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Reactive Power based Droop Control System using Photovoltaic Power System in AC Microgrid

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ABSTRACT

Battery Banks are important part of any independent microgrid system, which intakes majority of energy from renewable resources. The efficiency of system becomes dependent on the battery performance. To estimate battery life and performance, it is important to regulate State of Charge (SoC) of the battery. This parameter is used by system controllers to develop applications to improvise microgrid operations. In this report, a control system is designed for improving the droop control in distributed energy storage units in AC microgrids. The controlling is based on State of Charge measurement. The conventional Active Power -Frequency (P-f) Droop Control method is implemented in conjunction with State-of-Charge of battery unit. By using a SoC-based droop method, the ESUs with higher SoC deliver more power, whereas the ones with lower SoC deliver less power. The effectiveness of the system is simulated and validated.

Keywords- Energy Storage Units (ESU), Distributed Generators (DGs), State of Charge (SoC), Droop Control, Distributed Energy Storage Devices (DESUs), Microgrid (MG)

I. INTRODUCTION

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid -connected or “island” mode. [1] Microgrid based on renewable energy sources have experienced a fast development in recent years. Microgrids are commonly comprised of renewable energy sources, distributed energy storage units (DESUs), power-electronic interfaces, and electrically connected loads. [2] Microgrids can operate in parallel to the grid or as an island. It is usually connected to the main distribution system by the Point of Common Coupling (PCC). A Microgrid will disconnect automatically from the main distribution system and change to islanded operation when a fault occurs in the main grid or the power quality of the grid falls below a required standard and A Microgrid will reconnect to the grid once they are resolved [2]. The micro sources in a Microgrid are made of micro-turbine, fuel cell, photovoltaic (PV) arrays, wind turbine generator (WTG), energy storage devices (battery or high-speed flywheel). Most micro sources are interfaced through power electronic converters as the sources produce either DC (e.g. photo-voltaic or fuel cells) or variable frequency AC (e.g. micro-turbines, wind turbines). [3] The static transfer switch (STS) determines the operation modes of micro-grids, i.e., grid-connected mode or autonomous islanded mode, and benefits both the utility and the customers regarding to efficiency, reliability, and power quality.

II. DISTRIBUTED ENERGY STORAGE

Energy storage system can be categorized by storing form of energy into five groups: mechanical, electrochemical, chemical, electrical, and thermal storage. Different energy storage transforms different forms of energy to electricity and vice versa. There are two function modes of energy storage. It is in "charge" mode when electrical energy from power system is converted in other forms and stored in energy storage. On the contrary, when energy is transformed to electrical energy in order to inject to the system, it then is in "discharge" mode. [4] Pumped Hydroelectric Energy System (PHES) such as high efficiency (70-85%), very long life time, long storage period, practically unlimited cycle stability of the installation, and relatively low capital cost per unit of energy generated. Compressed energy storage systems have high efficiency around 70-89%, however, it is dependent on fossil fuel. It has to be connected to gas turbine plant. Chemical energy storage is performed by batteries like Lead acid battery (Pb-acid), Nickel cadmium battery (NiCd), Nickel metal battery (NiMH), Lithium ion battery (Li-ion), Sodium sulphur battery (NaS), Metal air battery (Me-air), and Sodium nickel chloride battery (NaNiCl). [5]

Distributed energy storage units (DESUs) such as batteries, super-capacitors, and flywheels are very important for renewable-energy-based microgrids since they can cope with the power fluctuations caused by the intermittent and stochastic character of Renewable energy sources (RES). Furthermore, the application of DESUs is also indispensable to improve the power quality and satisfy various demand side management function such as valley filling, peak shaving, black-start, voltage support.

III. STATE-OF-CHARGE ESTIMATION

The SOC of a battery is defined as the ratio of its current capacity to the nominal capacity. The nominal capacity is given by the manufacturer and represents the maximum amount of charge that can be stored in the battery. The various mathematical methods of estimation are:

- Direct measurement: this method uses physical battery properties, such as the voltage and impedance of the battery.
- Book-keeping estimation: this method uses discharging current as the input and integrates the discharging current over time to calculate the SOC.
- Adaptive systems: the adaptive systems are self-designing and can automatically adjust the SOC for different discharging conditions. Various new adaptive systems for SOC estimation have been developed.
- Hybrid methods: the hybrid models benefit from the advantages of each SOC estimation method and allow a globally optimal estimation performance. It produces good estimation of SOC, compared to individual methods. [9]

Accurate estimation of SOC cannot only protect battery, prevent overcharge or discharge, and improve the battery life, but also let the application make rationally control strategies to achieve the purpose of saving energy.

