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A Flexible AC Distribution System for a Microgrid with a Photovoltaic System in Islanded Mode

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ABSTRACT

This paper presents a FACT ac distribution system device for micro grid applications. The device aims to improve the power quality and reliability of the overall power distribution system that the micro grid is connected to. The control design employs a new model predictive control algorithm which allows faster computational time for large power systems by optimizing the steady-state and the transient control problems separately. Extended Kalman filters are also employed for frequency tracking and to extract the harmonic spectra of the grid voltage and the load currents in the micro grid. Simulation results is verified through different case studies.

KEYWORDS: *Extended Kalman filter, micro grid, model predictive control, power quality.*

I. Introduction

The concept of micro grid has offered consumers with increased reliability and reduction in total energy losses, and has become a promising alternative for traditional power distribution system .One area of study for the connection of a micro grid to the distribution grid is the impact of power quality (PQ) problems on the overall power system performance. These PQ problems include voltage and frequency deviations in the grid voltage and harmonics in the grid voltage and load currents. To overcome the aforementioned PQ problems, several power-conditioning equipment such as active filters, uninterruptible power supplies, dynamic voltage restorers, and unified PQ conditioners are usually employed by consumers to protect their loads and systems against PQ disturbances in the distribution network. However, these devices are usually installed at the consumer sides and the PQ problems that they are capable to handle are usually limited. This paper proposes a flexible ac distribution system device for the micro grid that is realized using a combination of series and shunt voltage source inverters (VSIs). The proposed device is installed at the point of common coupling (PCC) of the distribution grid that the microgrid and other electrical loads are connected to. The proposed source for the dc-link voltage of the flexible ac distribution system device consists of a photovoltaic (PV) array and a battery to store the excess energy generated by the PV array and to provide power during sunless hours. The device is equipped with the capability to improve the PQ and reliability of the microgrid. Furthermore, during islanded operation of the microgrid, the device can provide real and reactive power to the microgrid. The proposed controller is based on a newly developed model predictive control (MPC) algorithm to track periodic reference signals for fast sampling linear time invariant (LTI) systems that are subject to input constraints. This control methodology controls the input signals of the VSIs and decomposes the control problem into steady-state and transient sub problems which are optimized separately. In this way, the computational times can be greatly reduced. In what follows, this paper provides a comprehensive solution for the operation of the flexible ac distribution system device for a micro grid based on a multi-input–multi-output (MIMO) state-space model.

II. System Description

The configuration of the microgrid considered in this paper for implementation of the flexible ac distribution system device is shown in Fig. 1. The proposed microgrid 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 load types in the microgrid will be discussed in Section VI. The flexible ac distribution system device is operated in two modes:

1) Power quality compensation
2) Emergency operation.

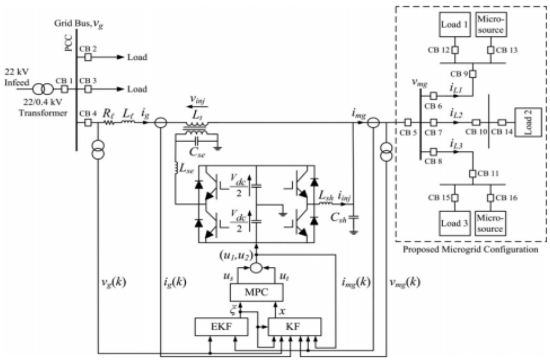

Fig. 1. Overall configuration of the proposed flexible ac distribution system device and the microgrid architecture with EKF denoting the extended Kalman filter and KF denoting t Kalman filter for the plant

During grid-connected operation, the microgrid 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. The flexible ac distribution system device functions to compensate for any harmonics in the currents drawn by the nonlinear loads in the microgrid 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 microgrid from the grid.

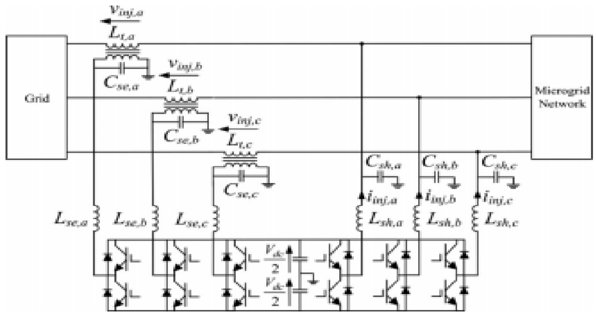

Fig. 2. Configuration of the three-phase flexible ac distribution system device.

