# VOLTAGE CONTROL IN DISTRIBUTION GRID WITH DISTRIBUTED GENERATION

**[1]Murtuza Challawala, [2]Sumit K Rathor**
[1] PG Scholar, [2]Assistant Professor
[1]Department of Electrical Engineering,
G H Patel College of Engineering and Technology, Anand, India

***Abstract— The PV solar inverter plays a vital role in solar for electrical power generation to support the energy requirements at the distribution end. With the increasing penetration level of PV solar farms in the distribution grid results like voltage rise issues and some voltage fluctuations that affect the power quality standards. Increasing renewable generation sources connected with power system causes increase reverse power flow when demand is not is not adequate, which raises the voltage level at point of common coupling at grid connection. To regulate the voltage at PCC, there are power electronic converter based FACTs devices used in practice. During night time or some cloudy days, when PV system is unable to generate active power, photovoltaic inverters are utilized for reactive power support to the grid by operating in VAR mode for voltage regulation and with the help of new control design in typical PV inverter. Some inverter techniques use to compensate voltage profile in desired limit like PWM, SPWM, and Close loop control. The advantage of this technique can increase the distributed generators connection at PCC and to regulate grid voltage without requiring any conventional reactive power compensators.***

***Index Terms— Voltage Regulation, Distribution Generation, Inverter control technique***

## I. INTRODUCTION

Distributed generation (DG), also known as on-site generation, distributed resources (DR), distributed energy resources (DER) or dispersed power (DP) is the use of small-scale power generation technologies located close to the load being served. One of these new features is the ability to connect a small-scale generation unit directly on the distribution network. This kind of power generation has been referred to as Distributed Generation (DG). Generators larger than 10MW are typically interconnected at transmission voltages where the system is designed to accommodate many generators.

## II. INTERFACING WITH UTILITY GRID

The primary concern here is the impact of DG on the distribution system power quality. While the energy conversion technology may play some role in the power quality, most power quality issues relate to the type of electrical system interface. Some notable exceptions include:

1. The power variation from renewable sources such as wind and solar can cause voltage fluctuations.
2. Some fuel cells and micro turbines do not follow step changes in load well and must be supplemented with battery or flywheel storage to achieve the improved reliability expected from standby power applications.
3. Mis-firing of reciprocating engines can lead to a persistent and irritating type of flicker, particularly if it is magnified by the response of the power system.

The main types of electrical system interfaces are

1. Synchronous machines
2. Asynchronous (induction) machines
3. Electronic power inverters

### 1. ELECTRONIC POWER INVERTERS

All DG technologies that generate either dc or non–power frequency ac must use an electronic power inverter to interface with the electrical power system. The early thyristor-based, line-commutated inverters quickly developed a reputation for being undesirable on the power system. These inverters produced harmonic currents in similar proportion to loads with traditional thyristor-based converters. To achieve better control and to avoid harmonics problems, the inverter technology has changed to switched, pulse width modulated technologies. This has resulted in a friendlier interface to the electrical power system. Figure shows the basic components of a utility interactive inverter that meets the requirements of IEEE Standard 929-2000. Direct current is supplied on the left side of the diagram either from a conversion technology that produces direct current directly or from the rectification of ac generator output. The dc voltage is switched at a very high rate with an insulated gate bipolar transistor (IGBT) switch to create a sinusoid voltage or current of power.

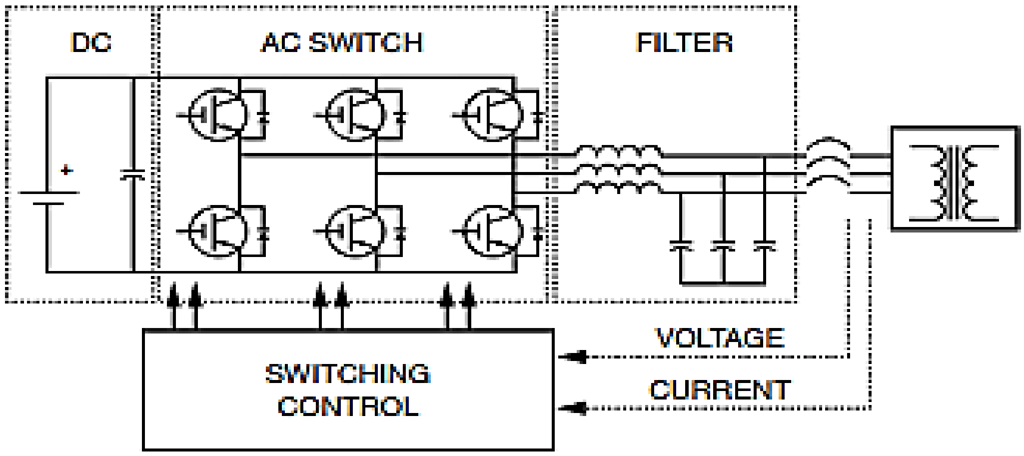


Figure II-1 Simplified Schematic Diagram Of A Modern Switching Inverter

The switching frequency is typically on the order of 50 to 100 times the power frequency. The filter on the output attenuates these high-frequency components to a degree that they are usually negligible. However, resonant conditions on the power system can sometimes make these high frequencies noticeable. The largest low order harmonic (usually, the fifth) is generally less than 3 percent, and the others are often negligible. The total harmonic distortion limit is 5 percent, based on the requirements of IEEE Standard 519-1992.

