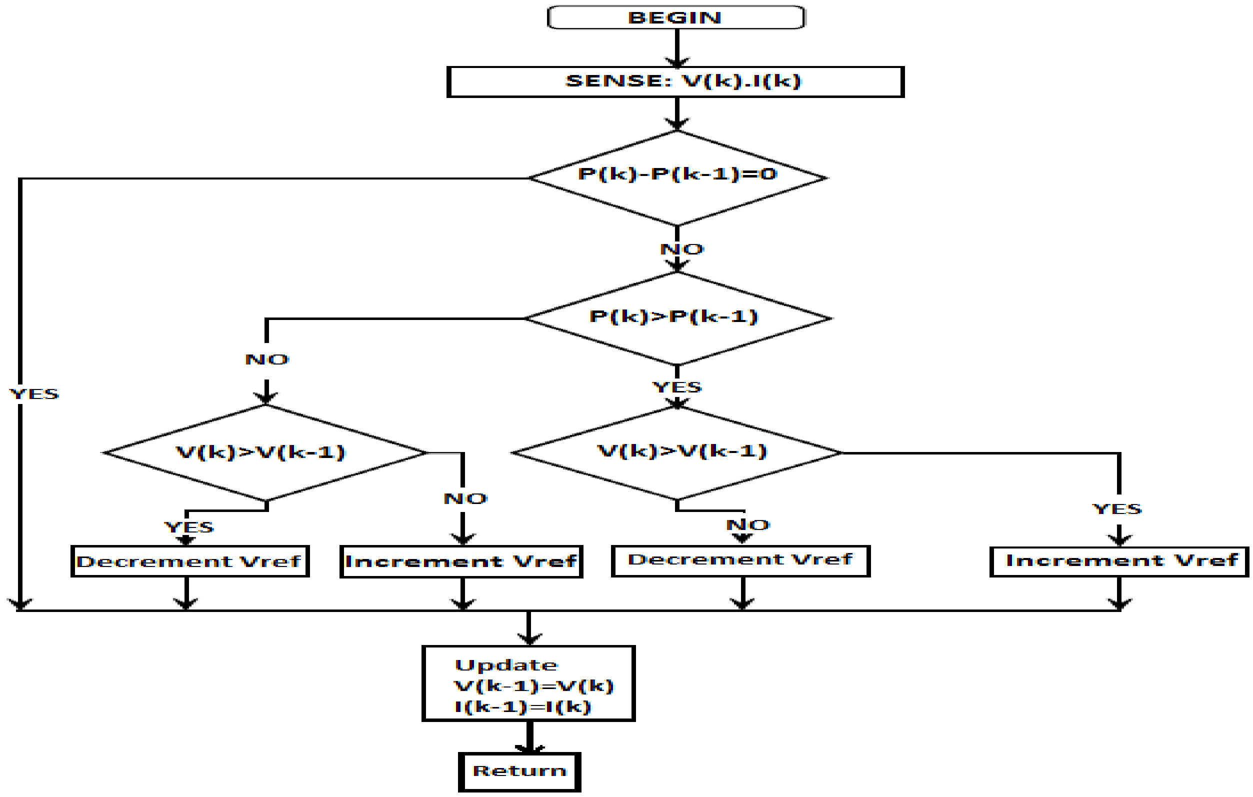


Fig.3: Flow chart algorithm for perturb & observe method.

There are some limitations of P & O technique that reduces MPPT's efficiency:

- It cannot determine when it has actually reached the MPP in P & O. Instead, it oscillates the operating point around the MPP after each cycle and somehow reduces PV efficiency during the constant irradiance situation.
- It has been shown that it can exhibit erratic response in cases of rapidly changed atmospheric conditions as a result of moving clouds.

IV. 3-LEVEL DIODE CLAMPED INVERTER

Conventional simple two-level inverters are mostly used to generate an AC voltage from a DC voltage, As we know the two-level inverter can create only two different output voltages for the load, +Vdc/2 and –Vdc/2 (This is when the inverter is fed with Vdc). The concept of 3-level diode clamped inverters as shown in **Fig. (4)** does not depend on just two levels of voltage to create an AC signal. Here there are several voltage levels +Vdc/2, 0,–Vdc/2 is produced to each other to get a smoother stepped waveform, [3]-[4]. With the more voltage levels generated in the inverter the waveform it creates becomes smoother, but if many levels of voltage will make increase the complexity of the circuit, with more components and a more complications the controllers for the inverter are required and being used, [4].

