A FLEXIBLE AC DISTRIBUTION SYSTEM DEVICE FOR PHOTOVOLTAIC AND MPPT TECHNIQUE AT MICRO GRID

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ABSTRACT

Distributed flexible AC transmission system (D-FACTS) devices offer many potential benefits to power systems. This work examines the impact of installing D-FACTS devices by studying the sensitivities of power system quantities such as voltage magnitude, voltage angle, bus power injections, line power flows, and real power losses with respect to line impedance. These sensitivities enable us to identify and develop appropriate applications for the use of D-FACTS devices for the enhanced operation and control of the grid. The design concept is verified through different test case scenarios as well as applied to multiple induction machine drive checking to evaluate the performance of proposed concept to demonstrate the capability of the proposed device and the simulation results obtained are discussed.

Index Terms—Extended Kalman Filter, Micro Grid, Model Predictive Control, Power Quality

I. INTRODUCTION

Power flow in alternating current (AC) systems is unlike other flow problems such as in transportation or telecommunications. In a transportation system, trucks can be routed along a desired path from a source to a destination. Similarly, in a communications system, packets can be routed such that they travel along a shortest path between a sender and a receiver. However, electricity must follow the laws of physics, so power flow is not routable and cannot be directly controlled. Power flow control is also different from other types of flow problems since electricity must also be produced exactly when it is needed. Generation must constantly track the load as the customers' demands change. In other systems for distributing goods and services, products are stored in a warehouse until they need to be sent to the end user. If the desired supply is unavailable, the end user can wait and it will arrive later. In power systems, customers are in control of how much power they use and always expect that amount of power to be available. More recently, distributed flexible AC transmission system (D-FACTS) devices [3],[4] such as the Distributed Static Series Compensator (DSSC) have been designed to address power control types of problems. D-FACTS devices attach directly to transmission lines and can be used to dynamically control effective line impedance. Also, D-FACTS devices are smaller and less expensive than traditional FACTS devices which may make them better candidates for wide scale deployment. From a power systems perspective, D-FACTS devices have many potential benefits. This paper discusses some principles of power flow control and then examines the impact of using D-FACTS devices in a power system. In particular, this paper analyzes some effects of changing transmission line impedances and the use of D-FACTS devices for loss minimization and voltage control.

II. SYSTEM DESCRIPTION

The configuration of the micro grid considered in this paper for implementation of the flexible ac distribution system device is shown in Fig. 1. The proposed micro grid consists of three radial feeders (1, 2 and 3) where feeders 1 and 3 are each connected to a distributed generation (DG) unit consisting of a micro-generator, a three-phase VSI, and a three-phase LC filter. Feeder 2, however, is connected to an electrical load. The flexible ac distribution system device is operated in two modes: 1) PQ compensation and 2) emergency operation. During grid-connected operation, the micro grid is connected to the distribution grid at the PCC. In this mode, the two DG units are controlled to provide local power and voltage support for loads 1–3 and hence reduce the burden of generation and delivery of power directly from the utility grid.