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IV. DROOP CONTROL SYSTEM

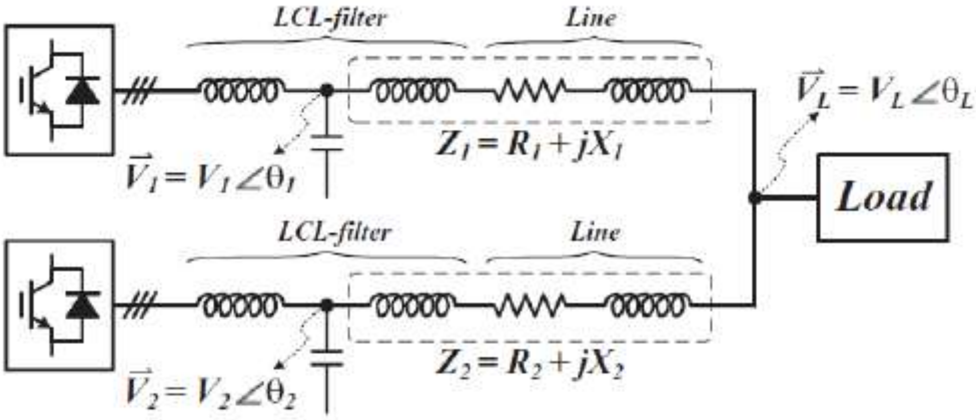

Fig 2 – AC Microgrid with 2 Inverter Inputs

The main goals to ensure stable and efficient operation are frequency and voltage regulation, power control, synchronization, management of energy flow, and economic optimization. When in islanded mode, droop control is adopted. Based on the relationship between active power and frequency, reactive power and voltage, inverters can control the output to realize proper power sharing. [6] The Energy storage devices provides the power required for achieving the power balance in the islanded MG and thus the power is equal to the difference between the total power generated by the Distributed Generators (DGs) and the total power demand. Conventionally, the absorbed and injected power of the storage device is positive when operated in discharging mode and negative in charging mode. Because of the lack of inertia in MGs, the droop control method used depends on whether the line impedance is resistive or inductive. [7]

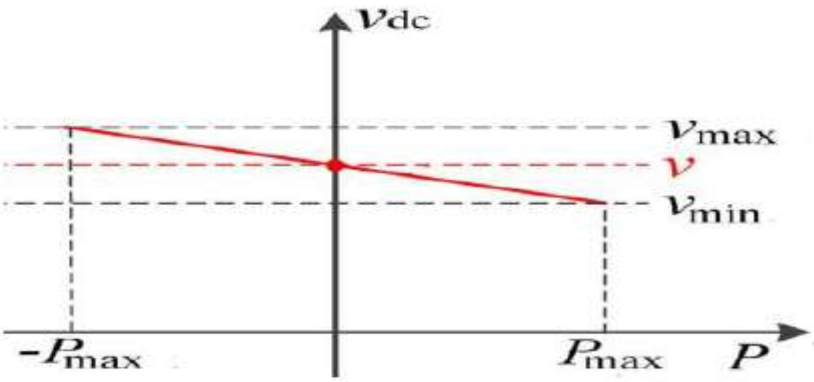

Fig 3 - Droop in System Voltage profile

Droop control is based on the frequency and voltage deviation to realize the power sharing strategy. But this kind of deviation could have an impact on the stability of microgrids. Factually droop control strategy is usually unstable due to the power coupling; consequently its sharing is inaccurate.

