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Control and Stability of Microgrid During Grid to Island Mode

Bangar Raju. L
Research Scholar, EEE Department
Koneru Lakshmaiah Educational Foundation
Guntur, Andhra Pradesh, India

Dr. Subba Rao. K
Professor, EEE Department
Koneru Lakshmaiah Educational Foundation
Guntur, Andhra Pradesh, India

Abstract:- This paper predicts islanding and controls the behaviour of microgrid during transition from grid to islanded mode of operation. In grid-connected mode the distributed generators (DGs) are supposed to share active and reactive power to the loads based on their capacities. But during the islanded mode the micro-sources are required to control voltage and frequency at the Point of Common Coupling of Microgrid. Lot of transients will be introduced during transition from grid to islanding mode and hence additional controls are necessary to ensure smooth transition from power control mode((P/Q) of grid to voltage-frequency (V/f) island mode . Islanding is not desirable to the operating personnel and equipment. A robust hybrid controller is designed and implemented for its efficiency, which also takes care of the Non-Detective Zone(NDZ) . The performance of the output feedback controller is tested in Matlab / Simulink environment for its validity.

Keywords:- *DGs-Distributed Generators;Microgrid;PCC-Ponit of Coomon Coupling ; P/Q-active to reactive power; V/f-voltage to frequency;NDZ-Non-Detection Zone; RES-Renewable Energy Sources;DERs –Distributed Energy Resources;DOE-Department of Energy;CERTS-Consotium of Electric Reliability Solutions; PLL- Phase locked Loop; SRF-Synchronous Reference Frame; VCM-Voltage Control Mode; CCM-Current control mode; SOC-State Of Charging.*

I. INTRODUCTION

Microgrid researchers are consistingly developing latest technologies to make the Microgrids more reliable, efficient and resilient. They are not only reducing the Green House Gas emissions but also protecting the environment, The Microgrids are revolutionizing the power systems.The Microgrids are reducing the transmission losses and are able to feed the remote places where power lines can not reach.

By making the RESs dispatchable, the Microgrids efficiency is improved. But to make the Microgrids active networks, lot of challenges are to be met. The Microgrids are not only supplying to local and remote loads but also exporting to Utility grids through PCC. At this point to coordinate bidirectional current flow, the Microgrid controllers must be always vigilant to monitor voltage , current, frequency, active and reactive powers.

Lot of inverter control topologies are implemented in Microgrids for proportional load sharing to the capacities of

DGs. The most sensitive stage of Microgrid is during transition from islanding to grid and islanding to resynchronization back to grid from islanding. After smooth change over to islanding, the Microgrid has to feed the loads to meet the demand as usual and has to be stable in steady state stage from transient state.

In this paper, it is discussed and implemented the robust controller which will cater to the transient state and smooth transition from grid to island mode.

As defined by DOE and CERTS, “ The Microgrid is a network consisting of a group of interconnected DERs and Loads within a clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode”.

In grid mode the voltage and frequency is set by grid and DG inverters to feed power to loads and also export power to grid.

Islanding is not desirable [1]. But the Microgrid must operate in both the modes. Islanding is of 2 types,

1. Unintentional: Islanding is required when there is a fault in the grid and Microgrid[2].
2. Intentional: Islanding is required when maintainance is to be done on Grid or Microgrid

During grid mode, the voltage is sensed by Synchronous PLL, the static switch smoothly isolates the microgrid, bringing it to islanding. This is called Islanding Detection Method[3].

There are a lot of islanding detection methods which are discussed in the following sections.

In this paper the most robust method of SRF-PLL method is utilized to detect the islanding phenomena of considering virtual impedance, which is very well taking care of NDZ also. Finally the smooth transition is achieved through the robust islanding detection method and the Microgrid stability is achieved during transient stage and even after islanding to take care of voltage, frequency deviations and transients.

II. LITERATURE REVIEW

The heart of any Microgrid is controller. The controller must be capable enough to be stable in synchronous mode, to be stable in transition from grid to island mode, stable in island mode and must be ready to synchronize to grid again for exporting and importing for economical benefits. Nowadays , the Microgrids may be owned by consumers and they can become prosumer by supplying power to another Microgrid with agreed tariff arrangements. There are many islanding techniques which are listed in references. A few of them are discussed below [4] [5].

They are first classified as 1. Remote islanding technique 2. Local islanding technique. Again the local islanding techniques are devided into active and passive.