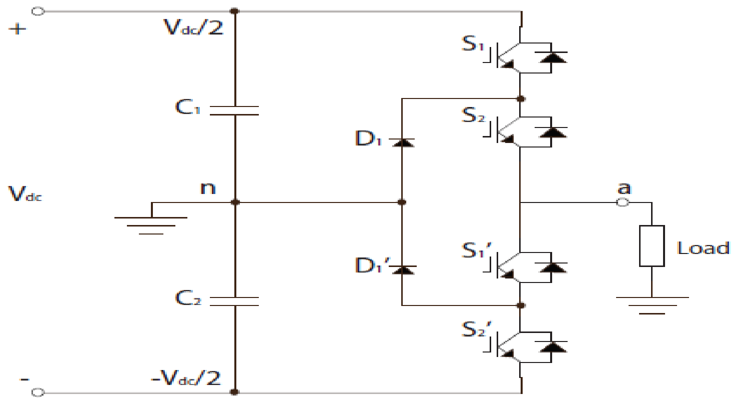


Fig.4: Three level diode clamp inverter for 1-phase.

In diode clamp or neutral point clamp topology, multilevel inverter diodes have been used as a clamping device to create required output voltage levels, [3].
The duty cycle for switches ON/OFF in 3-level diode clamp inverter done as per **Table. (1)** available here, [3].

Magnitude of voltage(Vdc)	No. of switches to be ON/OFF			
	S1	S2	S3	S4
+Vdc/2	ON	ON	OFF	OFF
0	OFF	ON	ON	OFF
-Vdc/2	OFF	OFF	ON	ON

Table 1: Switching modes of 3-level inverter.

V. PWM TECHNIQUES

The modulation strategies can be divided mainly into two parts: Fundamental switching frequency and high switching frequency PWM. And the **Fig. (5)** Given shows the overview of different PWM techniques.

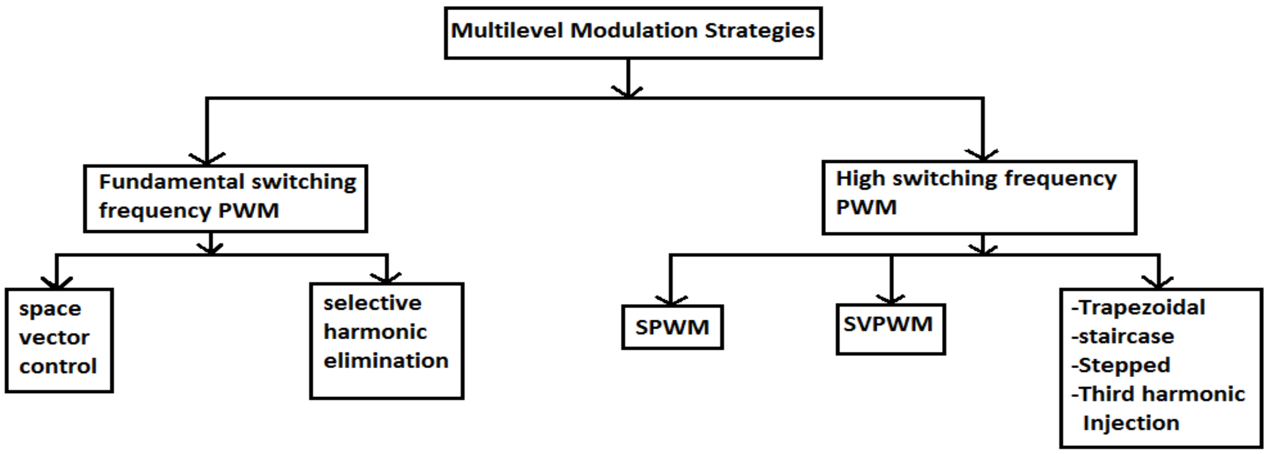


Fig.5: Different PWM techniques.

Above block diagram **Fig. (5)** represents the overview of different PWM techniques. Out of them in this paper, the sinusoidal pulse width modulation (SPWM) & space vector pulse width modulation (SVPWM) is discussed.

5.1.SPWM(SINUSOIDAL PWM)

Inverters that use PWM switching techniques have a DC input voltage that is always constant in magnitude. The inverter will take this as an input voltage and output AC where the magnitude and frequency can be controlled as per the requirement/demand. There are many different ways by which pulse-width modulation can be implemented to make the output to be AC. A common technique known as sinusoidal PWM has been used and has been discussed here. In order to output a sinusoidal waveform for 3-level inverter at a specific frequency a sinusoidal control signal(Vsine) at the specific frequency is compared with a (m-1) triangular waveform(Vtri) as shown in **Fig. (6)**;where, m is number of inverter level(2,3,4,...,etc). The inverter will use than the frequency of the triangle wave as the switching frequency which is basically kept constant, [3]-[4]-[5].