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.

III. Flexible AC Distribution System Device Model

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

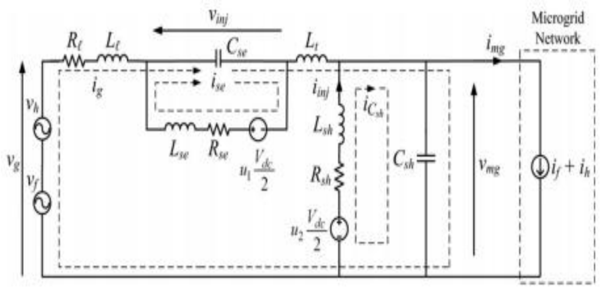

Fig. 3. Single-phase representation of the flexible ac distribution system device.

IV. Photovoltaic Array

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels comprising a number of cells containing a photovoltaic material. Materials presently used for photovoltaic include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium serenade/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years

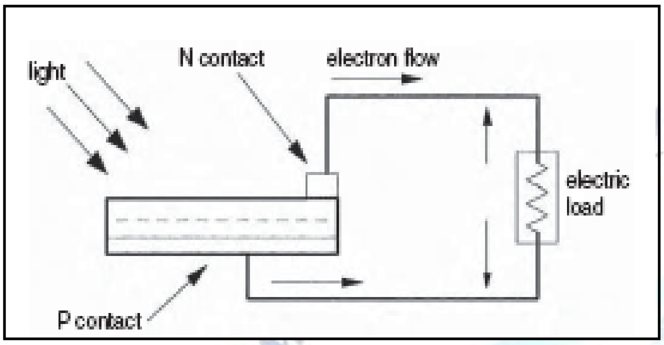

Fig.4 PV effect converts the photon energy into voltage across the pn junction

Fig 4:The photovoltaic effect is different in that the generated electrons are transferred between different bands (i.e. from the valence to conduction bands) within the material, resulting in the buildup of a voltage between two electrodes. In most photovoltaic applications the radiation is sunlight and for this reason the devices are known as solar cells. In the case of a p-n junction solar cell, illumination of the material results in the generation of an electric current as excited electrons and the remaining holes are swept in different directions by the built-in electric field of the depletion region.

V. MPPT Controller

Maximum power point tracker (or MPPT) is a high efficiency DC to DC converter that presents an optimal electrical load to a solar panel or array and produces a voltage suitable for the load. PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPP) occurs at the knee of the curve, where the resistance is equal to the negative of the differential resistance (V/I = -dV/dI). Maximum power point trackers utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell. Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy. Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

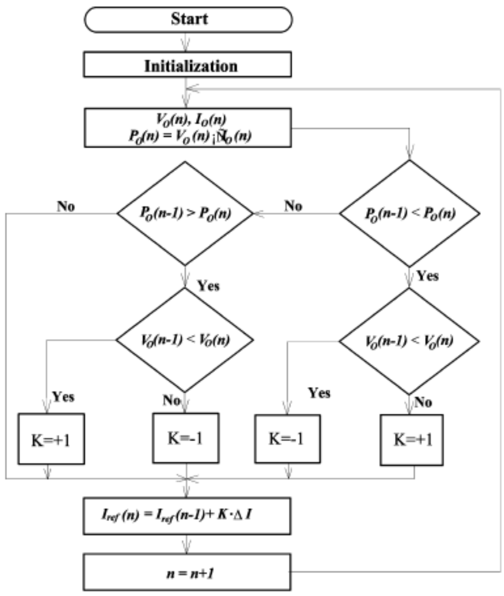

Fig5: Algorithm of Perturb Observe Method

At night, an off-grid PV power system uses batteries to supply its loads. Although the battery pack voltage when fully charged may be close to the PV array's peak power point, this is unlikely to be true at sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the array peak power point, and a MPPT can resolve this mismatch.