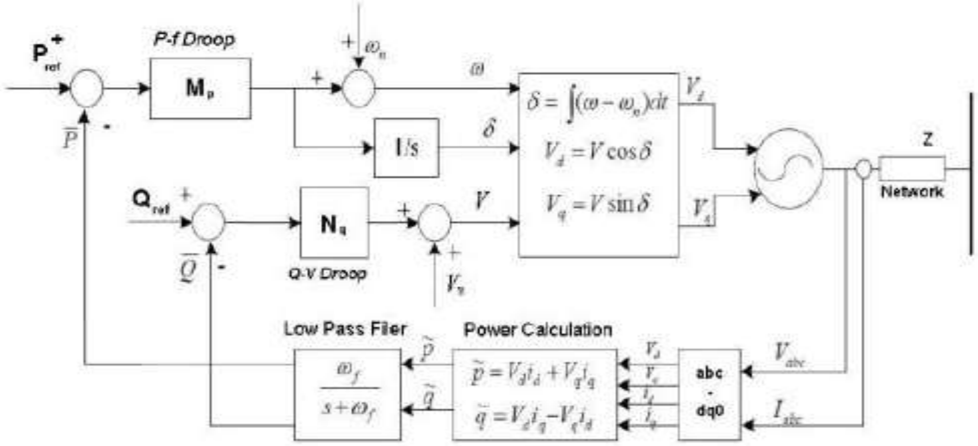

Fig 4- P-f & Q-V Droop Control

Droop method consists of subtracting proportional parts of the output average active and reactive powers to the frequency and amplitude of each module to emulate virtual inertias. These control loops, also called P-f & Q-V droops, have been applied to avoid mutual control wires while obtaining good power sharing. However, the droop method has also several drawbacks. For example, it is load-dependent frequency deviation and it is possible to induce system frequency unstable; it is not suitable when the paralleled-system must share nonlinear loads; and the power sharing is affected by the output impedance of the units and the line impedances. [8]

IV. REACTIVE POWER SHARING CONTROL

Load power sharing is one of the significant aspects in the development of autonomous micro-grids. However, since the reactive power of each inverter depends on the voltage amplitudes due to the Q-V droop, the reactive power sharing between the inverters becomes undesirable. The output active power of the inverter with conventional droop method is regulated by the historical information of active power.

$$P = \frac{V_{PCC}\int_0^t (\omega_0 - D_P P)dt}{x} \quad (1)$$

The conventional Q-V droop method reduces the voltage proportionally to the current value of reactive power instead of the historical information of it which results in,

$$Q = \frac{V_{PCC}(E_0 - V_{PCC})}{X + V_{PCC}D_Q} \quad (2)$$

The output reactive power is totally determined by the immediate voltage and line impedances instead of the historical information of the reactive power. Once the steady state is reached, different inverters will operate at different positions on the voltage droop curve, resulting in the unshared reactive powers.

Imitating the power flow of conventional P-f droop control, the historical information of reactive power is injected into the Q-V droop method artificially, being called the ∫Qdt-V droop control, as can be seen in, where Et is the magnitude of the output voltage reference at t and KQ is the coefficient of the ∫Qdt-V droop control.

$$Et = E0 - KQ \int Qdtt0 \quad (3)$$

The reference voltage magnitude carries the information of the reactive power and determines the output voltage magnitude to achieve reactive power sharing. More specifically, with the ∫Qdt-V droop method the voltages of energy delivery systems delivering more reactive powers will decrease more than the others.

In the grid-connected mode, the voltage of the microgrid is dominated by the main grid due to the large capacity of the utility grid. Hence, the main task of the microgrid in this mode is to deliver the scheduled power. In the islanded mode, it is necessary to not only dispatch the real and reactive power among the inverters but also maintain the voltage magnitude to a certain allowable range, i.e., ±5%. In autonomous micro-grids, one of the main tasks of the DESUs is to keep the voltage magnitudes in the allowable range.

V. SOC BASED DROOP CONTROL

The parallel operation characteristic of synchronous generators, the frequency and voltage droop control is employed for active and reactive power regulation, which is expressed as:

$$\omega = \omega_0 - D_P P \qquad (4)$$

$$E = E_0 - D_Q Q \qquad (5)$$

where ω and E are the angular frequency and the magnitude of the output voltage reference, respectively; ω0 and E_0 are the angular frequency and the magnitude of the output voltage at no load, respectively; P and Q are the average value of active power pout and reactive power qout of inverters, respectively; D_P and D_Q are the slope of droop characteristics. The droop method in microgrids is based on the power flow between two nodes across the line impedance.