## 2. Power Quality Issues

*1) Sustained Interruption*

Much of the DG that is already in place was installed as backup generation. The most common technology used for backup generation is diesel gen-sets. The bulk of the capacity of this form of DG can be realized simply by transferring the load to the backup system. However, there will be additional power that can be extracted by paralleling with the power system. Many DG installations will operate with better power quality while paralleled with the utility system because of its large capacity. However, not all backup DG can be paralleled without great expense. Not all DG technologies are capable of significant improvements in reliability. To achieve improvement, the DG must be capable of serving the load when the utility system cannot. Unfortunately, the less costly systems do not have the proper inverter and storage capacity to operate stand-alone. Therefore, there is no improvement in reliability. Utilities may achieve improved reliability by employing DG to cover contingencies when part of the delivery system is out of service. In this case, the DG does not serve all the load, but only enough to cover for the Capacity that is out of service.

*2) Voltage Regulation*

It may initially seem that DG should be able to improve the voltage regulation on a feeder. Generator controls are much faster and smoother than conventional tap-changing transformers and switched capacitor banks. With careful engineering, this can be accomplished with sufficiently large DG. However, there are many problems associated with voltage regulation. In cases where the DG is located relatively far from the substation for the size of DG, voltage regulation issues are often the most limiting for being able to accommodate the DG without changes to the utility system. It should first be recognized that some technologies are unsuitable for regulating voltages. Large DG greater than 30 percent of the feeder capacity that is set to regulate the voltage will often require special communications and control to work properly with the utility voltage-regulating equipment. One common occurrence is that the DG will take over the voltage-regulating duties and drive the substation load tap changer (LTC) into a significant bucking position as the load cycles up and down. This results in a problem when the DG suddenly disconnects, as it would for a fault. The voltage is then too low to support the load and takes a minute or more to recover. Large voltage changes are also possible if there were a significant penetration of dispersed, smaller DG producing a constant power factor. Suddenly connecting or disconnecting such generation can result in a relatively large voltage change that will persist until recognized by the utility voltage-regulating system.

*3) Harmonics*

There are many who still associate DG with bad experiences with harmonics from electronic power converters. If thyristor-based, line-commutated inverters were still the norm, this would be a large problem. This has eliminated the bulk of the harmonics problems from these technologies. One problem that occurs infrequently arises when a switching inverter is installed in a system that is resonant at frequencies produced by the switching process. The symptom is usually high-frequency hash appearing on the voltage waveform. The usual power quality complaint, if any, is that clocks supplied by this voltage run fast at times. This problem is generally solved by adding a capacitor to the bus that is of sufficient size to shunt off the high frequency components without causing additional resonances. Harmonics from rotating machines are not always negligible, particularly in grid parallel operation. The utility power system acts as a short circuit to zero-sequence triplen harmonics in the voltage, which can result in surprisingly high currents. For grounded wye-wye or delta-wye service transformers, only synchronous machines with 2/3 pitch can be paralleled without special provisions to limit neutral current. For service transformer connections with a delta-connected winding on the DG side, nearly any type of three-phase alternator can be paralleled without this harmonic problem.

*4) Voltage Sag*

The most common power quality problem is a voltage sag, but the ability of DG to help alleviate sags is very dependent on the type of generation technology and the interconnection location. DG is interconnected on the load side of the service transformer. During a voltage sag, DG might act to counter the sag. Large rotating machines can help support the voltage magnitudes and phase relationships. Although not a normal feature, it is conceivable to control an inverter to counteract voltage excursions The DG influence on sags at its own load bus is aided by the impedance of the service transformer, which provides some isolation from the source of the sag on the utility system. However, this impedance hinders the ability of the DG to provide any relief to other loads on the same feeder. DG larger than 1 MW will often be required to have its own service transformer. The point of common coupling with any load is the primary distribution system. Therefore, it is not likely that DG connected in this manner will have any impact on the voltage sag characteristic seen by other loads served from the feeder.

## III. CONTROLLER OVERVIEW

*2.1 Synchronous Reference Frame Control*

Synchronous reference frame control, also called *dq* control, uses a reference frame transformation module, e.g., $abc \rightarrow dq$, to transform the grid current and voltage waveforms into a reference frame that rotates synchronously with the grid voltage. By means of this, the control variables become dc values; thus, filtering and controlling can be easier achieved.