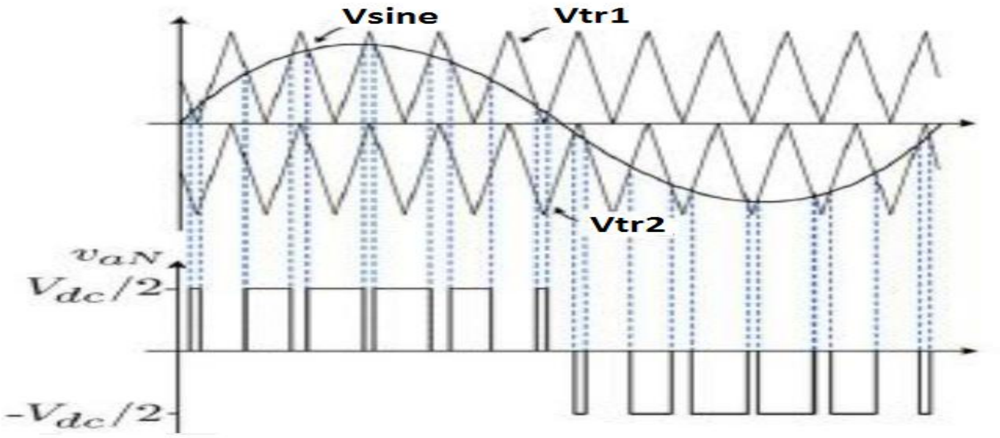


Fig.6 : SPWM for 3-level inverter.

The triangle waveforms (Vtr1, Vtr2) are at the switching frequency (fs); this frequency controls the speed at which the inverter switches can turned on and off. The control signal (Vsine) is used to modulate the switch duty ratio and has a frequency f, which is known as fundamental frequency of the inverter output voltage. The output of the inverter is affected by the switching frequency. Here, it contains harmonics at the switching frequency. The duty cycle of the one of the inverter switches here is called as amplitude modulation ratio (Ma).

$$\mathbf{Ma} = \frac{\mathbf{Vsin}}{\boldsymbol{Vtri}} \text{..................(6)}$$

When,
Vsin > Vtr1 = +Vdc/2

When,
Vsin < Vtr2 = -Vdc/2

when,
Vtr2 > Vsine = 0

In **Fig. (6)** the switches S+ and S- are controlled based on the comparison of signals Vsine and Vtri. Here, The two switches are never gets off at the same time which results in the output voltage fluctuating between +/- Vd/2 and the remaining switches will be output as 0, [3]-[4]-[5].

5.2.SVPWM(SPACE VECTOR PWM)

Space vector pulse width modulation (SVPWM) is far different from the other PWM techniques. With other PWM techniques or can say in SPWM technique, the inverter can be thought of as three separate push-pull driver stages which create each phase waveform independently. SVPWM treats the inverter as a single unit. Specifically the inverter can be driven to twenty seven switching states for 3-level inverter in SVPWM, [3]-[6]-[7].

Modulation is accomplished by switching the state of inverter. SVPWM is a digital modulation technique where the objective is to generate PWM load line voltages. This is done in each sampling period by properly selecting the switching states of inverter and calculation of the appropriate time period for each state, [3]-[6]-[7].