$$P = V_{pcc} E \, \delta / X \qquad (6)$$

$$Q = V_{pcc} (E - V_{pcc}) / X \qquad (7)$$

Where, VPCC and E are the magnitudes of PCC voltage and inverter output voltage and X is the reactance of line impedance. SoC- based P-f droop method to achieve SoC balancing as per equation.

$$\omega = \omega_0 - K_{PP} - K_{SoC} (1 - SoC) \qquad (8)$$

Where, KP and K_{SoC} are the droop coefficient of SoC-based droop control method. The frequency of the DESU with higher SoC droops less compared with the ones with lower SoC, as shown in figure 6. As a result, the DESU with higher SoC delivers larger active power compared with the ones with lower SoC, which is beneficial to SoC balancing of DESUs as shown by figure 7. Assuming that the output active powers of the parallel-connected inverters are defined, and the frequencies satisfy an order, which results in sharing of power. Gradually, the active powers are equally shared in the steady state. Since the frequency of the microgrid is unified throughout the whole system once steady state conditions are reached, the output real powers are shared accurately between the inverters even with the mismatched line impedances.

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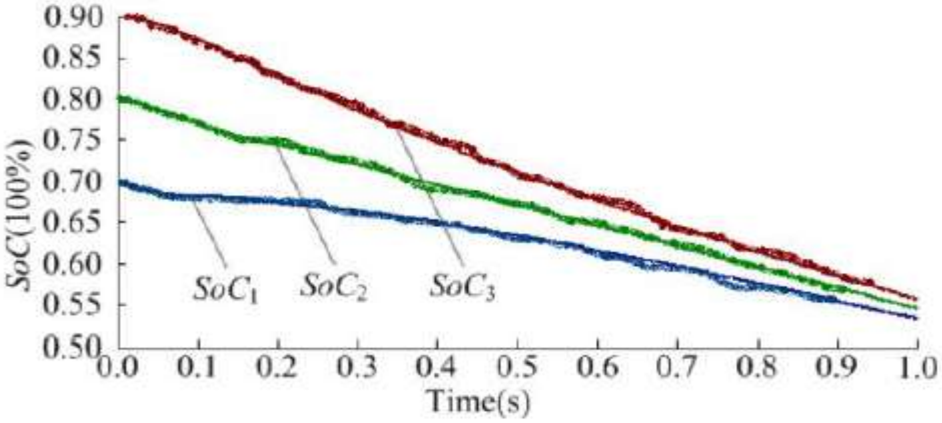

