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A Simplified Active-Reactive Power Control of Distributed Energy Resource Integration with Distribution Grid

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Abstract: Power system load demand is been increasing every day. If generation doesn't meet the required load demand, power system becomes un-stabilized. There is a need for increased generation capacity to meet up with required load demand. Use of fossil fuels for power generation creates green house problems, high cost and also extinction of fossil fuels is a concern for future generation. Distributed energy resources are a good preference over conventional fossil fuels which can be easily extracted from the environment free of cost. This paper explains the photo-voltaic system integration to grid through voltage source converter for active power injection keeping reactive power as null value. Voltage source converter is controlled by using a proposed simplified PQ control theory in this paper. Simulation work was carried out considering two cases for fixed active power injection and variable active power injection; results were obtained using MATLAB/SIMULINK software.

Keywords: Active power, load demand, generation, fossil fuels, distributed energy resource (DER).

1. INTRODUCTION

Electrical energy is been the key for growth in technology. It is one of the important needs in our daily schedule. Use of electrical energy in rural areas was later after independence in India. But now the situation is changing drastically where electricity is important factor in daily life. This increase in load demands additional power generation. Generally power is produced in bulk from conventional power generating stations where fossil fuels like coal, gas, nuclear energy are used. Use of fossil fuels increase the running cost of power generation as fossil fuels are high in cost [1-3]. Fossil fuels are in extinction these days and might not be available in mere future. Power generation using fossil fuel emits more pollution and is a concern globally and thus makes power researchers to think of alternative source of energy from which electrical energy can be produced. This makes a way for use of renewable energy resources as alternative energy source for power generation [4].

Renewable energy is freely available from the environment of no cost. Power generation from renewable energy source doesn't emit any green house gases making generation eco-friendly. With renewable energy source, power generation can be made at the load centre locally since they occupy very less space. Renewable energy sources like photo-voltaic (PV) systems, wind and fuel-cells are commonly used resources to produce electricity [5-6]. A PV cell is widely used of all available resources and is termed as distributed energy resource (DER). Excessive reactive drop in wind energy system and use of hydrogen in fuel-cell system makes them to review over PV cell system.

Distributed energy resource can be broadly classified in to two categories based on their connection to the system as grid connected system and standalone system. If the generated active power from the

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DER is fed to grid, it is termed as grid connected DER system and if the power generated from the DER is not fed to the grid system is termed as standalone system [7-9]. Grid connected system can feed active power and can also stabilize the system during peak load hours. Standalone system can also be called as islanded mode. Power generated from the standalone DER can individually feed local loads without grid support.

Grid connected system requires converters for its operation and many control strategies were proposed by researchers to control the DER converters [10-17]. A simplified active-reactive power control algorithm was proposed in this paper for the control of DER converter. The proposed control was tested for systems considering two conditions, one is the system with fixed active power injection from the DER and the other is variable active power injection from DER. Comparative analysis between the conventional PQ theory and the proposed simplified PQ theory was not presented but the proposed control strategy was very simple in construction eliminating the use of some components used for the extraction of power elements which are present in conventional PQ theory. Models were developed and results were obtained for the two conditions with proposed control strategy using MATLAB/SIMULINK software. Typical DER configuration systems and its classification were explained in subsequent section of this paper. DER integration with distribution system and proposed simplified active-reactive power control algorithm was detailed in next sections. Proposed active-reactive power control for DER integration was also detailed in coming sections of this paper.

2. TYPICAL DISTRIBUTED ENERGY RESOURCE (DER) CONFIGURATIONS

Distributed energy resources are small renewable energy source which can deliver electrical power to grid to stabilize power system. To meet the increasing load demands, DERs are a viable solution injecting active power in to the distribution system.

2.1. Grid Connected DER System

PV system is considered to be DER in this paper. Output of a PV cell will be low voltage DC. This obtained low voltage output needs to be stepped up to required voltage. For stepping up low voltage DC to high voltage DC, a DC-DC converter is needed. Boost converter which is simple is employed in this paper to step up low voltage DC to high voltage DC. The system to be connected to grid, boosted DC should be inverted to AC using an inverter and the inverted output is fed to grid through interfacing inductors. Typical grid connected DER system was shown in Figure 1. Active power is been injected to grid from PV system and this system can be handy to stabilize the grid during peak hours. Keeping reactive power zero, active power is injected in this paper.

2.2. Standalone DER System

Standalone DER system was shown in Figure 2. The only difference between grid connected system and standalone system was that the output of grid connected DER was fed to grid whereas the output of standalone DER was fed directly to AC load, without support from grid. PV system output was fed to boost converter to step-up low voltage DC output to required level of voltage. This was fed to inverter circuit to invert DC to AC. Obtained AC feeds three phase load directly. This is very much useful in remote locations and where grid connection was not available. Also since the system works independent of grid, stability is not at all related to this system.