The *dq* control structure is normally associated with proportional–integral (PI) controllers since they have a satisfactory behavior when regulating dc variables. The matrix transfer function of the controller in *dq* coordinates can be written as

$$G_{PI}^{(dq)}(s) = \begin{bmatrix} K_p + \frac{K_i}{s} & 0 \\ 0 & K_p + \frac{K_i}{s} \end{bmatrix}$$

Where *Kp* is the proportional gain and *Ki* is the integral gain of the controller.

Since the controlled current has to be in phase with the grid voltage, the phase angle used by the $abc \rightarrow dq$ transformation module has to be extracted from the grid voltages. As a solution, filtering of the grid voltages and using arctangent function to extract the phase angle can be a possibility. In addition, the phase-locked loop (PLL) technique, became a state of the art in extracting the phase angle of the grid voltages in the case of distributed generation systems.

In several research studies, proportional-integral (PI) controllers are employed to control the AC side currents. PI current regulators ensure that a clean, in phase AC current feeds the grid.

The control equations for ud and uq are given as

$$u_d = e_d - \omega L i_q + \left(k_p + \frac{k_i}{s}\right)(I_d^* - I_d)$$
$$u_q = e_q + \omega L i_d + \left(k_p + \frac{k_i}{s}\right)(I_q^* - I_q)$$

2.2 Hysteresis Band Current Control

Control strategy aim is compensating the load reactive power, eliminating the load current harmonics, and compensating the neutral current while delivers the total harvested power from PV during: 1) Ppv =0 and 2) 0 < Ppv < Pload, where Pload is the load power demand. Amount of the injected power to the grid can be determined by the amplitude of the inverter output current. As mentioned before, dc link voltage variation is caused by the power that should be transferred from PV to the grid. Therefore, the output of dc link voltage regulator is the amplitude of the reference current ($I_{ref}$)' Grid currents should have the same phase as their corresponding voltages for the reactive power compensation. Multiplication of $I_{ref}$ by unit grid voltage vectors (Va, Vb and Vc) will result in the desired current references. In order to produce unit vectors, grid synchronous angle (ωt + θ) should be obtained from a phase locked loop (PLL).

A fixed-hysteresis band current controller scheme that is used to control the phase current of the grid interface V SC is shown in Fig.2.2. Fixed-hysteresis band has a hysteresis around the reference line current. The fixed- hysteresis decides the switching pattern of VSC.

Fixed-hysteresis logic can be formulated as below:

If $I_{inva} < (I_{inva,ref} - HB)$ the upper switch will be OFF ($g_1$= 0) and the lower switch will be ON ($g_4$= 1) for leg "a"($S_1$ =off and $S_4$=on).

If $I_{inva} > (I_{inva,ref} - HB)$ the upper switch will be ON ($g_1$=1) and the lower switch will be OFF ($g_4$= 0) for leg "a"($S_1$ =on and $S_4$=off).

Where HB is the fixed-hysteresis bandwidth; and $I_{inva}$ is the output current of leg "a" of inverter. For other three legs, switching patterns can be derived on the same principle.

Switching frequency that is produced by fixed hysteresis band depends on how fast the error current reaches the upper or lower limits. Switching frequency is related to the rate of change of the actual load current. Due to the time variable nature of the mentioned rate of changes the switching frequency cannot remain constant and changes during the fundamental time period.