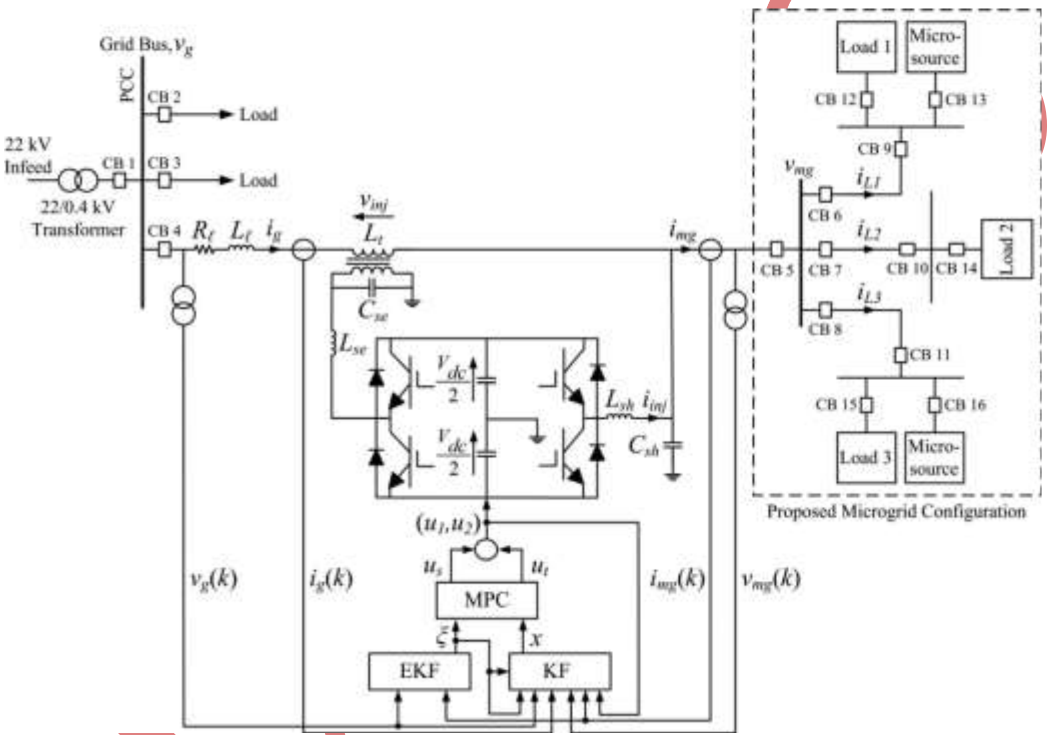

Fig. 1. Overall Configuration Of The Proposed Flexible Ac Distribution System Device And The Micro Grid Architecture With EKF Denoting The Extended Kalman Filter And KF Denoting The Kalman Filter For The Plant.

The flexible ac distribution system device functions to compensate for any harmonics in the currents drawn by the nonlinear loads in the micro grid so that the harmonics will not propagate to the rest of the electrical loads that are connected to the PCC. The device also functions to compensate for harmonics in the grid voltage that are caused by other nonlinear loads that are connected at the PCC. The energization of large loads and rapid changes in the load demand may also result in voltage and frequency variations in the grid voltage. Therefore, the device is also equipped with the capability to handle such voltage and frequency variations. When a fault occurs on the upstream network of the grid, the CBs operate to disconnect the micro grid from the grid. The DG units are now the sole power sources left to regulate the loads. In the case when the generation capacity of the micro generators is unable to meet the total load demand, the flexible ac distribution system device transits to operate in the emergency mode and functions to momentarily provide for the shortage in real and reactive power. In Fig. 2, the detailed configuration of the three-phase flexible ac distribution system device is shown.

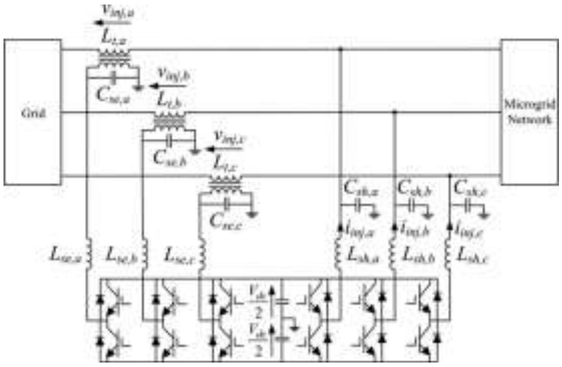

Fig. 2. Configuration of the Three-Phase Flexible AC Distribution System Device

III. FLEXIBLE AC DISTRIBUTION SYSTEM DEVICE MODEL

The single-phase representation of the flexible ac distribution system device is shown in Fig. 3 [10]. The distribution grid voltage at the PCC and the total current drawn by the micro grid are modelled as vg and img, respectively. With the proliferation of power electronics equipment being connected to the distribution grid and the micro grid, both vg and img could be distorted due to the presence of harmonic components. Therefore, vg is modelled as a source consisting of its fundamental vf and harmonic vh that can be represented by

$$v_g = v_f + v_h = V_f \sin(\omega t) + \sum_{h=3,5,\ldots}^{N} V_h \sin(h\omega t - \theta_h) \quad (1)$$