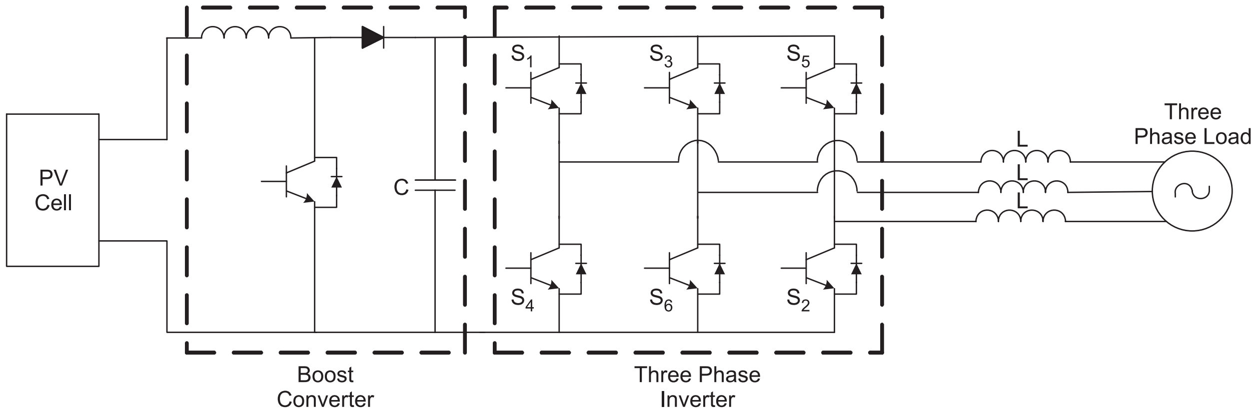

Figure 1: Grid connected DER system

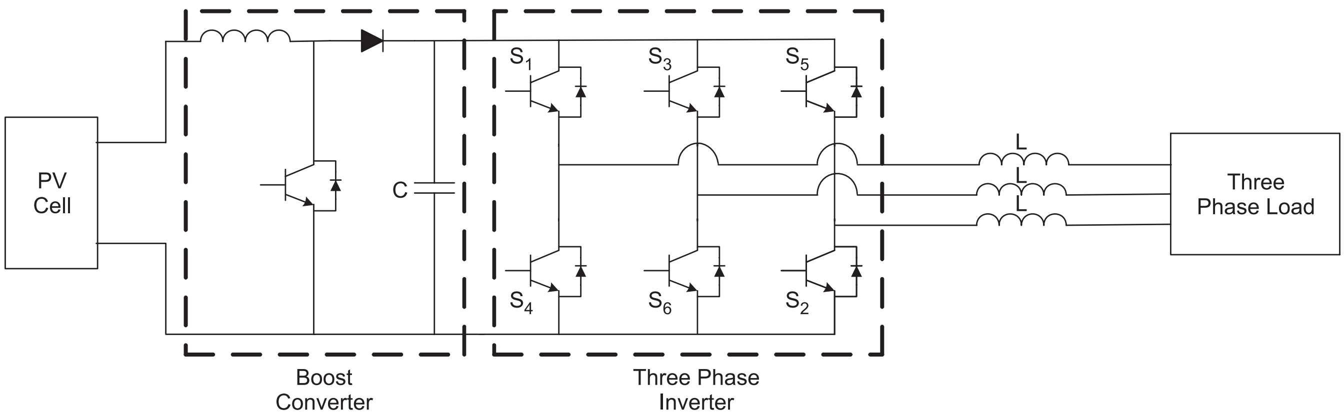

Figure 2: Standalone DER system

3. INTEGRATION OF DER WITH DISTRIBUTION SYSTEM

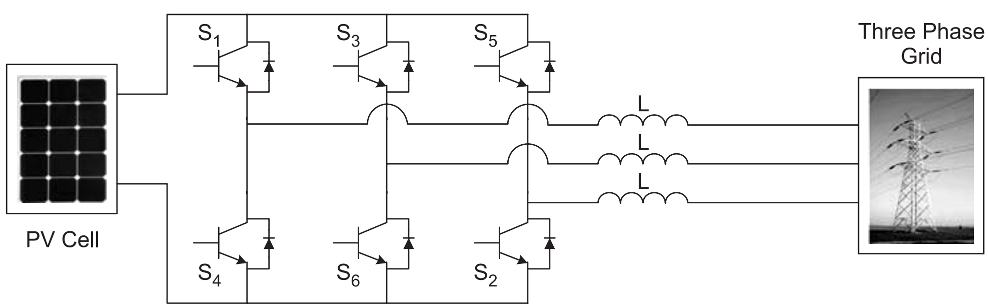

Figure 3: Integration of DER to distribution system

Integration of distributed energy resource to power distribution system was shown in Figure 3. The output of a PV system will be typically a DC type and is fed to inverter circuit. Inverter converts DC to AC and the obtained AC is fed to the power distribution system via interfacing inductors. Typically an integrating converter which converts DC to AC acts as a voltage source converter (VSC) which consists of static switches. Active power is been fed to grid via interfacing converter while reactive power is set to zero from DER. This fed active power can be used to meet load demand and also due to presence of DER, active power from main source produced from conventional generation can be cut down to some extent reducing running cost and pollution.