Fig 5 - Response of SoC balancing method

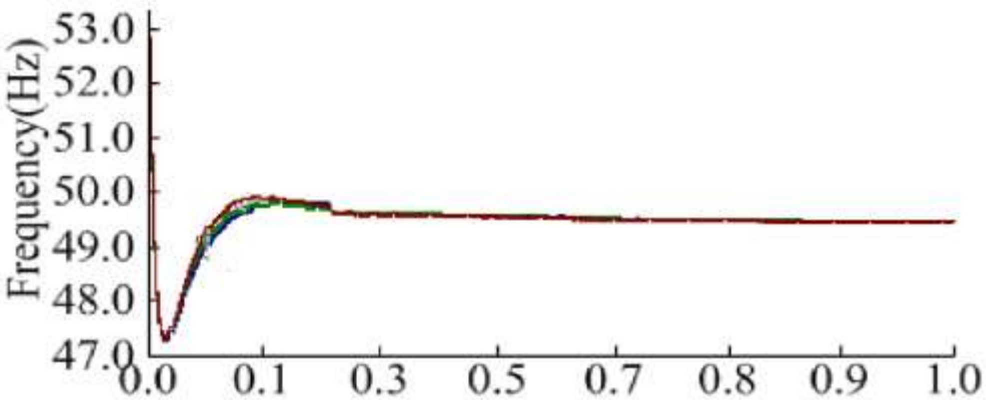

Fig 6- Response of Frequency

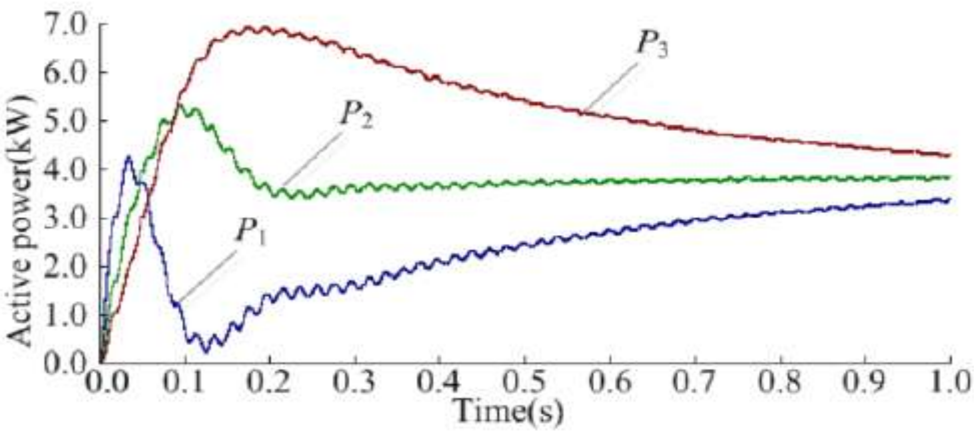

Fig 7- Active Power delivered

Whereas, there is an inherent trade-off between the voltage accuracy and power sharing existing in the proposed droop method. Hence, voltage restoration without communication links should also be employed into the control of the DESUs, simultaneously. Taking full advantage of the accurately shared active power, a compensation term proportional to the integration of the active power, which can be expressed as,

$$E_t = E_0 - K_Q \int_0^t Q dt + K_{PV} \int_0^t P dt \qquad (9)$$

Where, KPV is the voltage compensation coefficient. The Employment of the active power integration will not influence the performance of the reactive power sharing. The reactive power sharing is achieved through reducing the voltage by different extents. As aforementioned, the active powers are evenly shared due to the unified frequency and nearly decoupled with the reactive powers in the case of the high X/R-ratio line impedances. Different extents of voltage droops are implemented to achieve the reactive power sharing and the same voltage compensation is added to restore the voltage magnitude.

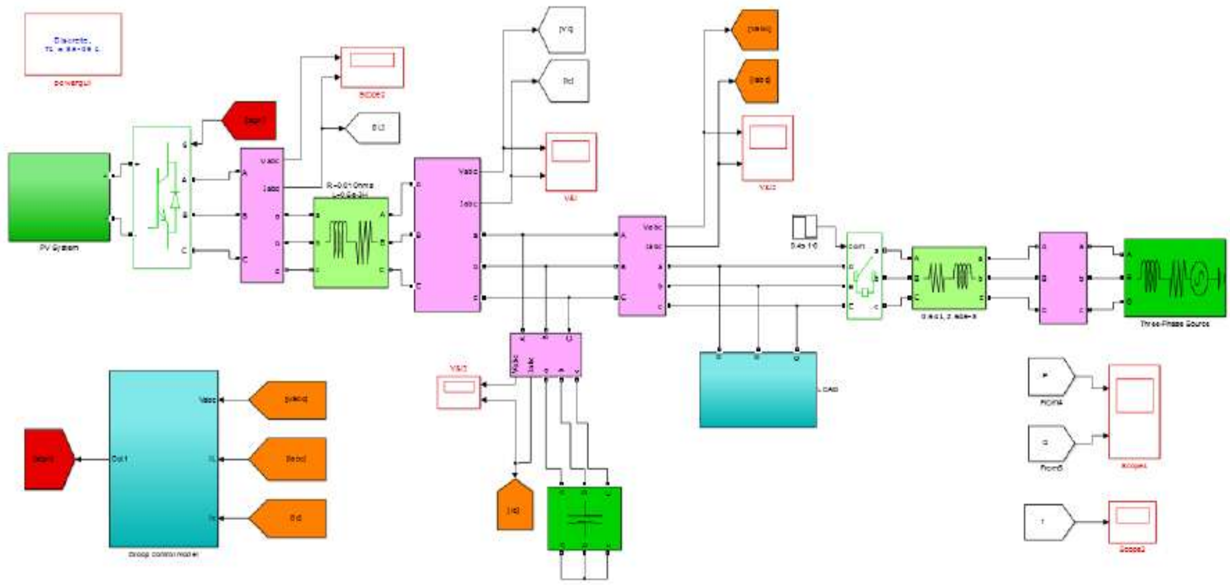

Fig 8- MATLAB Simulation of System

VI. MATLAB SIMULATION & RESULT

The performance of the methods of droop control is tested under MATLAB simulation environment. Figure 8 shows the overall model of the power system. The figure shows the total system of Distributed Energy storage system by using Photovoltaic energy source. In that system droop controlling is done by P-F control method for the purpose to prolong the service life of Distributed Energy Systems and effectively utilizing the available power handling capability of the Distributed Energy Units and integration of reactive power, Q and dt-V controlling which help to improve reactive power sharing by eliminating error.