Where vf is the fundamental component of vg with its peak amplitude Vf and vh is a combination of the harmonic components of vg with its peak amplitude Vh and phase angle θh. To compensate for the harmonics in vg , the series VSI injects a voltage vinj that is given by

$$v_{\text{inj}} = v_h - v_z - v_t \quad (2)$$

Where *vz* is the voltage drop across the line impedance of *R* and *L*, and *vt* is the voltage drop across the equivalent leakage reactance *Lt* of the series-connected transformer. Similarly, *i*mg is also modeled as two components consisting of fundamental *if* and harmonic *ih* with their peak amplitudes *If* and *Ih*, respectively and is represented by

$$\begin{aligned} i_{\text{mg}} &= i_f + i_h = I_f \sin(\omega t - \varphi_f) + \sum_{h=3,5,\ldots}^{N} I_h \sin(h\omega t - \varphi_h) \\ &= I_f \sin\omega t \cos\varphi_f - I_f \cos\omega t \sin\varphi_f \\ &\quad + \sum_{h=3,5,\ldots}^{N} I_h \sin(h\omega t - \varphi_h) = i_{f,p} + i_{f,q} + i_h \end{aligned} \quad (3)$$

Where ϕf and ϕh are the respective phase angles of the fundamental and harmonic components of img, and if,p and if,q are the instantaneous fundamental phase and quadrature components of img. To achieve unity power factor at the grid side, compensate for the harmonics in the micro grid current and achieve load sharing concurrently, the shunt VSI injects a current iinj that is given by

$$i_{\text{inj}} = (i_{f,p} - i_g) + i_{f,q} + i_h + i_{C_{\text{sh}}} \quad (4)$$

Where ig is the grid current. The switched voltage across the series and shunt VSIs of the flexible ac distribution system device are represented by u1 (Vdc/2) and u2 (Vdc/2) , respectively. To eliminate the high switching frequency components generated by the series and shunt VSIs, two second-order low-pass interfacing filters which are represented by Lse, Cse, Lsh, and Csh are incorporated. The losses of the series and shunt VSIs are modelled as Rse and Rsh, respectively.

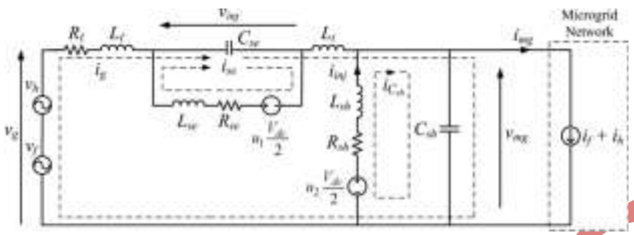

Fig. 3. Single-Phase Representation Of The Flexible AC Distribution System Device

IV. GRID CONNECTED PHOTOVOLTAIC SYSTEM

The photovoltaic (PV) power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirements. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV systems generally shape the grid current to follow a predetermined sinusoidal reference using hysteresis-band current controller, which has the advantages of inherent peak current limiting and fast dynamic performance. Fig.4 shows the schematic diagram of a grid connected PV system. It typically consists of two main parts: the PV array and the power conditioning unit (PCU). The PCU typically includes:

- A Maximum Power Tracking (MPPT) circuit, which allows the maximum output power of the PV array.
- A Power Factor (PF) control unit, which tracks the phase of the utility voltage and provides to the inverter a current reference synchronized with the utility voltage.
- A converter, which can consist of a DC/DC converter to increase the voltage, a DC/AC inverter stage, an isolation transformer to ensure that the DC is not injected into the network, an output filter to restrict the harmonic currents into the network.