4. SIMPLIFIED ACTIVE-REACTIVE POWER CONTROL ALGORITHM

The proposed control strategy was very simple in construction eliminating the use of some components used for the extraction of power elements which are present in conventional PQ theory. The proposed simple active-reactive power control theory was shown in Figure 4. Information regarding sine and cosine wave are obtained by sensing grid voltage and giving to PLL. Initially the actual values of active power and reactive power were sensed from the system. Active power is then compared with reference active power and error signal was fed to PI controller obtaining direct component of current. Similarly, actual reactive power was compared to reference reactive component and error obtained is fed to PI controller to obtain quadrature component of current. Both direct and quadrature components of current were combined keeping zero sequence current set to zero. The combined signal was sent to dq-abc transformation along with the sine wave and cosine wave information obtained from PLL thus obtaining reference three phase current. This reference current is compared with actual value of current obtaining gate pulses when passed through PWM generator. Integration of DER to grid using proposed active-reactive control is shown in Figure 5.

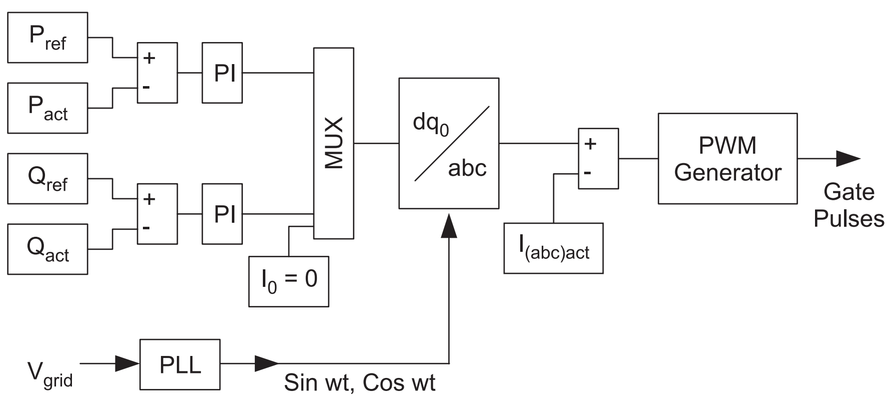

Figure 4: Proposed active-reactive control

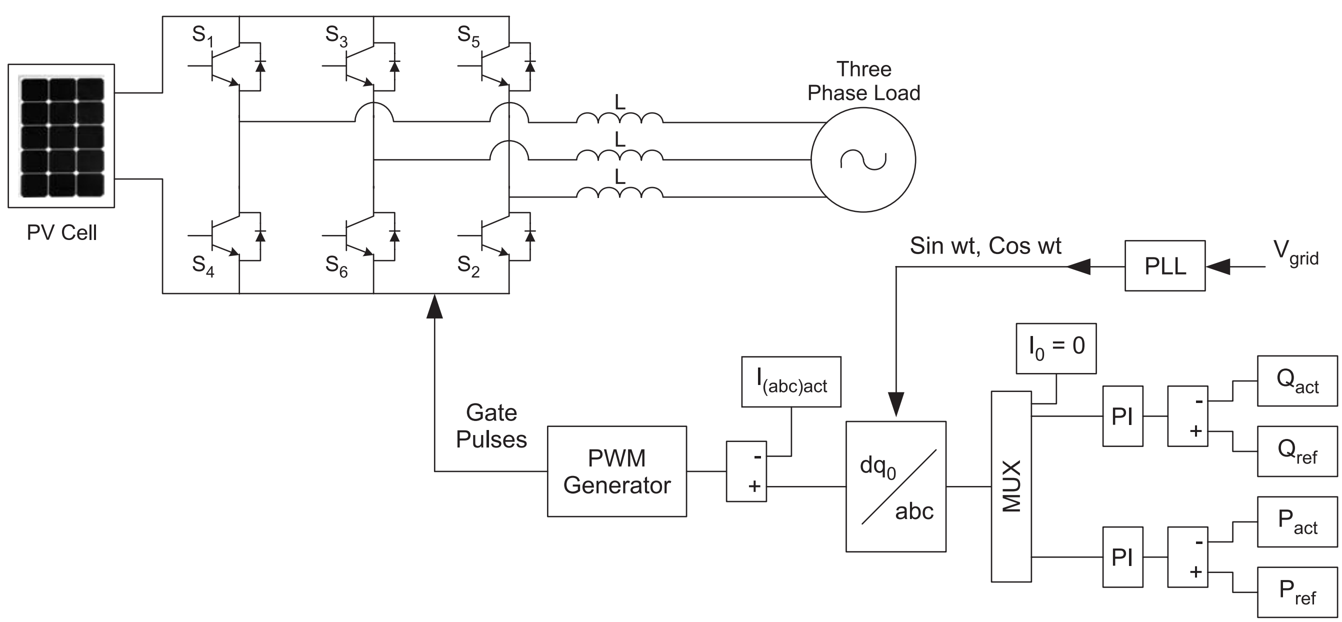

Figure 5: Integration of DER to grid using proposed active-reactive control

5. MATLAB/SIMULINK RESULTS AND DISCUSSIONS

Table 1
Simulation Parameters

Parameter	*Value*
Phase-Phase grid voltage	440 V RMS
Active Power	2 KW
Interfacing inductor	7.5 mH
DC link voltage	800 V

