# A Solar Power Generation System With A Seven-Level Inverter

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## ABSTRACT

This paper proposes a new solar power generation system, which is composed of a dc/dc power converter and a new seven-level inverter. The dc/dc power converter integrates a dc–dc boost converter and a transformer to convert the output voltage of the solar cell array into two independent voltage sources with multiple relationships. This new seven-level inverter is configured using a capacitor selection circuit and a full-bridge power converter, connected in cascade. The capacitor selection circuit converts the two output voltage sources of dc–dc power converter into a three-level dc voltage, and the full-bridge power converter further converts this three-level dc voltage into a seven-level ac voltage. In this way, the proposed solar power generation system generates a sinusoidal output current that is in phase with the utility voltage and is fed in to the utility. The salient features of the proposed seven-level inverter are that only six power electronic switches are used, and only one power electronic switch is switched at high frequency at any time.A prototype is developed and tested to verify the performance of this proposed solar power generation system.

**Index Terms—**Grid-connected, multilevel inverter, pulse-width modulated (PWM) inverter.

## Introduction

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts.

## Types of Renewable Energy Source

### 1. Water Power

The power of water is abundant. Water power accounts for 73 percent of all renewable energy according to the Energy Information Administration (EIA). Water power is generated using the mechanical energy of flowing water by forcing it through pipes, which then turns a generator in order to produce electricity. Water power also consists of tidal and wave energy, both in the infant stage of research, as scientists try to discover how to harness energy produced by the ocean's movement.

### 2. Solar Power

Solar cells made of silicon absorb the sun's radiation, also called photovoltaic cells. The photovoltaic process involves the movement and displacement of electrons to absorb the sun's radiation and create electricity, but there are also solar systems that use large scale mirrors to heat water, or produce high temperatures and generate steam, which is used to turn a generator.

## 3. Wind Power

Wind power is a very simple process. A wind turbine converts the movement energy of wind into mechanical energy that is used to generate electricity. The energy is fed through a generator, converted again into electrical energy, then transmitted to a power station. Wind power is abundant in some states, with the largest wind farms located in Texas.

## 4. Geo Thermal Power

The process involves trapping heat underground, then building energy that rises near the surface in the form of heat. When this heat naturally creates hot water or steam, it is harnessed and then used to turn a steam turbine to generate electricity. Geothermal .energy was first used for commercial purposes in the early 1900s.

## Multilevel power converter structures

As previously mentioned, three different major multilevel converter structures have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. Before continuing discussion in this topic, it should be noted that the term multilevel converter is utilized to refer to a power electronic circuit that could operate in an inverter or rectifier mode. The multilevel inverter structures are the focus of in this chapter; however, the illustrated structures can be implemented for rectifying operation as well.

## Advantages of multilevel inverters

- In High power circuits if you switch at high frequency switching losses are high.
- Particularly in Low power & low voltage circuits Mosfets are used.
- In Mosfets the conductions losses 70% of total losses and switching losses are 30 % of total losses.
- So switching the Mosfets at high switching frequency not effects the total losses much.
- In case of High power high voltage circuits IGBT’s are used.
- In IGBT’s the conduction losses 50 % of total loss and switching losses are 50 % of total loss. So if you switch at high frequency the efficiency of the system reduces.
- SO in High power High frequency PWM is not suitable, so we need to use multilevel inverter for high power application

## The most attractive features of multilevel inverters are as follows.

- They can generate output voltages with extremely low distortion and lower *dv/dt*.
- They draw input current with very low distortion.
- They generate smaller common-mode (CM) voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated

modulation methods, CM voltages can be eliminated.

➢ They can operate with a lower switching frequency.