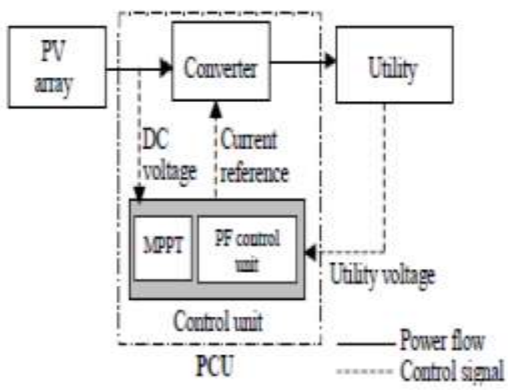

Fig. 4. Schematic Diagram of Grid-Connected PV System

The model of grid connected photovoltaic system to control active and reactive power injected in the grid is presented. The proposed multilevel power converter uses two single-phase voltage source inverters and a four wire voltage source inverter. The structural design of this new power converter allows a seven level shaped output voltage wave at the output of multilevel inverter. The MPPT algorithm, the synchronization of the inverter and the connection to the grid are discussed.

4.1. Photovoltaic Array Modeling

Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts solar radiation into dc current using photovoltaic effect. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode, shown in Fig. 5

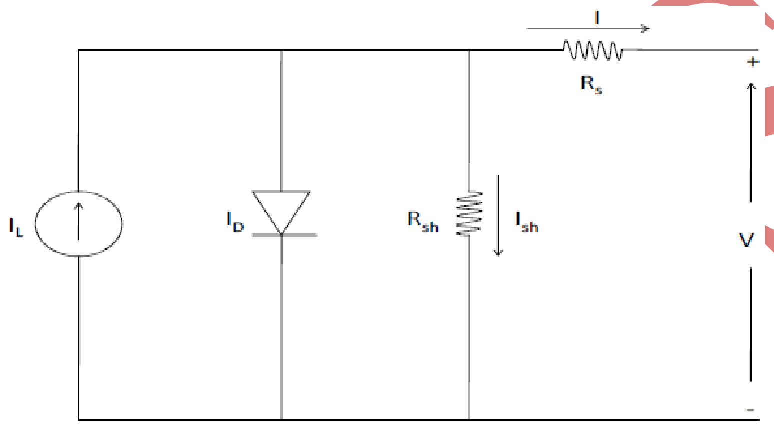

Fig. 5. Circuit Diagram of a Solar Cell

The series resistance RS represents the internal losses due to the current flow. Shunt resistance Rsh, in parallel with Diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell. The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems. This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems.

4.2. Proposed Hybrid Source for DC Link

The proposed source for the dc-link voltage of the flexible ac distribution system device consists of a PV array and a battery as shown in Fig. 6. The PV array and the battery are connected to the VSI of the device through a boost converter and a buck-boost converter, respectively, to facilitate charging and discharging operations for the battery and to regulate the dc-link voltage at the desired level. To maintain the dc-link at the reference voltage V ∗ dc/2, a dual loop control scheme in, which consists of an outer voltage loop and an inner current loop for the bidirectional converter, is implemented to compensate for the variation in the output voltage Vdc/2 of the dc/dc boost converter. In this section, the operation of the PV/battery system is briefly explained. When there is ample sunlight, the PV array is controlled by the dc/dc boost converter to operate in the MPPT mode to deliver its maximum dc power Ppv at Vdc/2, which induces a voltage error (V*dc/2 − Vdc/2) at the dc-link. The error is passed to a PI controller, which produces a reference battery current iab for the inner current loop to operate the battery in either the charging mode for a positive error or discharging mode for a negative error.