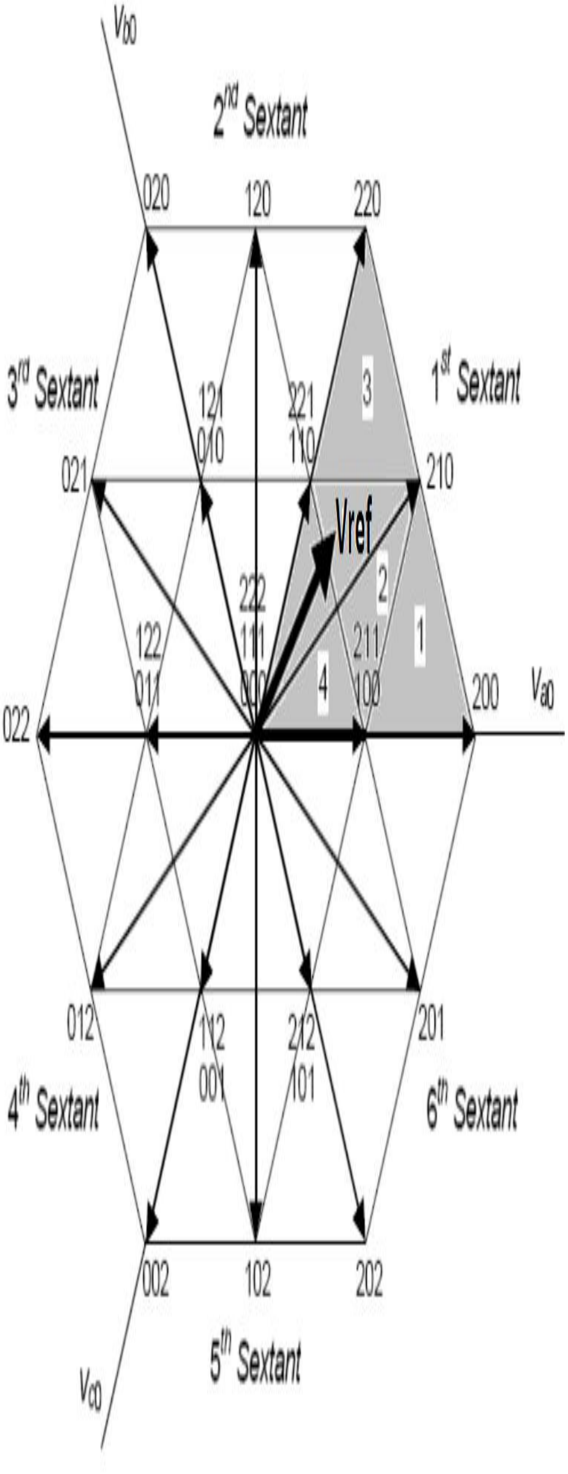


Fig.7: Voltage vector of 3-level inverter system.

Switching states	S_a	S_b	S_c	Voltage Vectors
S_1	0	0	0	V_0
S_2	1	1	1	V_0
S_3	2	2	2	V_0
S4	1	0	0	V_1
S_5	1	1	0	V_2
S_6	0	1	0	V_3
S_7	0	1	1	V_4
S_8	0	0	1	V_5
S_9	1	0	1	V_6
S_{10}	2	1	1	V_7
S_{11}	2	2	1	V_8
S_{12}	1	2	1	V_9
S_{13}	1	2	2	V_{10}
S_{14}	1	1	2	V_{11}
S_{15}	2	1	2	V_{12}
S_{16}	2	1	0	V_{13}
S_{17}	1	2	0	V_{14}
S_{18}	0	2	1	V_{15}
S_{19}	0	1	2	V_{16}
S_{20}	1	0	2	V_{17}
S_{21}	2	0	1	V_{18}
S_{22}	2	0	0	V_{19}
S_{23}	2	2	0	V_{20}
S_{24}	0	2	0	V_{21}
S_{25}	0	2	2	V_{22}
S_{a26}	0	0	2	V_{23}
S_{27}	2	0	2	V_{24}

Table 2: Switching states and vector selection for 3-level inverter.