## CLASSIFICATION OF MULTILEVEL INVERTERS

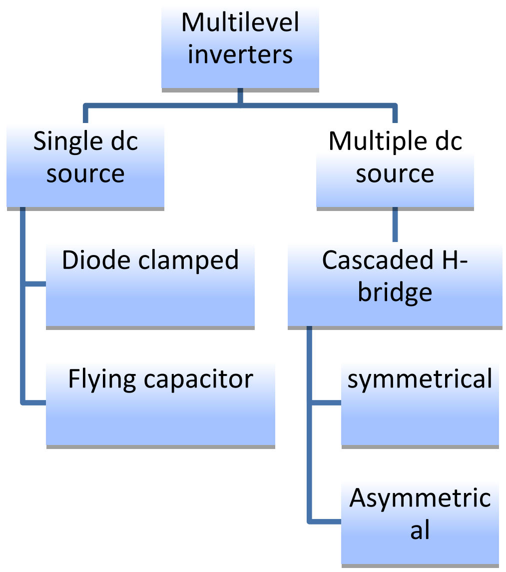


**Figure 2.6: Classification of multilevel Inverters**

In General, the multilevel inverters are classified as Single DC source and Multiple DC sources or Several Separate DC Sources (SDCS).Both the Dode Clamped Multilevel Inverter and the Flying Capacitor inverter comes under the category of Single DC source where the input supply is taken from a single DC source.

## Off-line or Pre-Calculated PWM Technique

Selective Harmonic Elimination (SHE) and Selective Harmonic Minimization (SHM) are two off-line (pre-calculated) non carrier based PWM techniques. SHE was proposed in a early paper by Patel and Hoft . Accepting first the conditions of quarter and half wave symmetry to cancel all even harmonics, the angles of the switching edges in the first quarter cycle can be considered variables for optimization. Each angle is one degree of freedom. For each degree of freedom, one harmonic may be set to zero or any other reasonable desired value. Using Fourier transforms, simultaneous equations in these angles are solved given desired values for the fundamental and the lowest significant harmonics. These calculations are slow and are done off-line. A look up table of edge angles is created which the on-line controller uses to set the edge times. A summary of Harmonic elimination PWM techniques is presented by Enjetiet al.

Optimal PWM or selected harmonic elimination PWM (SHE-PWM) seems attractive, but cannot react to transients quickly. This is because pulses do not occur at fixed intervals, that is, the switch period is not constant. Moving one edge may completely upset the optimized spectrum. Closed loop control using SHE/SHM is generally limited to cycle by cycle control of the fundamental frequency and modulation depth. Some works have been done on closing feedback loops around optimized PWM modulators to remove errors when they occur. These techniques cannot compensate for distortions due to DC bus ripple, or switching imperfections.

## Hysteresis Control PWM

A hysteresis band modulator calculates the error between the desired output and the measured output. The state of the switches is changed when this error exceeds a certain bound (leaves the hysteresis band) so as to drive the error back within that bound. This method requires that the controlled output quantity of the inverter is integrated either by the load, or as part of the controller. For example, in a voltage source hysteretic inverter, the output current (the measured and subsequently controlled quantity) will be integrated by an inductive load.

This technique has the advantage of bounded, predictable error and fast transient response to changes at either the input or the output. It is closed loop by nature and demonstrates low distortion. It is simple to implement in its simplest form. It has however a number of disadvantages, which limit its usefulness to low power, high switching frequency applications.

One disadvantage is the variable nature of the switch period. Because of this, the output spectrum is continuous and spread to an extent, rather than discrete and grouped as with carrier based techniques. Further, the switching instants are not necessarily synchronous or cyclic and so sub-harmonics may be present. For these reasons, hysteresis control is not applied for low switching frequencies.

One method of eliminating sub-harmonics is to force quarter wave symmetry by resetting the error at each zero crossing and forcing a switching, and hence a reflection of the pattern, at 90 degrees. This gives discrete spectra without sub-harmonics. Another technique which limits the variations in switching frequency is to modulate the width of the hysteresis band. This places upper and lower limits on the switching frequency, but does not address the problem of sub-harmonics.

## Carrier Based PWM Techniques

There are many variations of carrier based PWM.