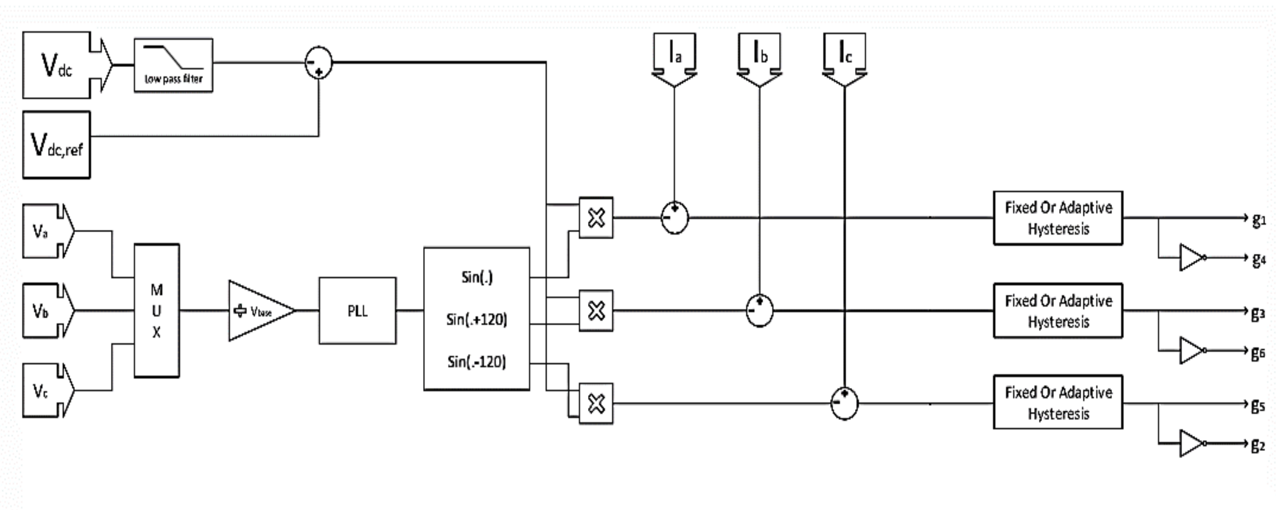


Figure III-1 Block diagram of the grid interface VSC controller

## IV. SIMULATION

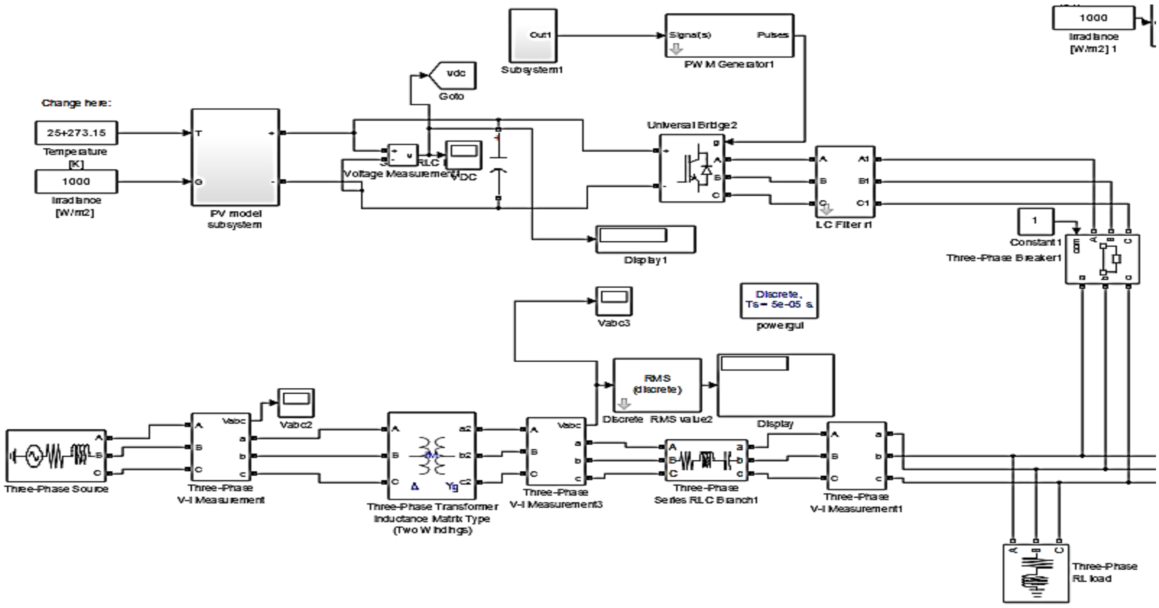


Figure IV-1 Inverter With d-q Control technique

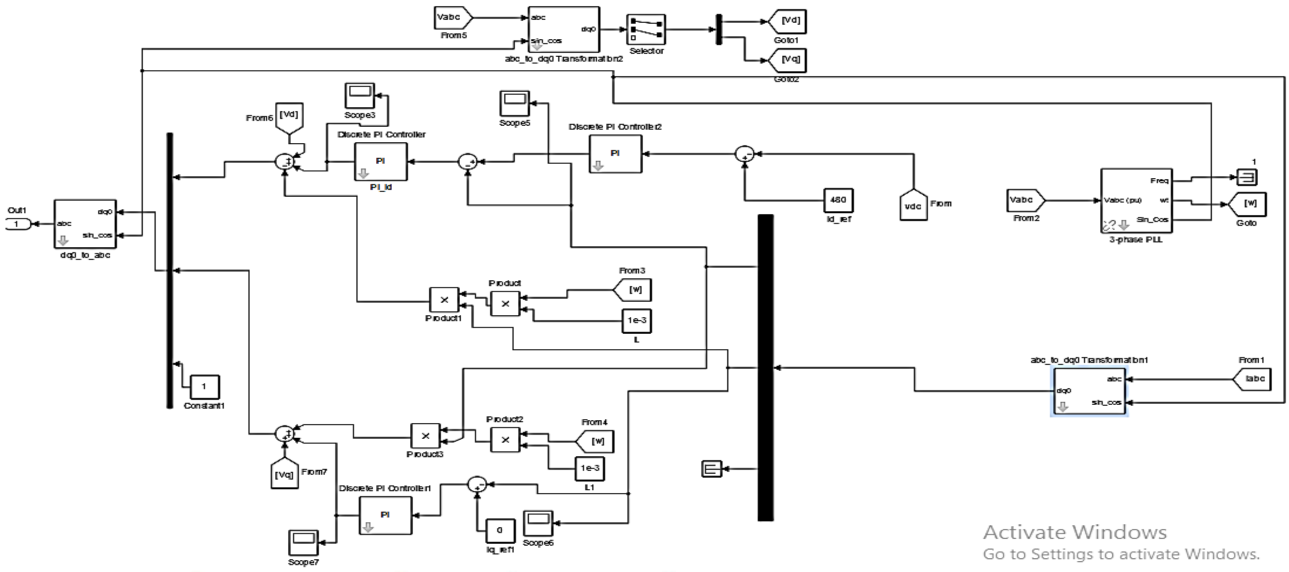


Figure IV-2 D-Q CONTROLLER

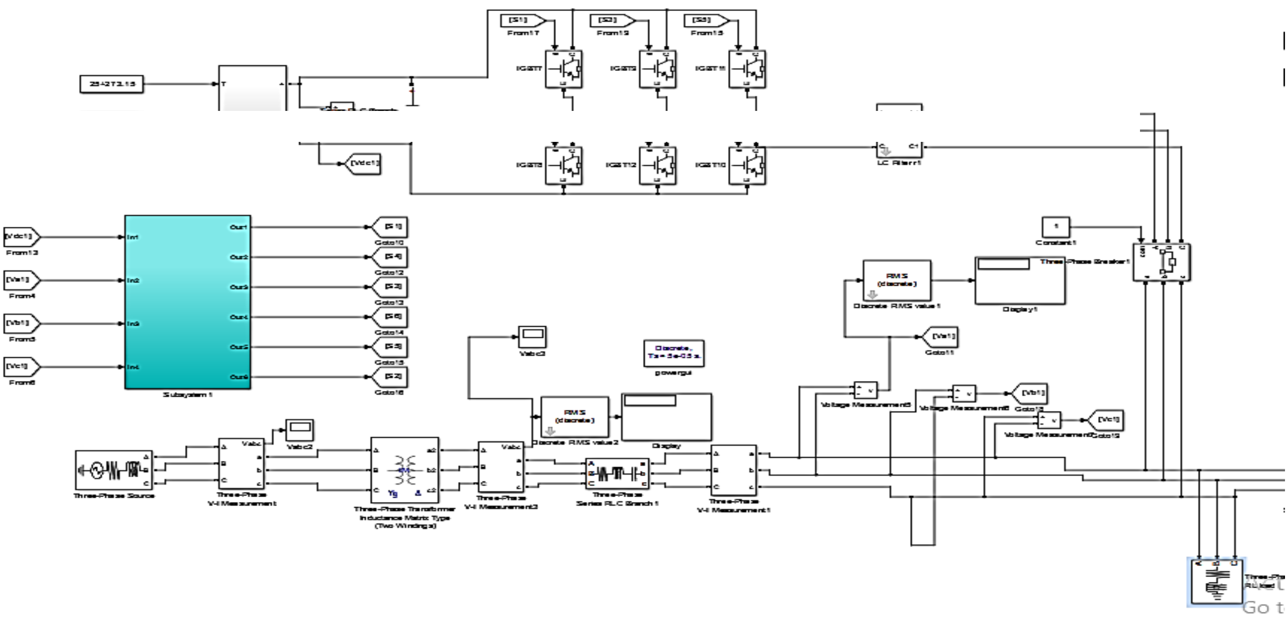


Figure IV-3 Inverter with Hysteresis Control technique