VI. SIMULATION & RESULTS

6.1.Simulink model of system along with SPWM &SVPWM

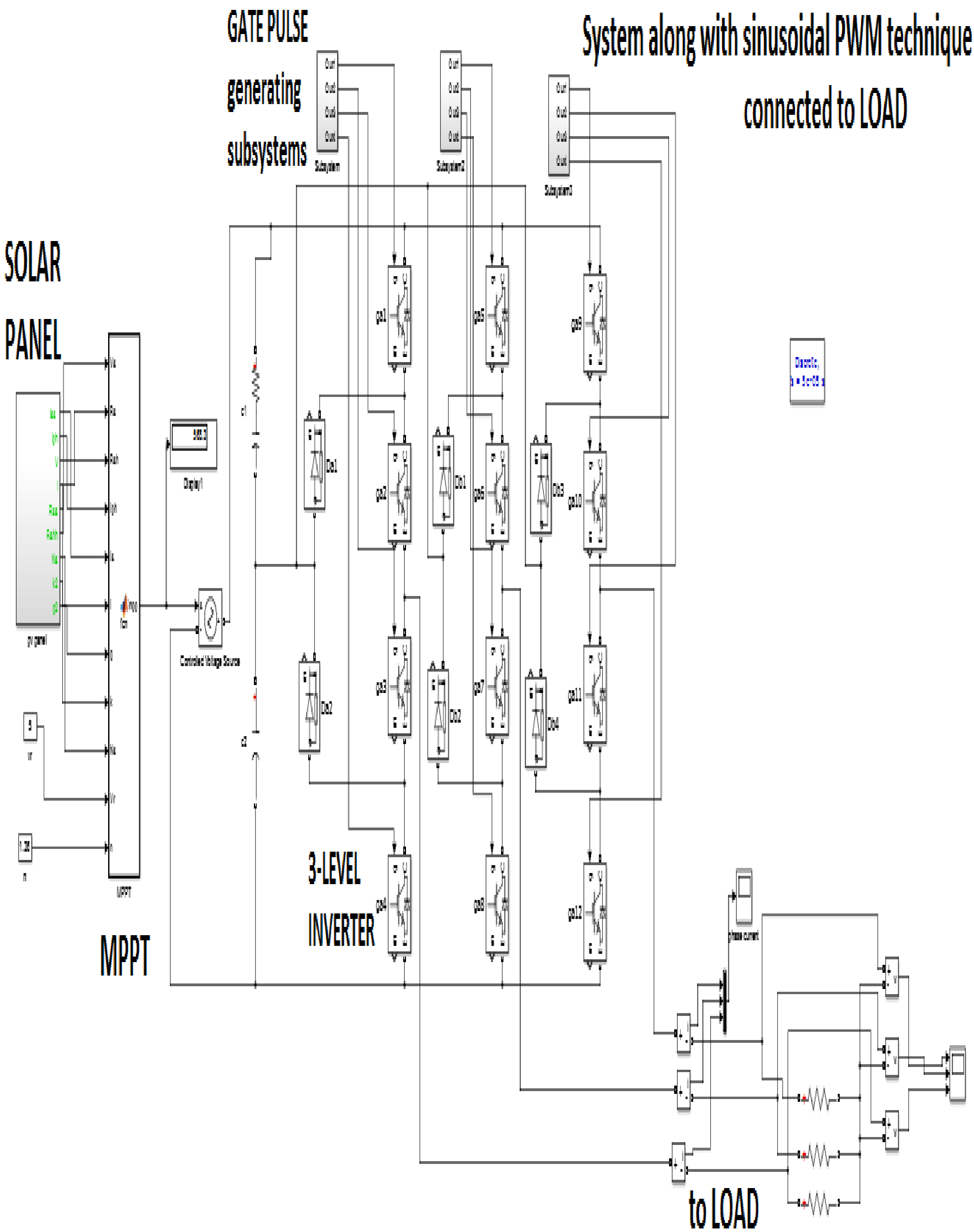


Fig.8: Simulink model of system along with SPWM.