1) analog vs. digital
2) sine-triangle vs. space vector (in reality very similar)
3) triangular vs. saw tooth carrier
4) symmetric vs. asymmetric (sampled once/twice per triangle)
5) uniform sampling vs. natural sampling
6) Periodic vs. aperiodic carrier.

For the purposes of defining this broad category, carrier based PWM methods are those where the switching decisions of the inverter are made for each switching cycle either at the beginning or during that switch cycle. That is, the PWM waveform is calculated on a cycle by cycle basis, either pulse by pulse, or edge by edge. This distinguishes it from SHE and SHM PWM, where multiple switching edges are mapped out for the entire fundamental period or some fraction therein; and hysteresis PWM, where neither edges nor switch period are defined, calculated or even known in

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advance. A comparison of waveforms and frequency spectra of three different PWM strategies are shown in Fig. 2.17 below.

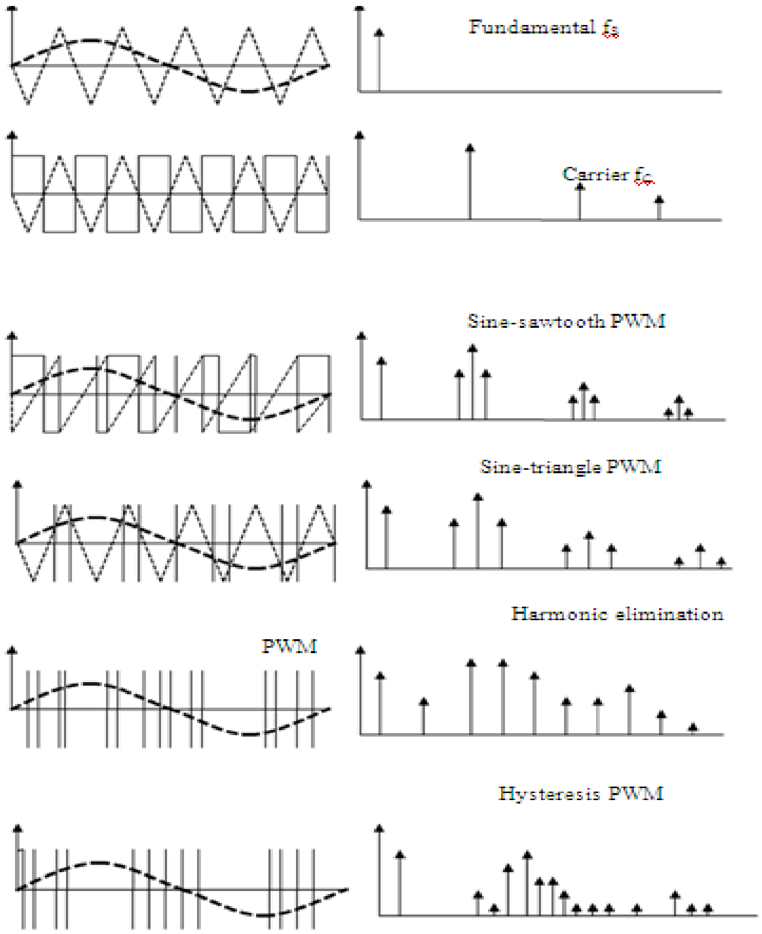


**Figure 2.17 From the top, wave forms and frequency spectra of the original sinusoidal modulating waveform, the unmodulated PWM square wave, sine-saw tooth (single edge carrier) PWM, sine-triangle (double edge carrier) PWM, Selective Harmonic Elimination (SHE) PWM and Hysteresis PWM.**

**The two basic approaches used to generate the PWM signals for multilevel inverters are:**

1. Sub harmonic or Sub-Oscillation carrier based PWM-modulating waveform comparison with offset triangular carriers.
2. Space Vector PWM-space vector modulation based on a rotating vector in multilevel space.

These are the extensions of traditional two level control strategies to several levels.The two main advantages of PWM inverters in comparison to square-wave inverters are

(i) control over output voltage magnitude

(ii) Reduction in magnitudes of unwanted harmonic voltages.