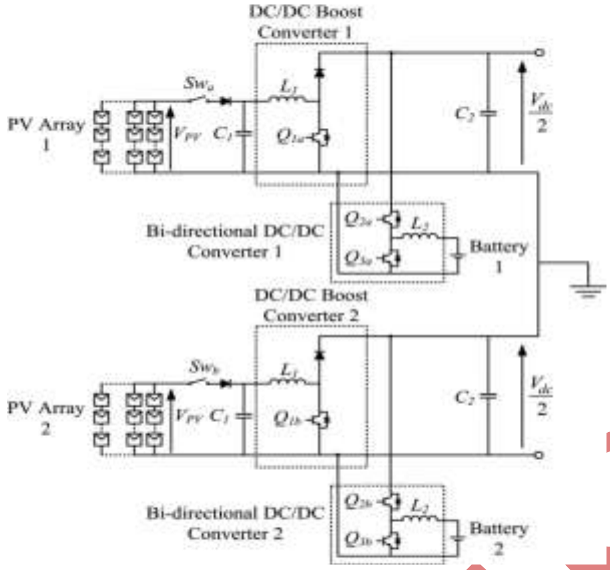

Fig. 6. Proposed PV/Battery System for the Device

When the battery is in the charging mode, the bidirectional converter operates as a buck converter by turning switch Q3a OFF and applying the control signal from the controller to switch Q2a ON as shown in Fig. 7. Conversely, when the battery is in the discharging mode, the bidirectional converter operates as a boost converter by turning switch Q2a OFF and applying the control signal from the controller to switch Q3a ON as shown in Fig. 4. Figs. 7 and 7 illustrate the charging and discharging operations of Battery 1, so as to maintain the upper dc-link voltage at a desired value. The same charging and discharging operations are applied to Battery 2 such that the dc-link voltages for both the upper and lower dc-link capacitors are maintained at V*dc/2.

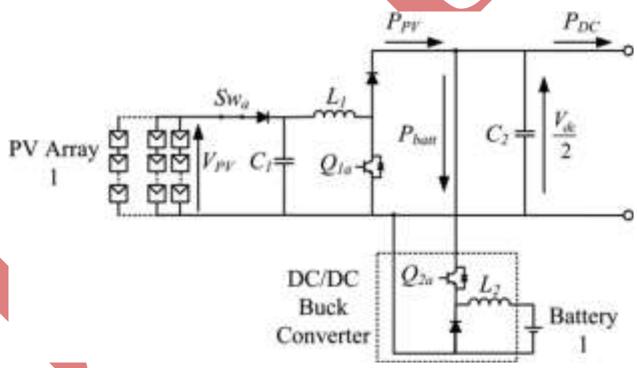

Fig. 7. Equivalent Circuit During Charging Operation.

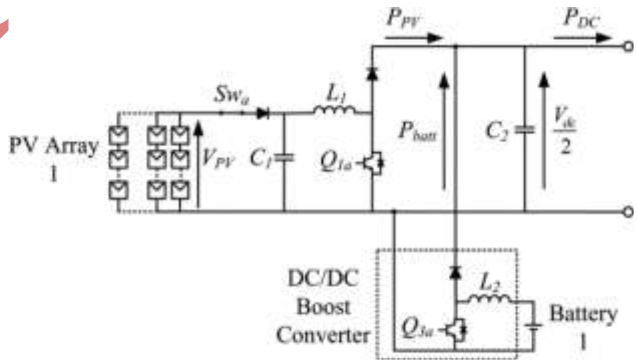

Fig. 8. Equivalent Circuit During Discharging Operation.

When the PV array is subject to prolonged period of sunless hours and the state-of-charge of the battery falls below a preset limit, a self-charging technique from the grid can be incorporated into the design of the device. The design of this self-charging technique is detailed in [4].

V. MATLAB/SIMULINK RESULTS

The proposed device is tested under different case scenarios using MATLAB/Simulink to evaluate its capability to improve the PQ and reliability of the distribution network that the micro grid is connected to.