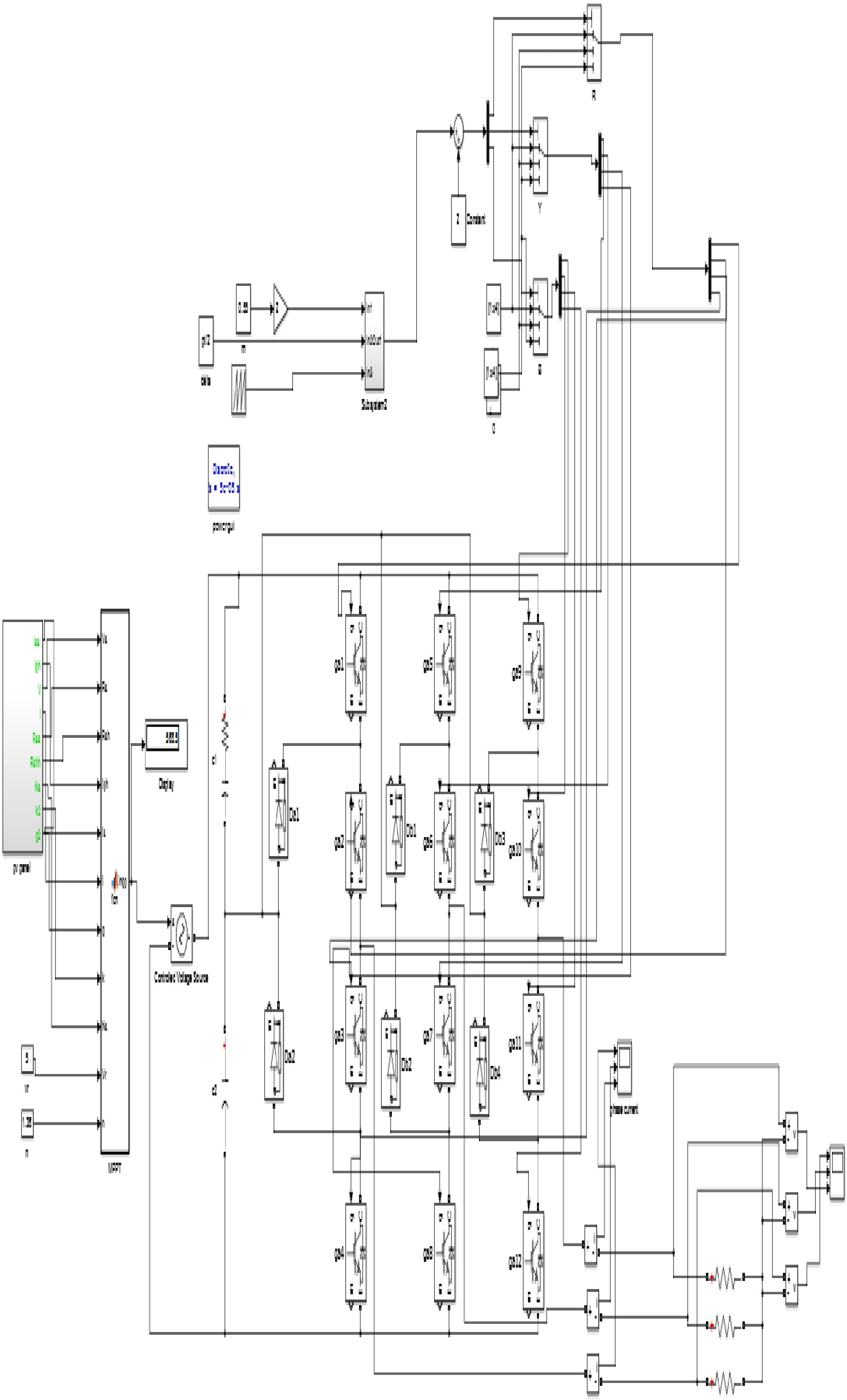


Fig.9: Simulink model of system along with SVPWM.

6.2.Simulink Results

(1) PV & IV curve from solar panel

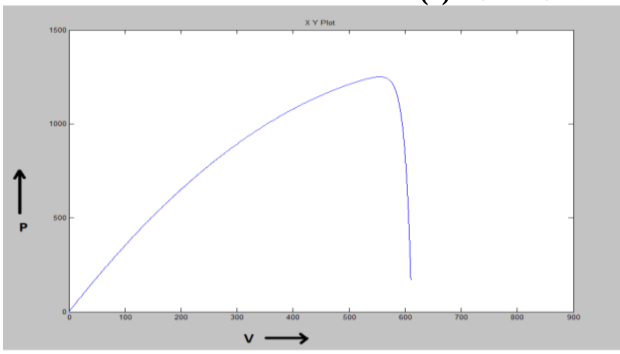


Fig.10: PV curve of solar panel output.

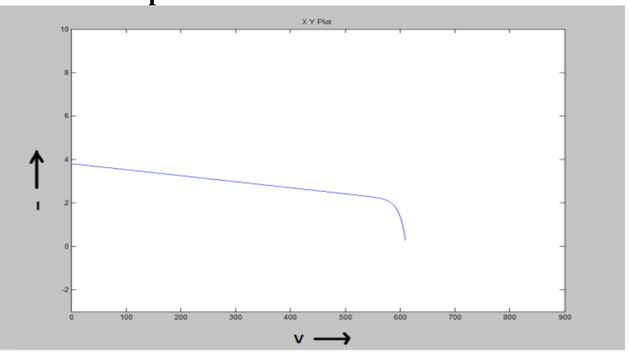


Fig.11: IV curve of solar panel output.

When solar radiation fed to photo voltaic cells and the photo voltaic cells are connected to the variable resistor, the PV and IV characteristics of the solar cell are like indicated in **Fig. (10)** and **Fig. (11)**.

(2) Maximum power point tracking by MPPT

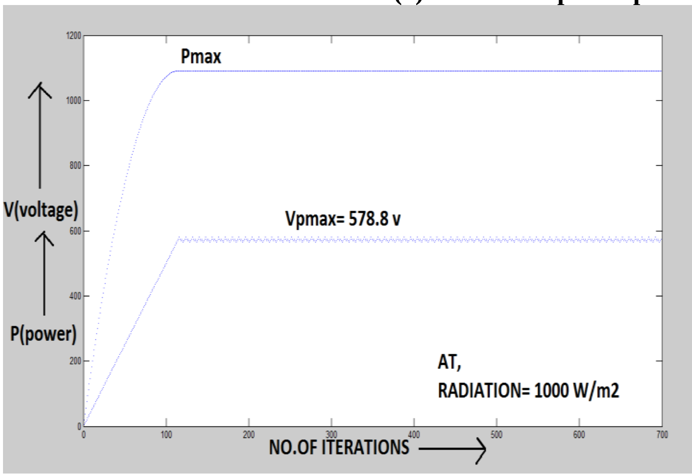


Fig.12: Voltage at maximum power by MPPT for 1000W/^{m2}.