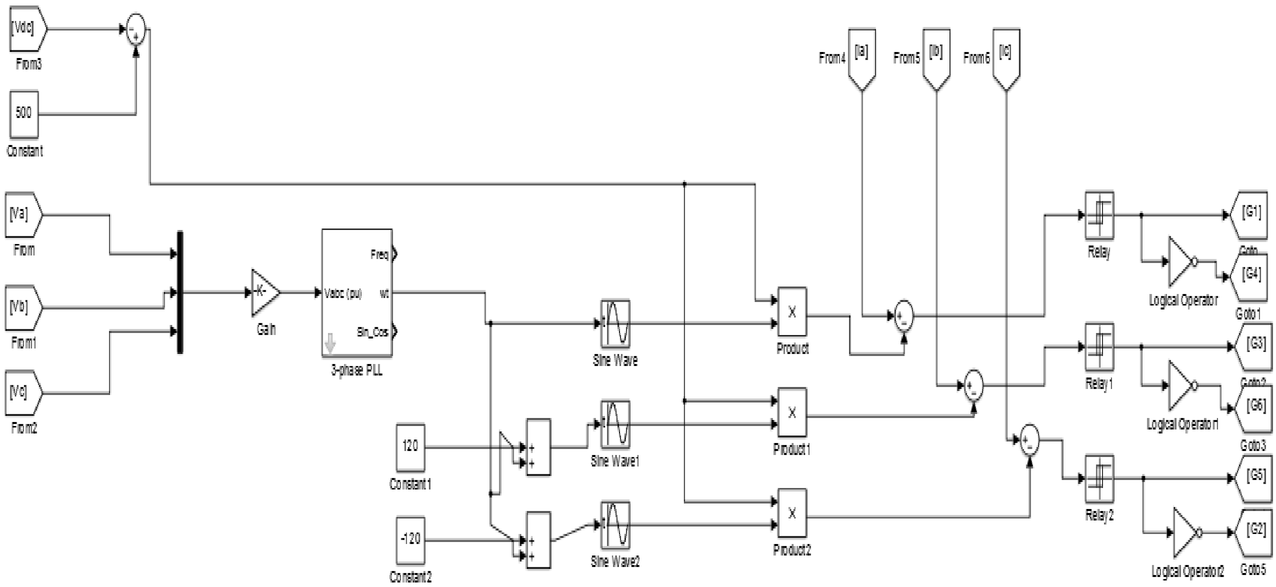


Figure IV-4 Hysteresis Controller

## V. RESULTS

| Simulation Without DG In Light Load Condition | | |
|---|---|---|
| | d-q controller | Hysteresis controller |
| Bus | Voltage | |
| V1 | 403 | 403 |
| V2 | 401 | 401 |

| Simulation With DG Connected In Light Load Condition | | |
|---|---|---|
| | d-q controller | Hysteresis controller |
| Bus | Voltage | |
| V1 | 422 | 417 |
| V2 | 427 | 415 |

| Simulation Without DG In Peak Load Condition | | |
|---|---|---|
| | d-q controller | Hysteresis controller |
| Bus | Voltage | |
| V1 | 387 | 387 |
| V2 | 379 | 379 |

| Simulation With 2 DG Connected In Peak Load Condition | | |
|---|---|---|
| | d-q controller | Hysteresis controller |
| Bus | Voltage | |
| V1 | 405 | 413 |
| V2 | 404 | 415 |