Good quality output voltage in SPWM requires the modulation index (m) to be less than or equal to 1.0. For m>1 (over-modulation), the fundamental voltage magnitude increases but at the cost of decreased quality of output waveform. The maximum fundamental voltage that the SPWM inverter can output (without resorting to over-modulation) is only 78.5% of the fundamental voltage output by square-wave inverter.

The merits and demerits of these two PWM techniques are compared under comparable circuit conditions on the basis of factors like (i) quality of output voltage (ii) obtainable magnitude of output voltage (iii) ease of control etc. The peak obtainable output voltage from the given input dc voltage is one important figure of merit for the inverter.

**Four alternative carrier PWM strategies with differing phase relationships for a multilevel inverter are as follows:**

- In-phase disposition (IPD), where all the carriers are in phase- Technique A1
- Phase opposition disposition (POD), where the carriers above the zero reference are in phase, but shifted by 1800 from those carriers below the zero reference- Technique A2
- Alternative phase opposition disposition (APOD), where each carrier band is shifted by 1800 from the adjacent bands- Technique A3; 4) Phase Disposition (PD), all the carriers are phase shifted by 2N/(N-1) radians- Technique B.PD strategy is used most frequently because it produces minimum harmonic distortion for the line–to–line output voltage.

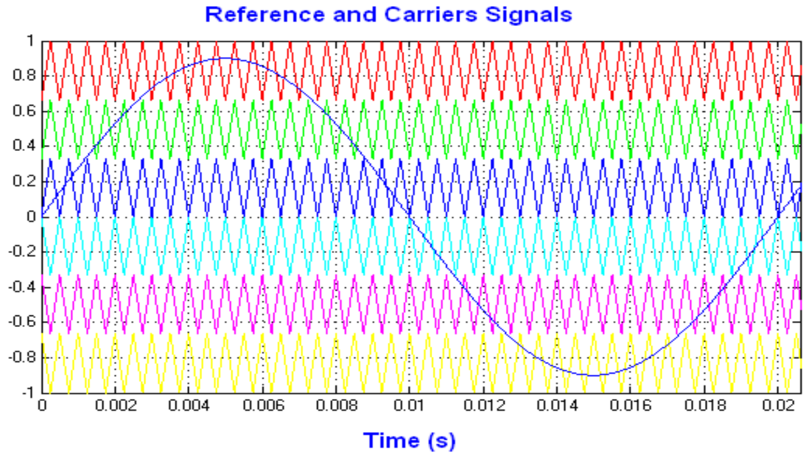


**Fig. 2.18 Reference and carriers signals for SHPWM technique.**

Fig. 2.18 shows generation of reference and carriers signal for SHPWM technique, which is used to control the switches of TBMCSL H- bridges inverter

## PWM Techniques

The fundamental methods of pulse-width modulation (PWM) are divided into the traditional voltage-source and current-regulated methods. Voltage-source methods more easily lend themselves to digital signal processor (DSP) or programmable logic device (PLD) implementation. However, current controls typically depend on event scheduling and are therefore analog implementations which can only be reliably operated up to a certain power level. In discrete current-regulated methods the harmonic performance is not as good as that of voltage-source methods. A sample PWM method is described below.