Case 1: ***Grid connected DER system injecting fixed active power***

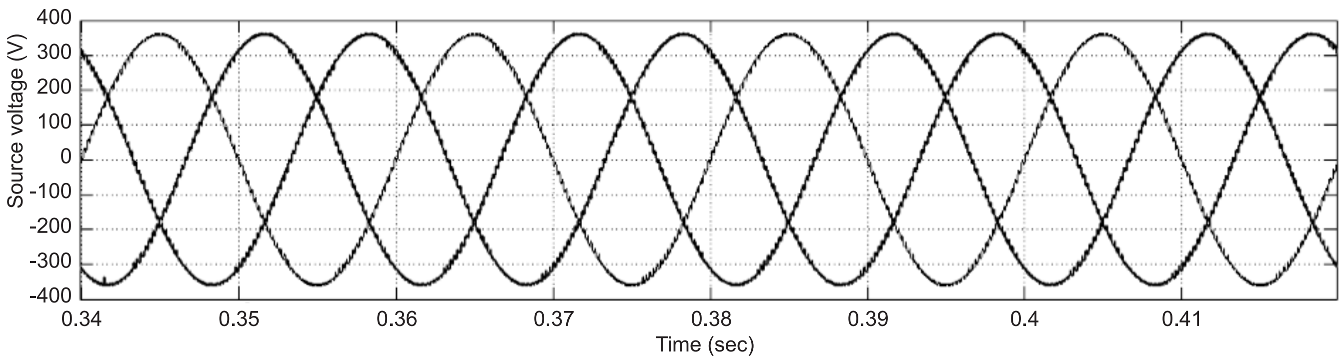

Figure 6: Three phase source voltages of grid connected DER system

Table 1 shows the system parameters used to model the grid connected DER system. Figure 6 shows the three phase source voltage of grid connected DER system which shows all three phases are balanced having amplitude of 360 V.

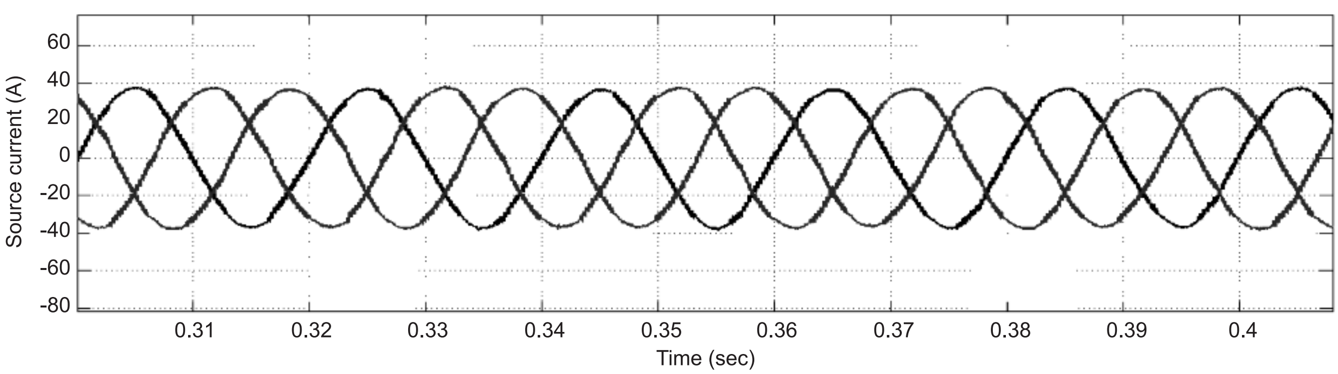

Figure 7: Three phase source currents of grid connected DER system

Figure 7 represents three phase source currents in grid connected DER system. All three phases are balanced and have amplitude of 40 A. All the three phases have the same amplitude and frequency.

Figure 8 shows the power factor angle between source voltage and source current in three phases of grid connected DER system. In all the three phases shown, source voltage and current waveforms does not have phase difference between them indicating power factor is maintained nearer to unity.

Figure 9 shows three phase outputs of inverter from which active power is transferred to grid. Output shown is waveform obtained before filter. Three level output is obtained before filter and active power is injected to grid.

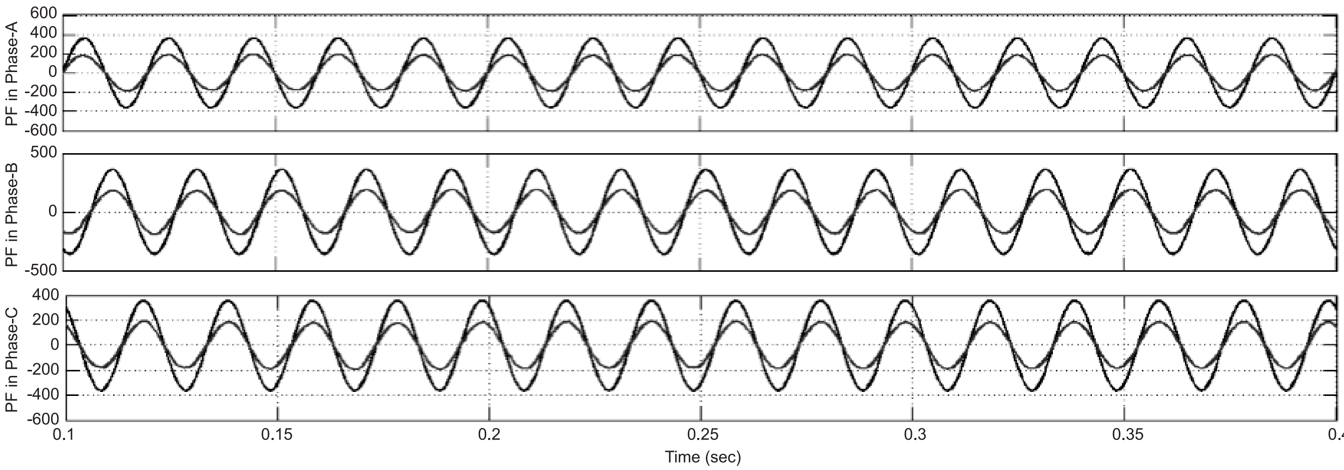

Figure 8: Power factor angle between source voltage and current in three phases of grid connected DER system