When the batteries in an off-grid system are full and PV production exceeds local loads, a MPPT can no longer operate the array at its peak power point as the excess power has nowhere to go. The MPPT must then shift the array operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the array to operate continuously at its peak power point.) In a grid-tied photovoltaic system, the grid is essentially a battery with near infinite capacity. The grid can always absorb surplus PV power, and it can cover shortfalls in PV production (e.g., at night). Batteries are thus needed only for protection from grid outages. The MPPT in a grid tied PV system will always operate the array at its peak power point unless the grid fails when the batteries are full and there are insufficient local loads. It would then have to back the array away from its peak power point as in the off-grid case (which it has temporarily become).

VI. Proposed Hybrid Source for DC –Link Voltage

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. 7. 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.

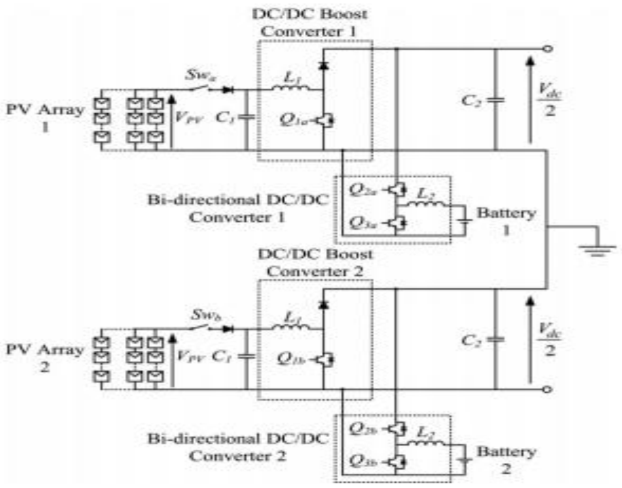

Fig.6:Proposed PV/battery system for the device.

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 I ∗ b for the inner current loop to operate the battery in either the charging mode for a positive error or discharging mode for a negativeerror. 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.6.both the upper and lower dc-link capacitors are maintained at V ∗ dc/2. 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.

VII. Simulation Circuit and Results

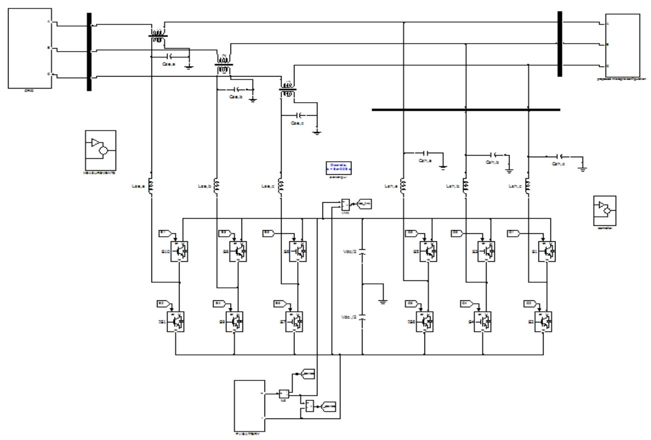

Fig7: Simulation implementation of Micro Grid with and without fuzzy controller

This simulation diagram for this system is shown in fig7: And results are verified under two cases.

Case 1: with PI Controller

In this the conventional PI controller is used for series and shunt controllers. The obtained results are shown in below Figures

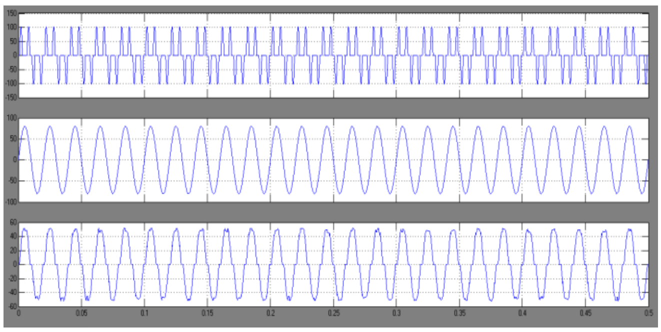

Fig8:Simulation result for Feeder currents 1, 2 and 3

Fig8:shows the simulation results for the system feeder currents under without and with compensation.