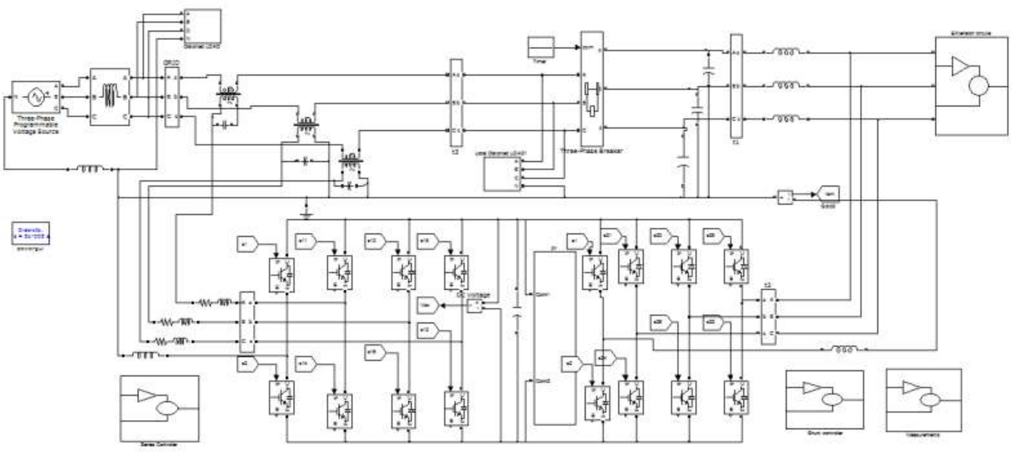

Fig. 9. Matlab/Simulink Model of Harmonic Compensation

Figure9 shows the Matlab/Simulink Model of Harmonic Compensation.

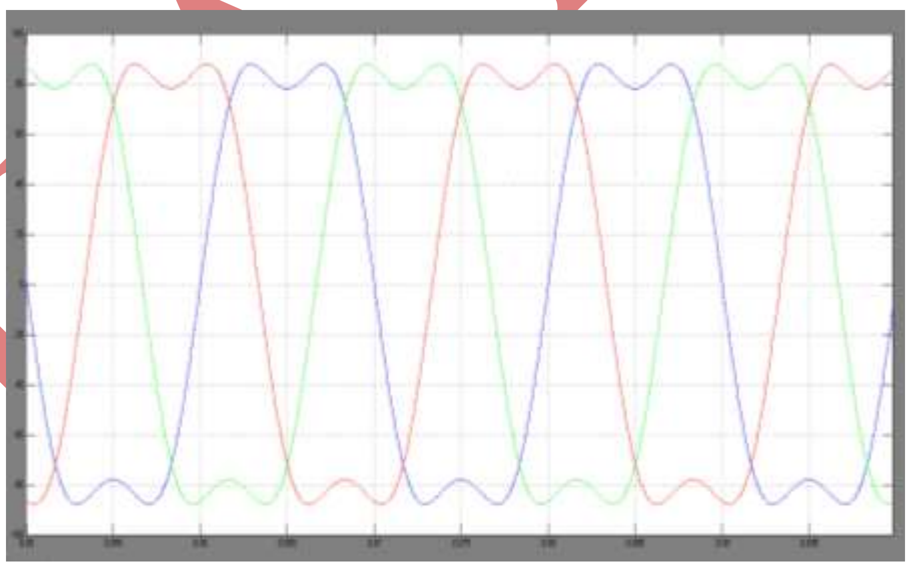

Fig. 10. Grid Voltage

Figure10 Grid Voltage of Harmonic Compensation and Power Factor Correction during Steady-State Operation with Load Sharing condition.