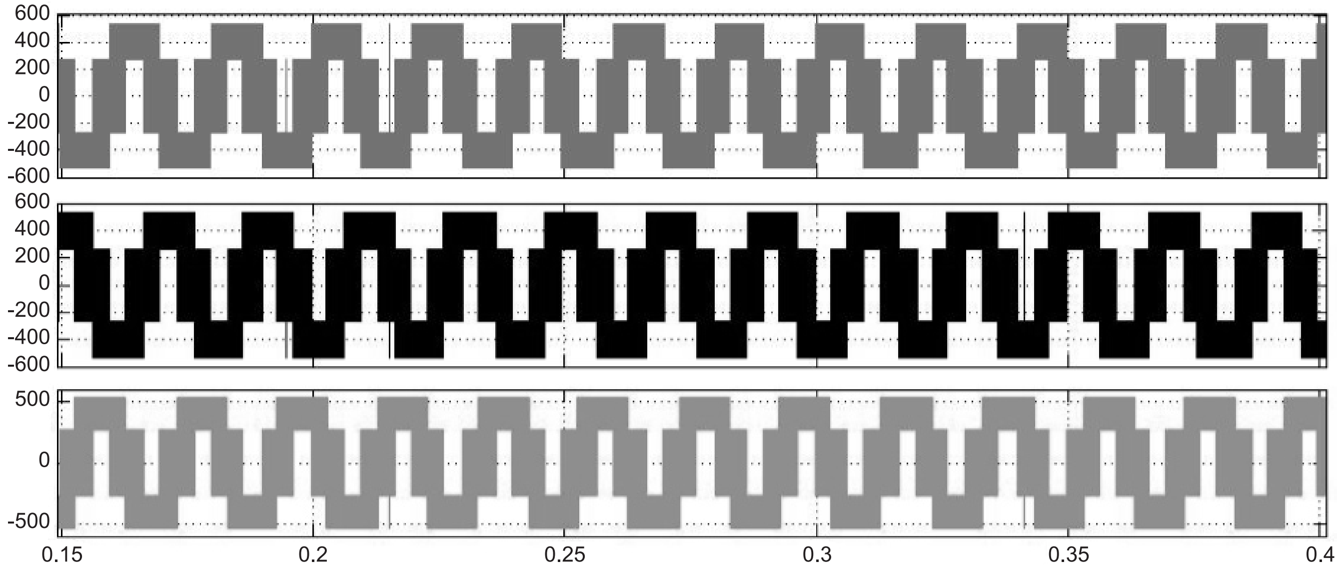

Figure 9: Outputs in three phases of inverter integrating grid to DER system before filter

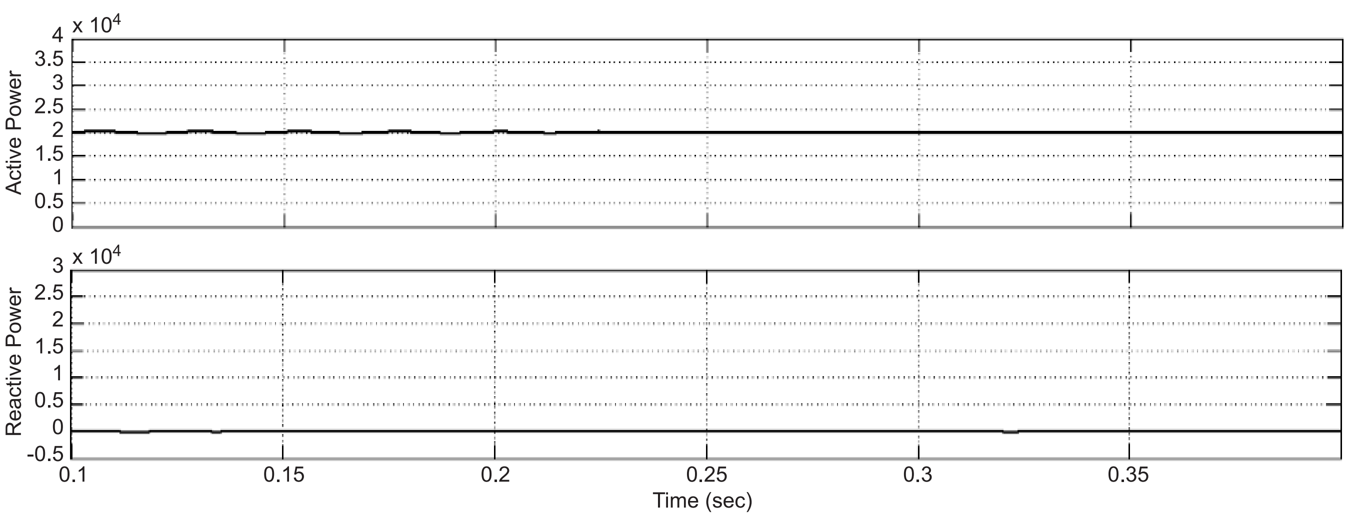

Figure 10: Active and reactive power of DER system injected to grid

The active and reactive power injected to grid from DER system through inverter is shown in Figure 10. Active power is maintained at 20KW constant and reactive power is maintained at zero indicating no reactive power consumption. Active power is maintained at constant value since fixed active power is been fed to distribution system from DER.