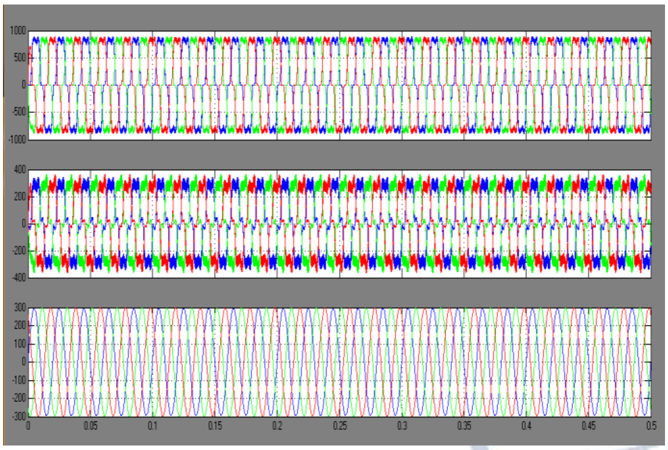

Fig9:Simulation result for Grid, Series Converter and Micro-Grid Voltage

Fig9: shows the simulation results for the system micro grid voltage under without and with compensation

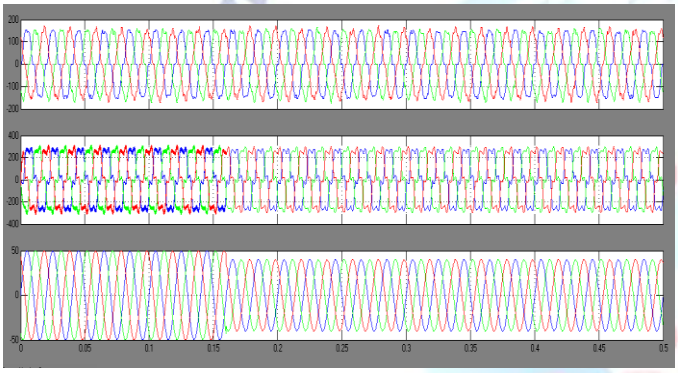

Figure 10:Simulation result for Grid, Series Converter and Micro-Grid Current

Figure 10:shows the simulation results for the system Micro-Grid Currents under without and with compensation

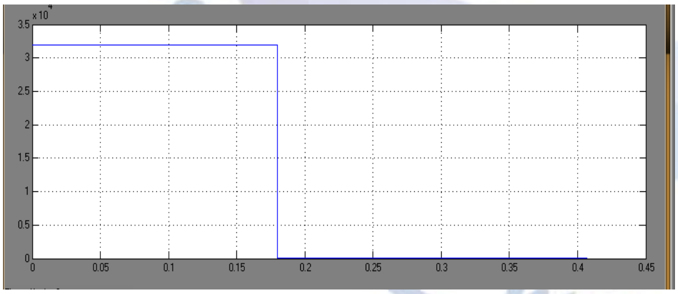

Fig 11: Simulation result for Active Power under Islanded condition

Fig11: shows the simulation result for the active and reactive powers under Islanded condition. In this case we consider the islanded condition at time t=0.17sec and at that the grid is disconnected from the system.

Case 1.with PI controller

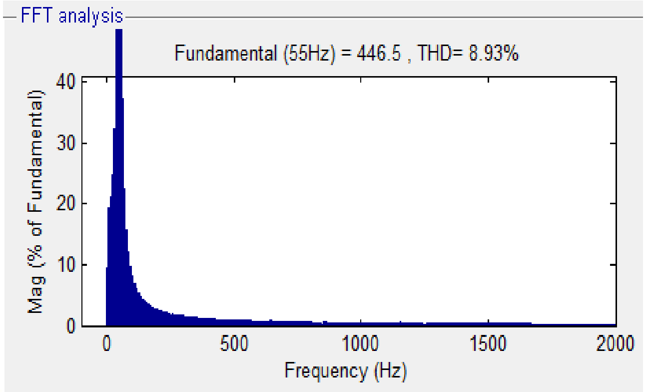

Fig12: shows the total harmonic distortion values under with PI controller.

VIII. Conclusion

This paper has successfully implemented the microgrid based unified power quality conditioner along with the PI controller. Generally, the microgrid concept mainly concentrates on the reduction of transmission losses and the power quality problems associated with the system, the later are compensated by unified power quality controller. The fuzzy logic controller is used for getting better performance by the reduction of total harmonic distortion in the system.

The simulation results are obtained for the Grid interfacing using series and parallel converter system with conventional PI controller. Due to the presence of non-linearity in the system, harmonics are produced which lead to voltage distortions. By using conventional PI controller in the system we can reduce these distortions.

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