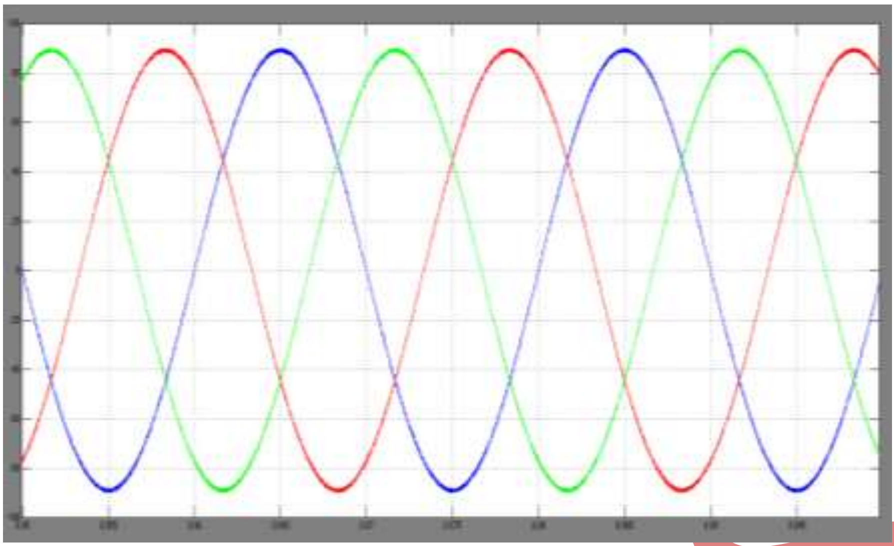

Fig. 11. Micro Grid Voltage

Figure11 shows the Micro Grid Voltage

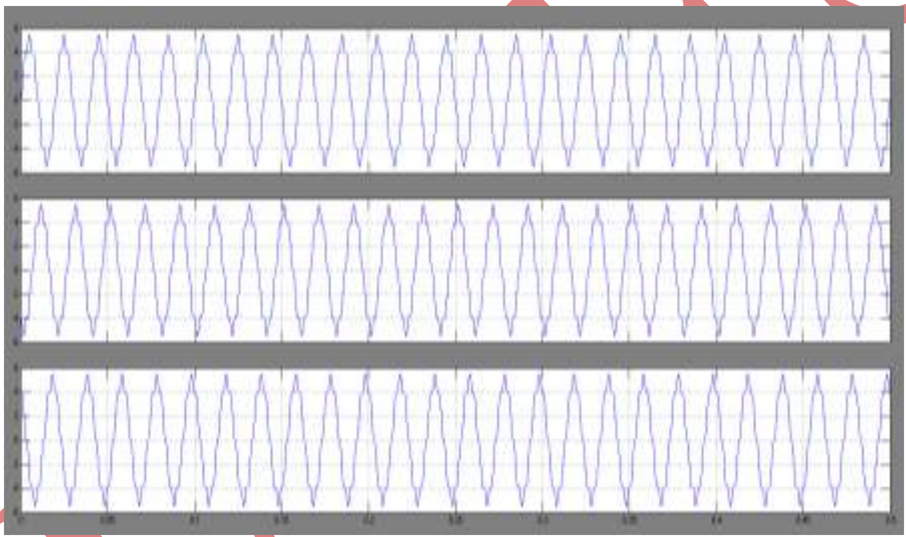

Fig. 12. Per-Phase Feeder Currents

Figure12 shows the Per-phase Feeder currents

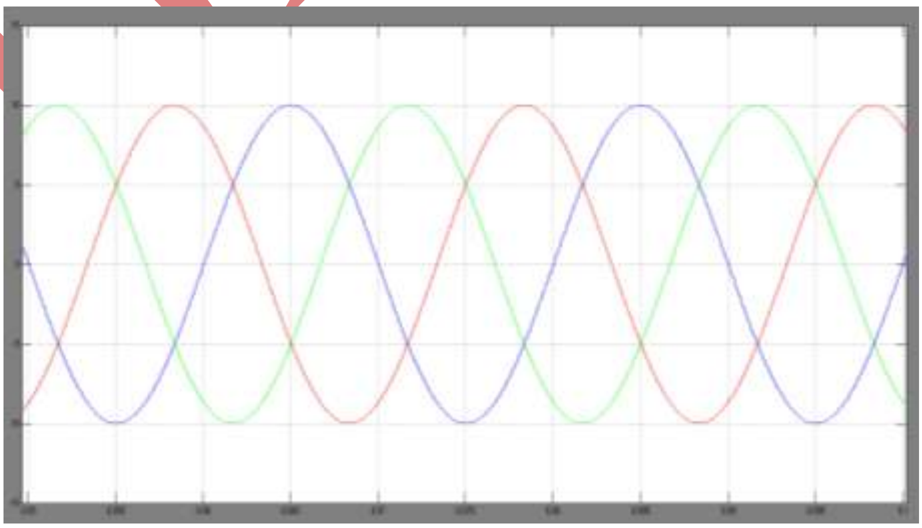

Fig. 13. Grid Current

Figure13 shows the Grid current, of Harmonic Compensation and Power Factor Correction during Steady-State Operation with Load Sharing condition