*4.4 Waveforms*

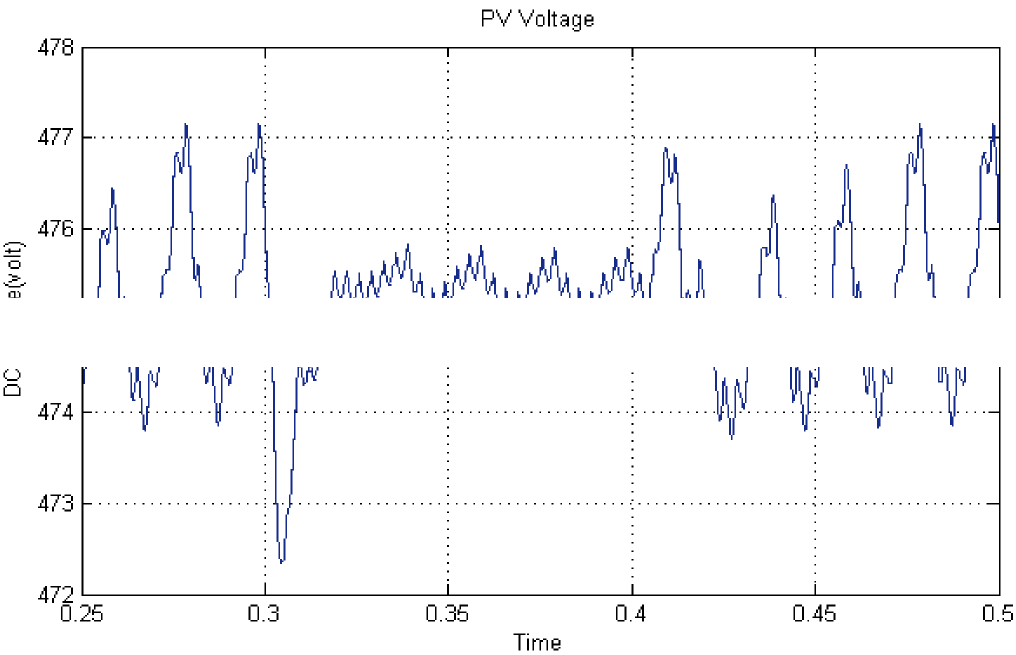


Figure V-1PV voltage

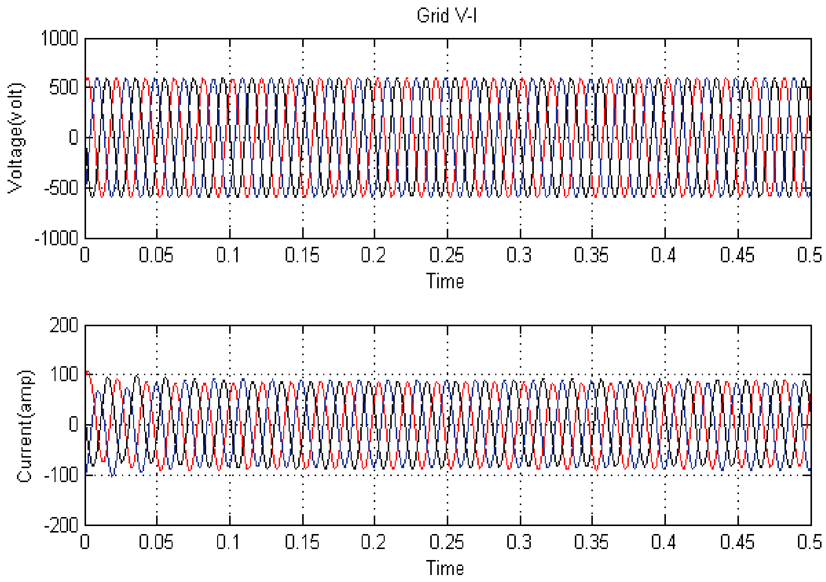


Figure V-2 d-q with Light Load

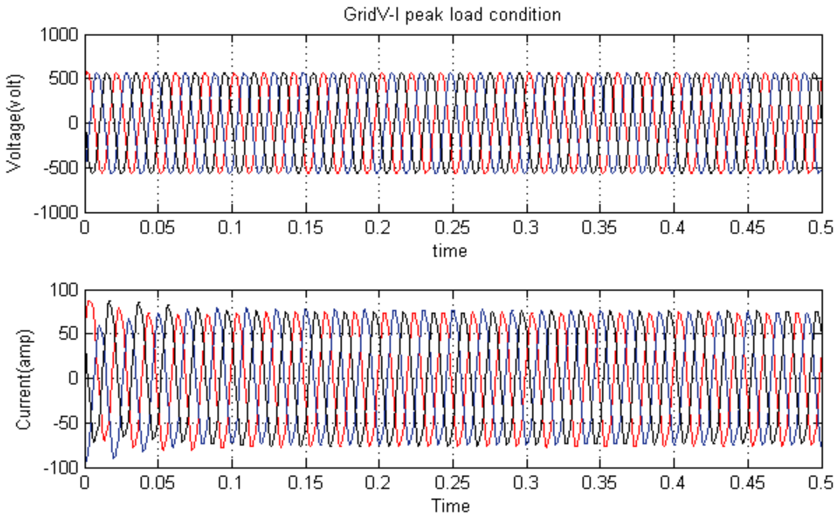


Figure V-3 dq with peak load

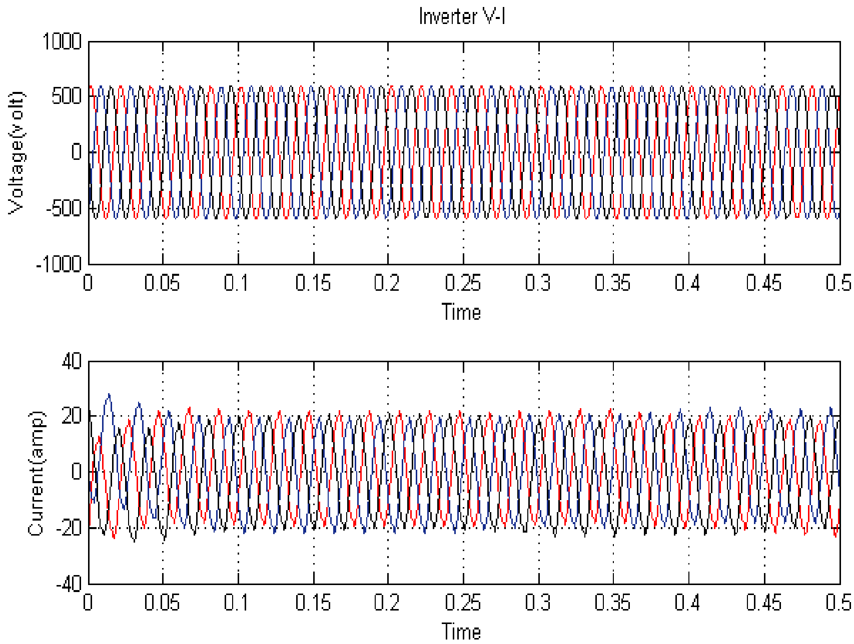


Figure V-4 inverter voltage current

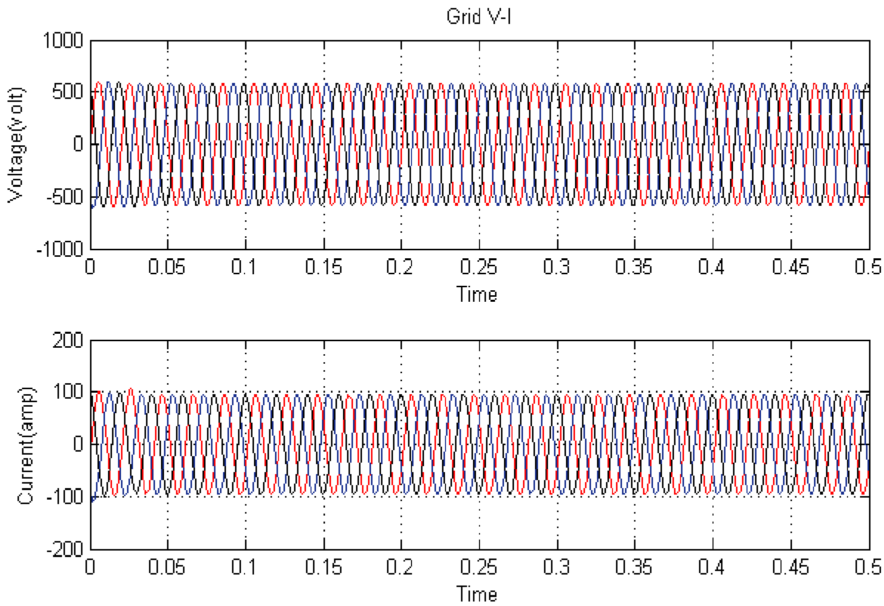


Figure V-5 Hysteresis with light Load

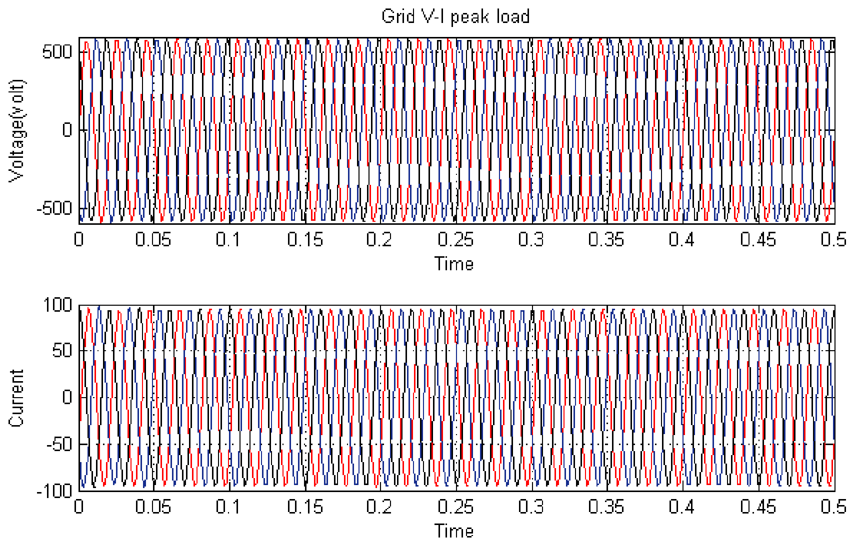


Figure V-6 Hysteresis with peak Load