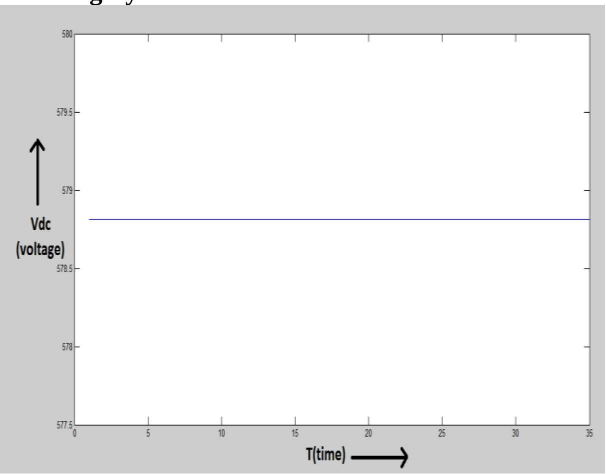


Fig.13: DC output voltage from MPPT.

Here, **Fig. (12)** shows the output DC voltage of the photo voltaic cell by means of MPPT at the point of maximum power and at the same time the DC output voltage can be shown in **Fig. (13).**

(3) GATE pulses by SPWM &SVPWM

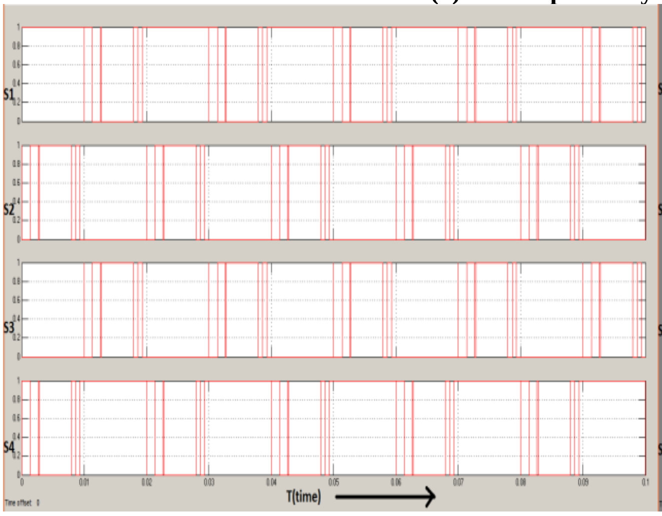


Fig.14: GATE pulses generated by SPWM.

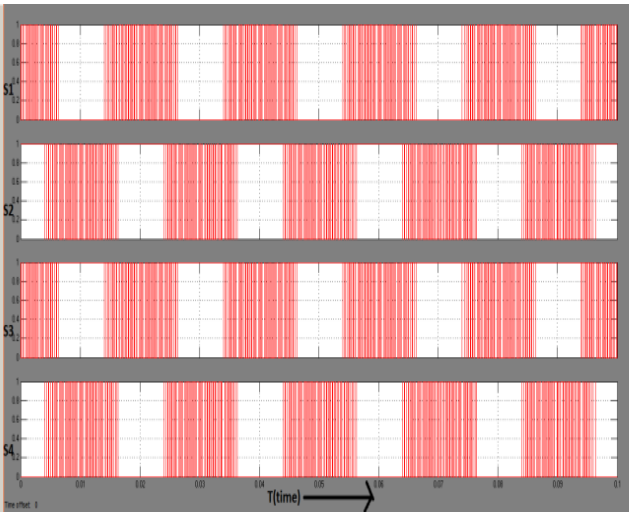


Fig.15: GATE pulses generated by SVPWM.

Here is **Fig. (14)** and **Fig. (15)** which shows the gate pulse generating signals by SPWM and SVPWM systems to making the switches on and off to convert the DC into AC to fed the load.

(4) AC output current waveforms by SPWM & SVPWM

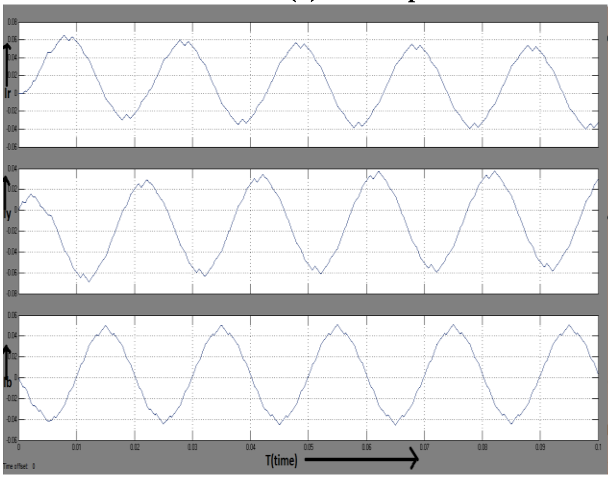


Fig.16: Phase current for inductive LOAD by SPWM.