Case 2: ***Grid connected DER system injecting variable active power***

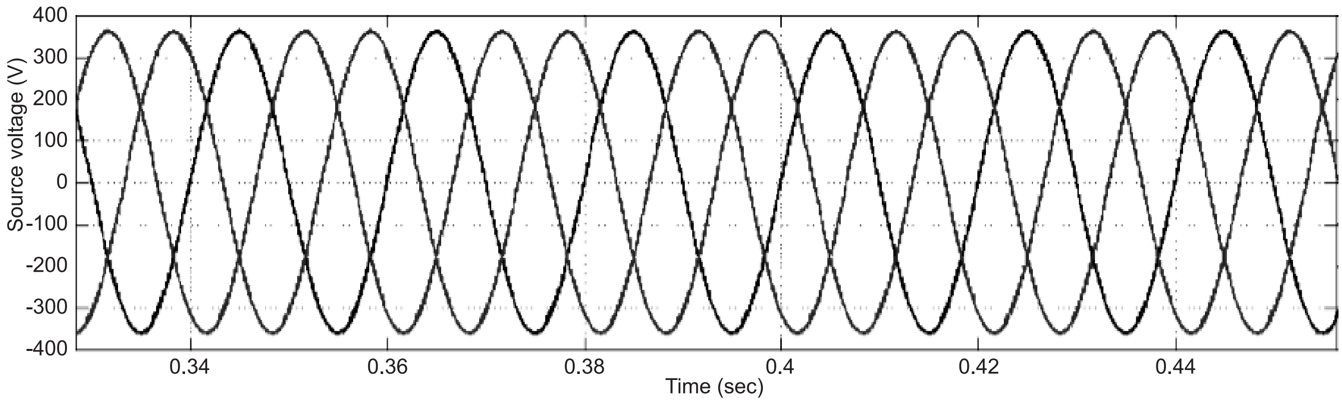

Figure 11: Three phase source voltage of grid connected DER system injecting variable active power

Three phase source voltage of grid connected DER system injecting variable active power from DER is shown in Figure 11. Even though the active power fed from DER to grid is varaible, the source voltage in all the three phases of grid are maintained constant at 360 V.

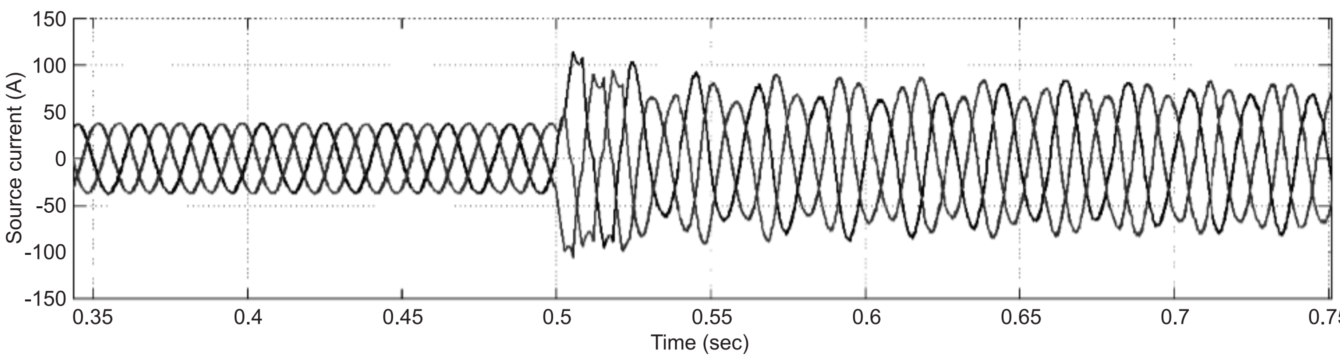

Figure 12: Three phase source current of grid connected DER system feeding variable active power

Three phase source currents in grid connected DER system was shown in Figure 12. In this case variable active power is fed to grid from DER system. Variable active power is fed to grid from the instant 0.5 sec. Before 0.5 sec, three phase source currents are maintained at 40 A constant in all the three phases and after 0.5 sec currents are varied since variable active power is fed to grid from DER.

Figure 13 shows the power factor angle in three phases of the distribution system and both source voltage and current waveforms does not have phase difference between them indicating power factor is maintained nearer to unity. Since variable active power is fed to distribution system from instant 0.5 sec, there is a slight distortion in current at 0.5 sec. But after 0.5 sec, no phase angle difference was observed indicating power factor is nearer to unity even when variable active power is fed to distribution system from DER.

Figure 14 shows the three phase output of the inverter before filter. Three level output is obtained from output of inverter before filter. Active power from DER is fed to distribution system through inverter and output in three phases was shown.