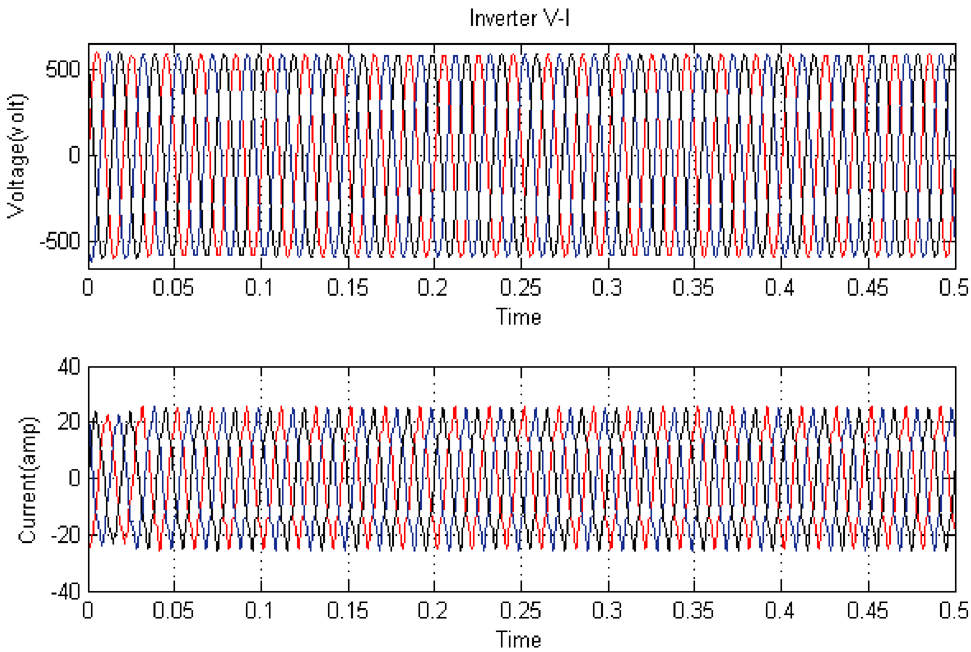


Figure V-7 inverter voltage current

## VI. CONCLUSION

Two inverter control technique were used to control voltage profile in prescribed limit 1) Synchronous reference frame 2) Hysteresis current control. After using both technique it was observed that hysteresis current control was better in terms of voltage level in peak load condition and SRF method better in peak load as well as in light load condition.

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