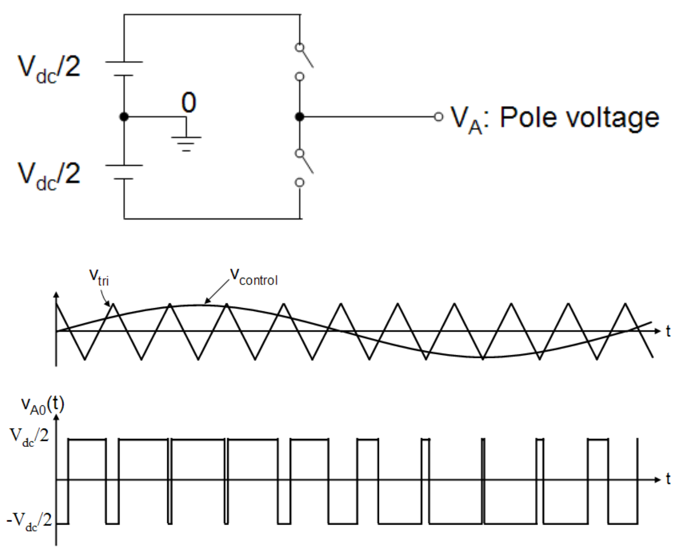


**Fig. Pulse-width modulation.**

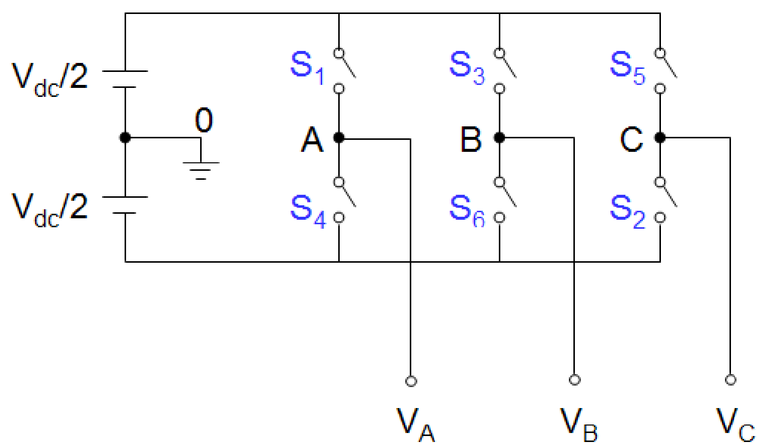


**Fig. 2.20 Three-phase Sinusoidal PWM inverter**

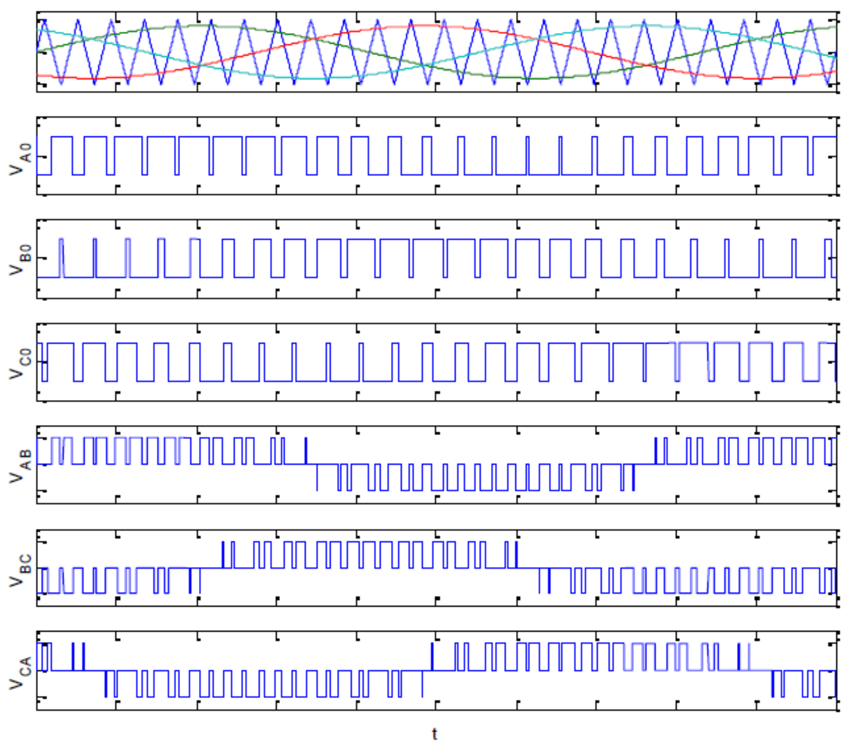


**Fig. 2.21 Waveforms of three-phase SPWM inverter**

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## Boost Isolated DC-DC Converter

High boost isolated dc-dc converter with closed loop control to provide high voltage regulation control suitable for renewable energy source. The circuit consists of active clamp circuit and boost converter with isolated transformer. The circuit employs capacitors are charged in parallel and discharged in series by isolated transformer inductors. The active clamp circuit is used during the turn off-period to reduce the voltage spike on power switch. To achieve high output voltage gain the converter output terminal and boost converter output terminal are connected in serially with the isolated inductors with less voltage stress on controlled power switch and power diodes.