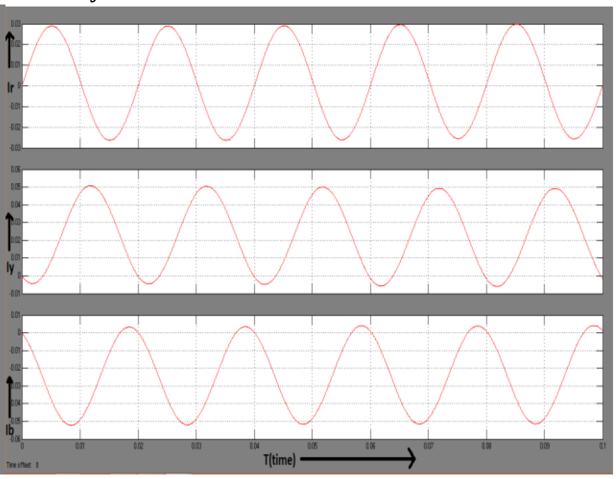


Fig.17: Phase current for inductive LOAD by SVPWM.

The output phase current waveform of the system can be shown by **Fig. (16)** and **Fig. (17)**. In which the waveform by SVPWM system are smoother than the waveform system along with SPWM. Where, the inductive LOAD is connected to the system.

(6) % THD analysis for line voltage & current for SPWM & SVPWM

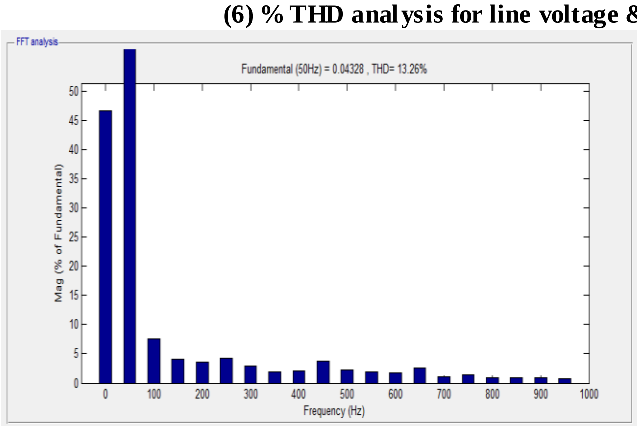


Fig.18: %THD analysis of current when inductive. LOAD for SPWM.

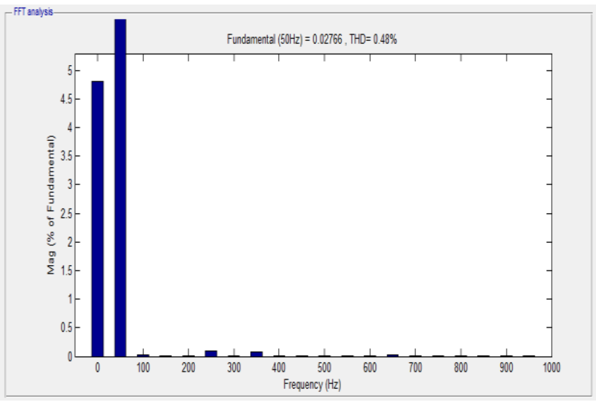


Fig.19: %THD analysis of current when inductive LOAD for SVPWM.

VII COMPARISON

The comparison of both the system along with the different modulation techniques (SPWM & SVPWM) can be done by different two ways:

(1) % THD Analysis

Total harmonic distortion(%THD)	SPWM	SVPWM
Inductive LOAD	-	-
	Current	Current
%THD	13.26%	0.48%

Table 3: %THD analysis of the system for SPWM & SVPWM

(2) Gate pulses, output voltage & current

- Generated GATE PULSES from SVPWM are more in proper manner than SPWM system.
- Output phase voltage and current waveforms are smoother of SVPWM system than SPWM.

VIII CONCLUSION

The paper has presented the modelling of the Three level diode clamped inverter for solar application along with MPPT by using SPWM & SVPWM modulation techniques on MATLAB/SIMULINK. By doing different analysis on basis of simulink results we can conclude that SVPWM technique is more efficient by giving enhanced and smoother output waveforms than SPWM technique. As well as the %THD of line voltage and current are less in the system in which SVPWM technique is being used. So % THD are more in the system in which SPWM technique is used. so, SVPWM technique is more suitable than SPWM technique for the proposed system.

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