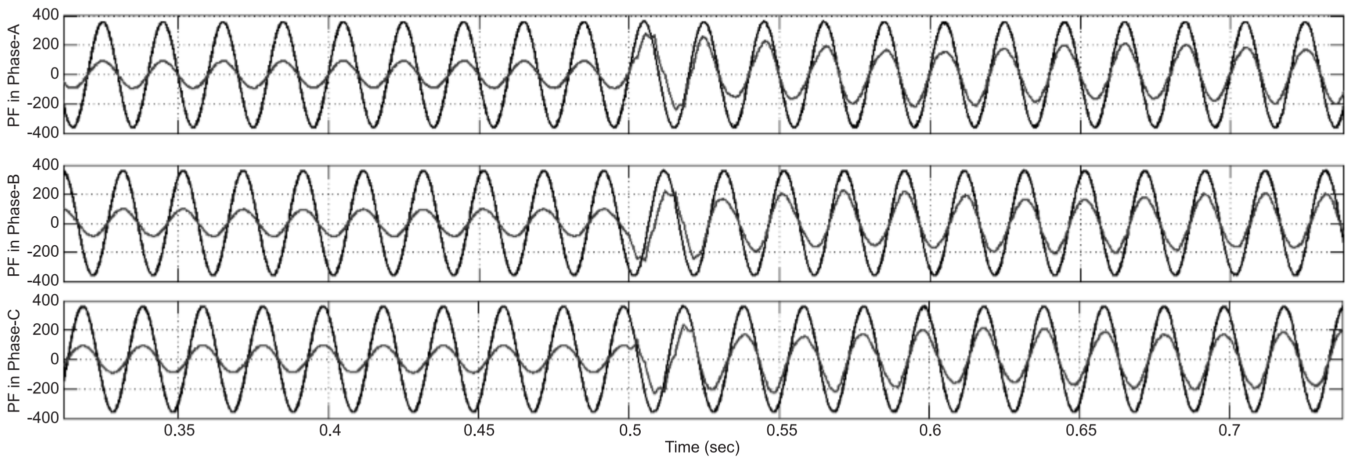

Figure 13: Power factor angle in three phases of distribution system

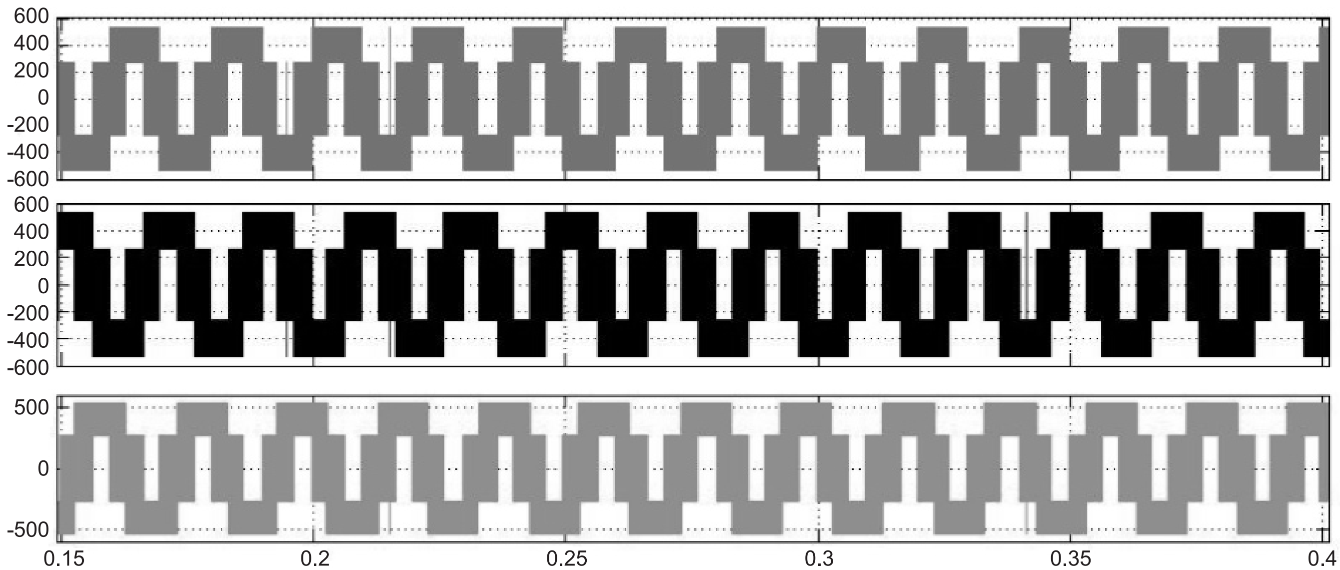

Figure 14: Three phase output of inverter before filter

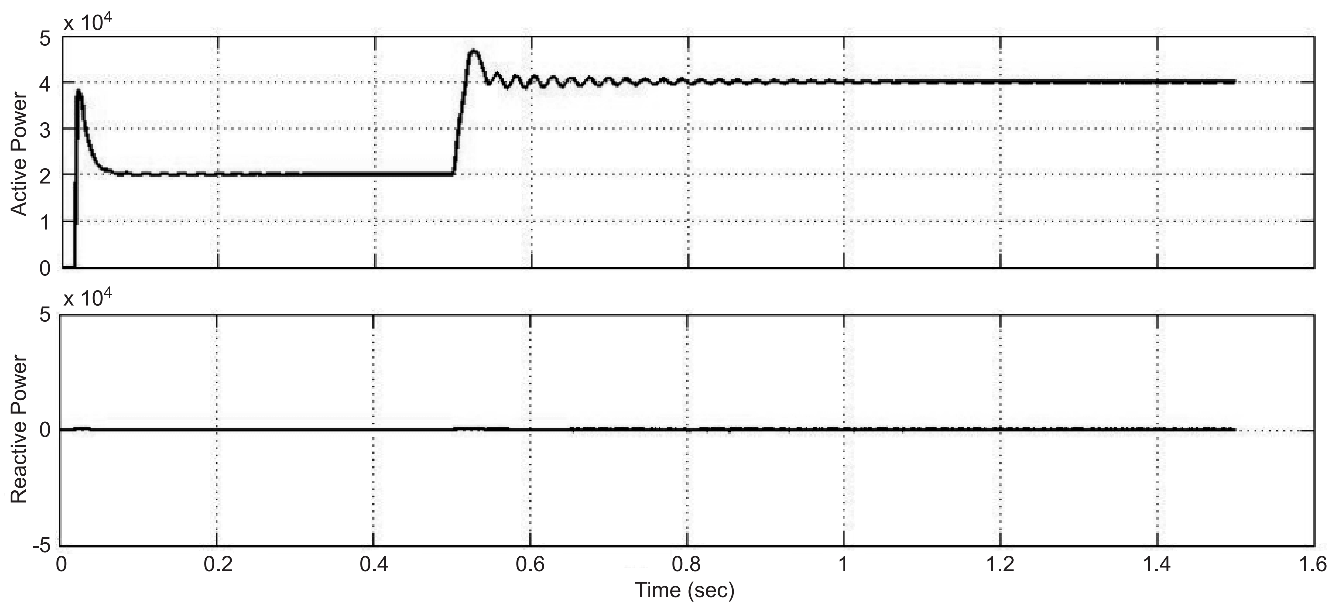

Figure 15: Active and reactive power injected to distribution system from DER

The active and reactive power in distribution system fed from DER is shown in Figure 15. Variable active power is fed to distribution system, in this case up to 0.5 sec, constant active power of 20KW is fed and from 0.5 sec active power of 40KW is fed to distribution system and reactive power is maintained at zero indicating no reactive power consumption.

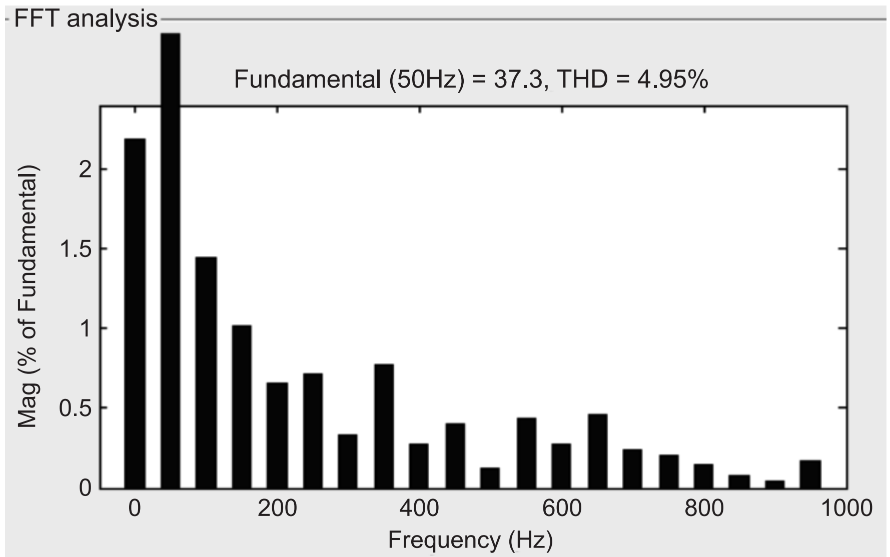

Figure 16: Total harmonic distortion in source current of system

Figure 16 shows total harmonic distortion of 4.9% in source current within acceptable limit. Though the variable active power is fed from DER to distribution system, total harmonic distortion is not large in source current and well maintained within 5%.

6. CONCLUSION

Use of fossil fuels for power generation increases the running cost of generation also increasing pollution. Renewable energy sources are viable to produce electrical energy with less running cost and pollution free. Distributed energy resource like PV system can inject active power to power distribution system to meet the ever growing load demand. Typical DER configurations and integration of DER to distribution system were explained in this paper. This paper depicts the distributed energy resource integration to distribution system to inject active power needed to meet load demand. DER is integrated with a voltage source converter consisting of switches. Static devices in voltage source converter are controlled using a simplified active-reactive control theory which was explained in detail. This simplified control theory was stated for injecting fixed active power and variable active power and was found suitable for integration to distribution system. With the said control strategy harmonics in source current were also reduced and maintained within nominal limits. Comparative analysis between the conventional PQ theory and the proposed simplified PQ theory was not presented but the proposed control strategy was very simple in construction eliminating the use of some components used for the extraction of power elements which are present in conventional PQ theory

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