High boost DC-DC converters operating at high voltage regulation are widely proposed in many industrial applications. High boost dc-dc converters are play a important role in renewable energy sources such as fuel energy systems, DC-back up energy system for UPS, High intensity discharge lamp and automobile applications. The converters require increasing low dc voltage to high dc voltage. The conventional boost converters are able to get high voltage gain with high voltage duty ratio the problem is Electro Magnetic Interference and complexity increases.

DC-DC converters with coupled inductors can provide high voltage gain, but their efficiency is degraded by the losses associated with leakage inductors. The solution would be the use of transformers to get the preferred voltage conversion ratio similar in forward or fly back converter the dc-isolation is no need for industrial applications. To suppress the high voltage spike on power switch non dissipative snubber circuit and active clamp circuit is used. The active clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance of the transformer. High boost dc-dc converter is shown in Fig 3.10

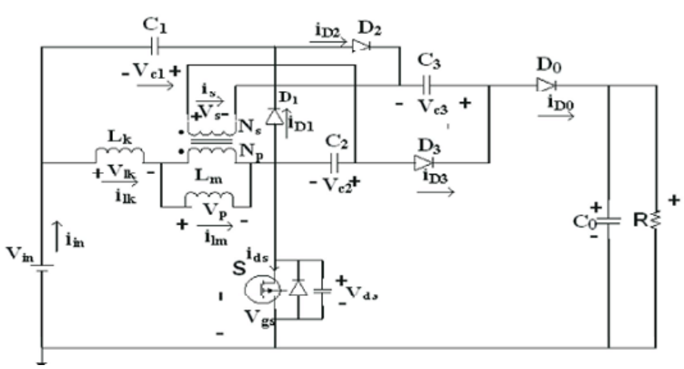


**Fig. 3.10 High Boost DC-DC Converter**

Without wasting through active clamp, active clamp circuit consists a clamped diode and clamped capacitor. The clamped-voltage dc-dc converter with reduced revere-recovery current and switch-voltage stress. The active switch in the converter can still sustain a proper duty ratio when even under high step-up applications, reducing voltage and current stresses significantly.

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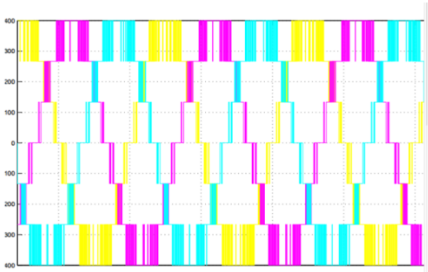
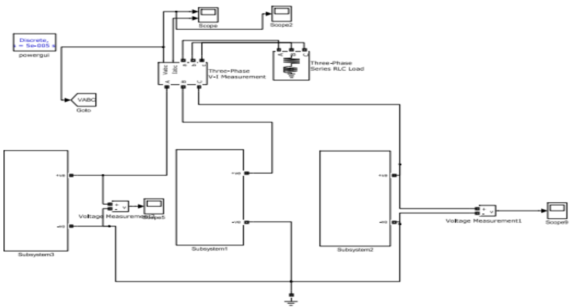
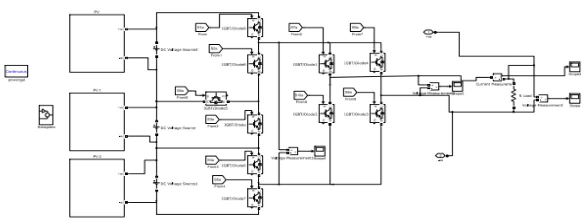
## SIMULATION RESULTS