The simulation results show proper stabilization of system voltage and current profiles. Figure 9 shows the voltage and current waveform under connected load condition, the results are derived for an interval from 0.2 to 0.4 pu. We can see that, the electrical parameter shows proper sinusoidal waveform. Distortion available is less, and is occurring due to controlling system. Also, figure 10 shows the active power & reactive power flow through the load connected power system. The system shows the share of reactive power. Figure 11 shows the total harmonic distortion level of voltage and current that should be in below 5% as per the IEEE levels which is good for system.

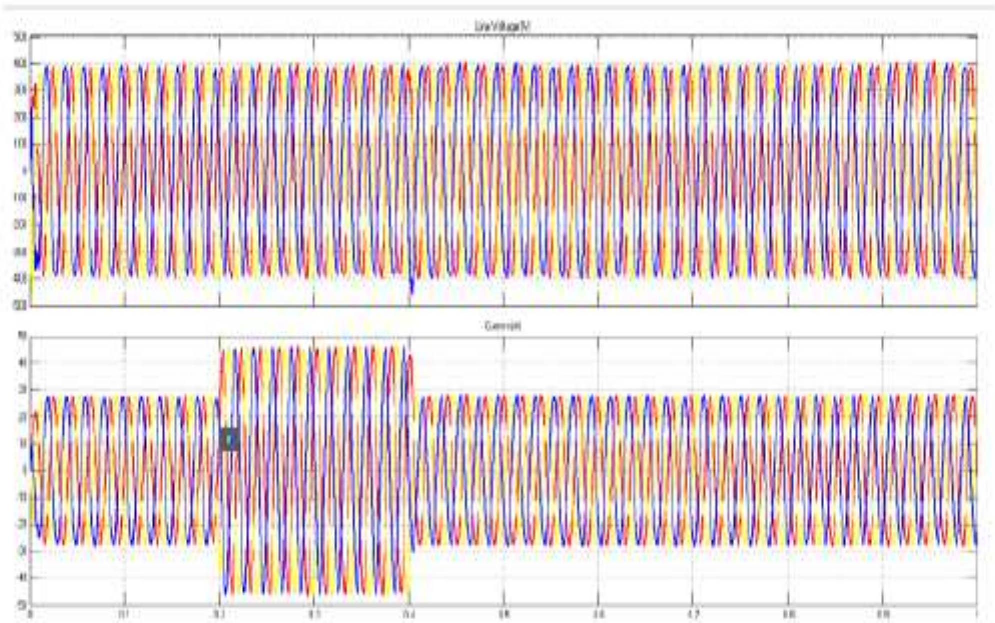

Fig- 9 Voltage & Current Profile of output

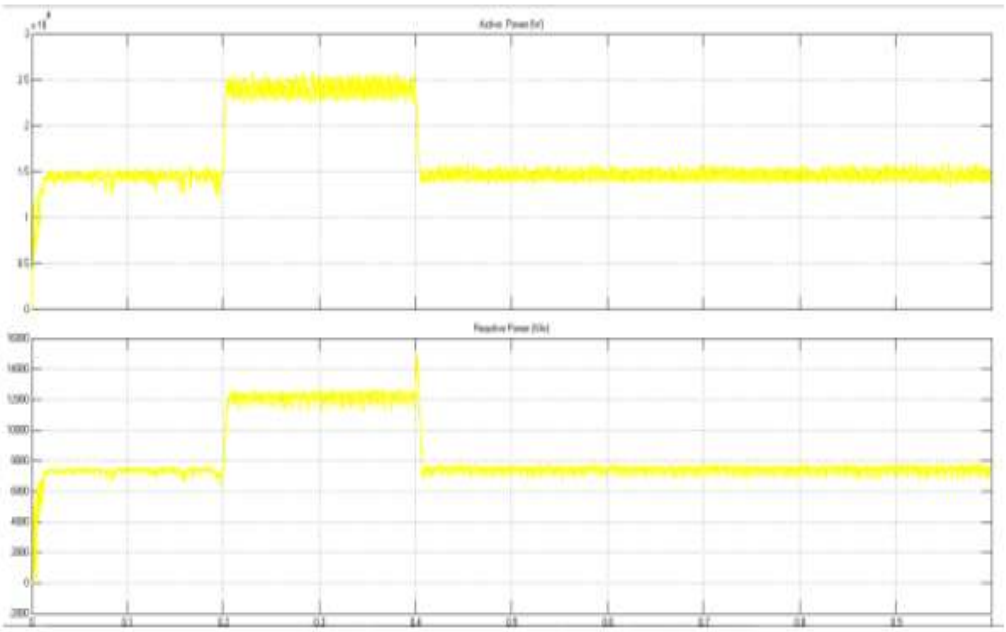