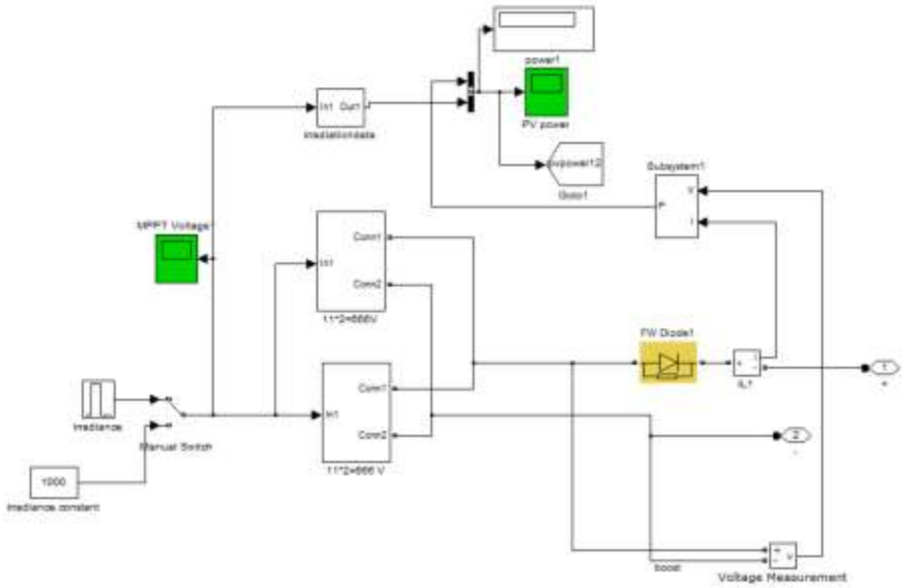

Fig. 14. Matlab /Simulink Model of PV and MPPT Technique.

Figure14 shows the Matlab /Simulink model of PV and MPPT technique.

Fig. 14. PV Power

Figure14 shows the PV power

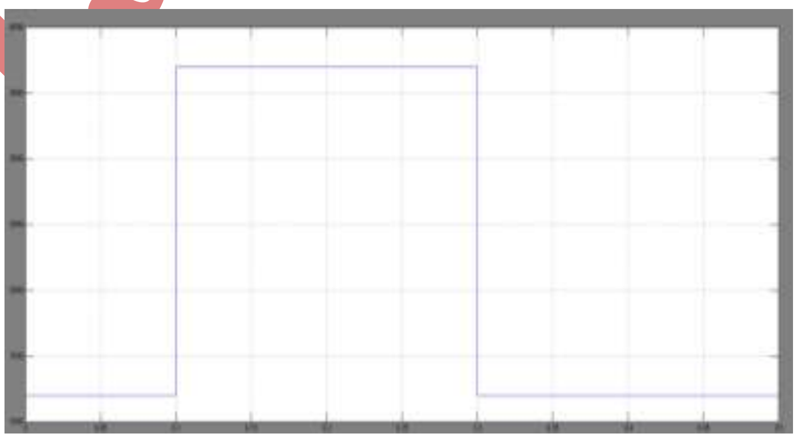

Fig. 15. MPPT Voltage

Figure15 shows the MPPT voltage

VI. CONCLUSION

In this paper, a flexible ac distribution system device for micro grid applications has been presented. The proposed solution integrates EKF into the control design for frequency tracking and to extract the harmonic spectra of the grid voltage and the load currents. The device is installed at the PCC that the micro grid and other electrical networks are connected to and is designed to tackle a wide range of PQ issues. It also operates as a DG unit to perform load sharing when the cost of generation from the grid is high such that peak shaving is achieved and also during islanded operation of the micro grid. The design concept has been tested under several case scenarios and the results obtained verified that the device can handle a wide range of PQ issues, thus increasing the overall PQ and reliability of the micro grid. However, the proposed design concept still needs further validation by experimental studies because measurement errors due to inaccuracies of the voltage and current sensors, and modeling errors due to variations in system parameters could affect the performance of the device in practical implementation.

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