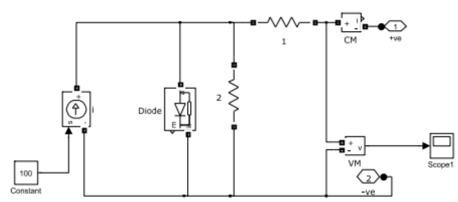
**Result-output voltage**



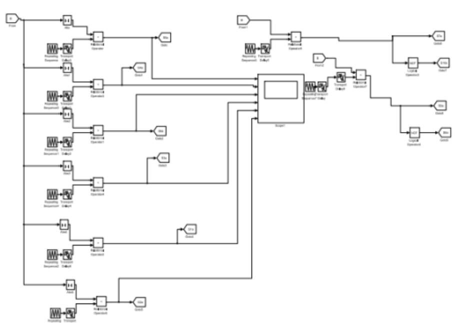

**Without LC Filter**



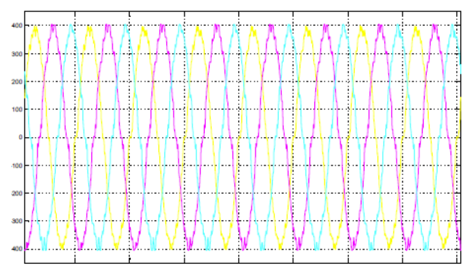
**Sub system-1**



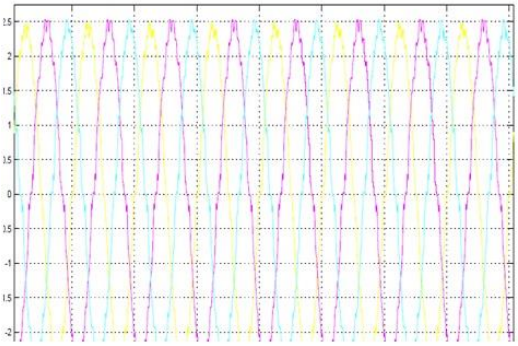

**Sub system-2**



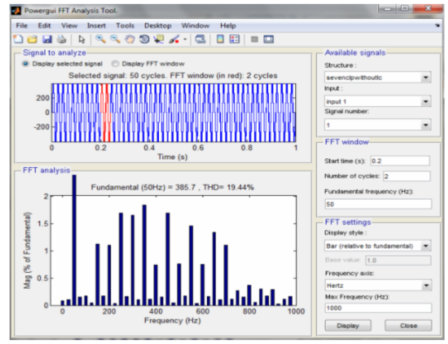
**Subsystem-3**



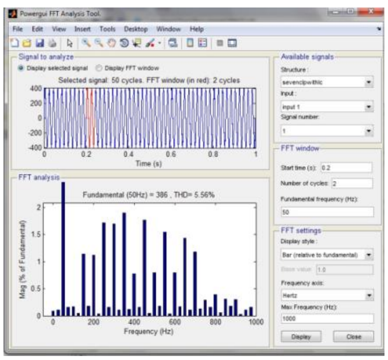
**result with lc filter load voltage**



**result with lc filter load current**




**thd without lc**




**thd with lc**

## CONCLUSION

This paper proposes a solar power generation system to convert the dc energy generated by a solar cell array into ac energy that is fed into the utility. The proposed solar power generation system is composed of a dc–dc power converter and a seven level inverter. The seven-level inverter contains only six power electronic switches, which simplifies the circuit configuration.

Furthermore, only one power electronic switch is switched at high frequency at any time to generate the seven-level output voltage. This reduces the switching power loss and improves the power efficiency. The voltages of the two dc capacitors in the proposed seven-level inverter are balanced automatically, so the control circuit is simplified. Experimental results show that the proposed solar power generation system generates a seven-level output voltage and outputs a sinusoidal current that is in phase with the utility voltage, yielding a power factor of unity. In addition, the proposed solar power generation system can effectively trace the maximum power of solar cell array.

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