Fig 10- Active & Reactive Power Sharing

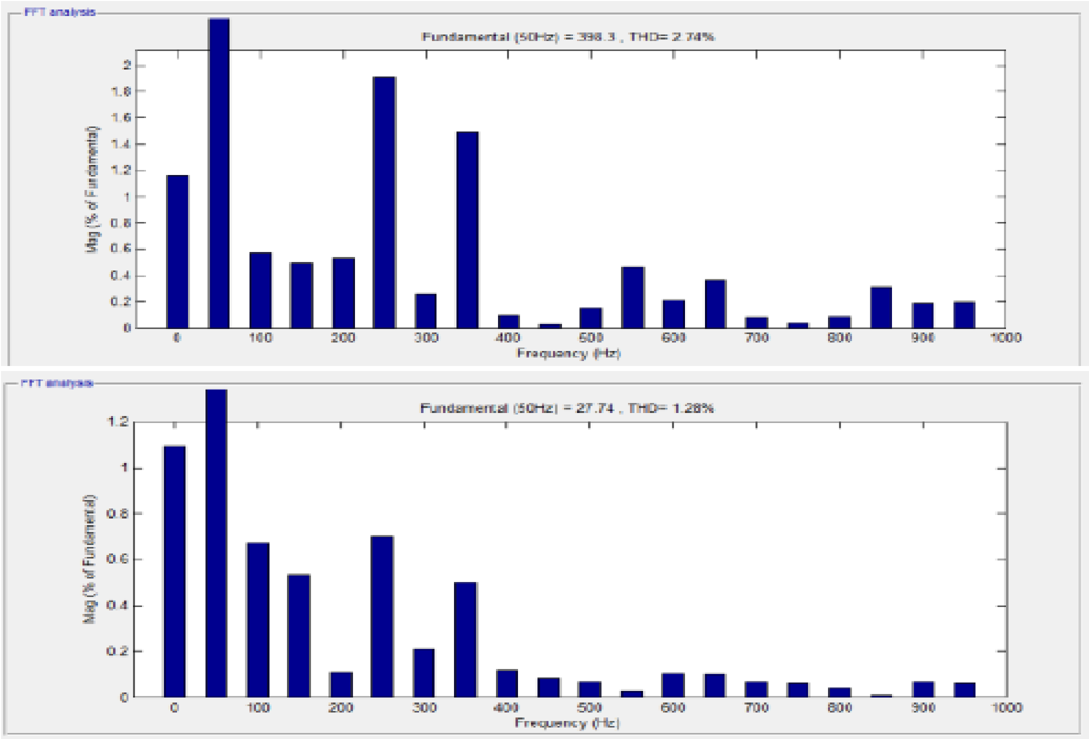

Fig 11- THD Levels of Voltage & Current

VII. CONCLUSION

The Reactive Power–Voltage (Q–V) droop control method with Voltage restoration mechanism is described in this paper, which is implemented through Photovoltaic energy system. The system is used to improve the reactive power sharing among converters in the microgrid environment. The system results shows clear improvement of reactive power sharing in the system compared to the conventional droop control. The voltage restoration method is also implemented, which controls the voltage to bring the value to zero so the line voltage magnitude is maintained at the steady state.

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