- Types of Islanding,

1. Active islanding,
2. Passive islanding

1. *Active Islanding:*

The active methods have been developed in order to overcome the limitations of the passive techniques in which NDZ is taken care. Generally, active methods intentionally introduce perturbances PCC to determine if they affect voltage, frequency and impedance parameters, in which case it is assumed that the grid has been disconnected.

- Sandia active frequency swift with positive feedback.
- Impedance measurement or harmonic injection.
- Detection of impedance at a specific frequency or monitoring of harmonic distortion
- Sandia Voltage Shift.
- Variation of Active or Reactive Power.

They have the advantage of excellent reducing or even eliminating the Non-detection zone (NDZ), but in order to achieve their purpose they may redcuce the quality of the grid voltage or even lead to instability. Although numerous techniques exist and their implementation varies, most of them are based on inverter based DG topologies. It is desirable for microgrid to be stable and robust as it is for practical engineering application.

2. *Passive Islanding :*

In these methods normally NDZ facility is not included. But in this paper a passive islanding detection is proposed with a robust inveretr controller topology which can take care of even NDZ facility with the introduction of virtual impedance in the line.

- Over-voltage/ under-voltage protection
- Over-frequency/ under- frequency protection.
- Voltage phase jump
- Voltage harmonic monitoring.
- Current harmonic monitoring

III. MICROGRID STRUCTURE

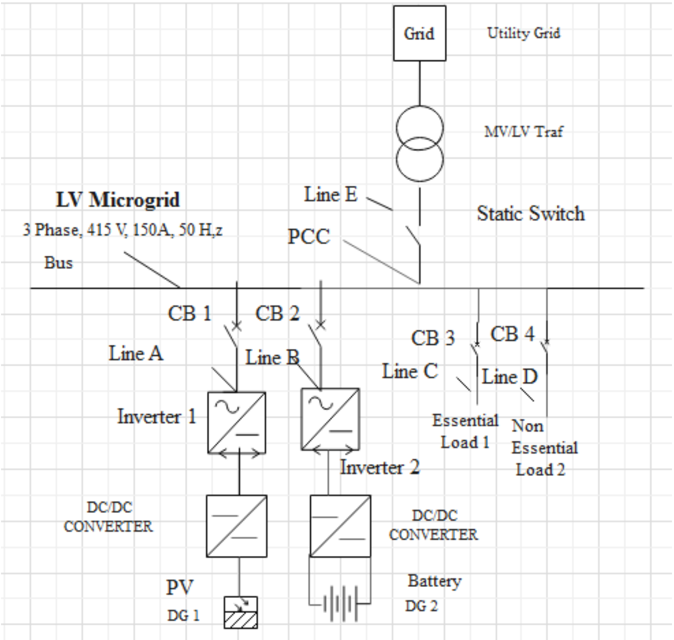

Fig.1:- Single line diagram of Microgrid structure

The Microgrid consists of a power control centre, in which grid incomer is connected through a static transfer switch for smooth transition between the transitions and all outgoing breakers are connected to DG interfaced inverters (PV and Battery Energy storage System)and loads. All these lines are connected via distribution lines or cables depending on requirement [6] [7]. The loads are segregated as essential and non-essential loads which are prioritized based on the custemer's specifications.

The Microgrid has to operate either with utility grid synchronized or has to independently work in islanded mode sharing the load power and maintaining voltage and frequency at PCC as per the DOE and CERTS.

The islanding is detected much before instability of Microgrid with the islanding detection method and brings back stability through smooth changeover from grid mode to island mode. Also it should reduce introduction of transients through filters.

The battery energy storage system is utilized to control voltage and frequency and DGs will try to supply active and reactive powers to the load proportional to their ratings. The reverse droop control method will cover this phenomena.

The loads are also prioritized as essential and non-essential loads. In the event of very serious perturbations the non-essential loads can be avoided by means of automatic load shedding panel. The Microgrid stability can be achieved through the control of voltage and frequency[8] [9].

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IV. ROBUST INVERTER CONTROLLER

There are two modes of control, one while in grid mode and another in island mode. They are CCM or VCM. They can also be called as P-Q control mode and V-f control mode [10] [11].

- *P-Q control*

The P-Q control is used for grid control The individual DGs are supposed to take care of proportional load sharing while the grid takes care of voltage and frequency. But during after islanding mode the controller has to take care of both P=Q and V-f controls. The controller scheme is shown Fig.2 below.

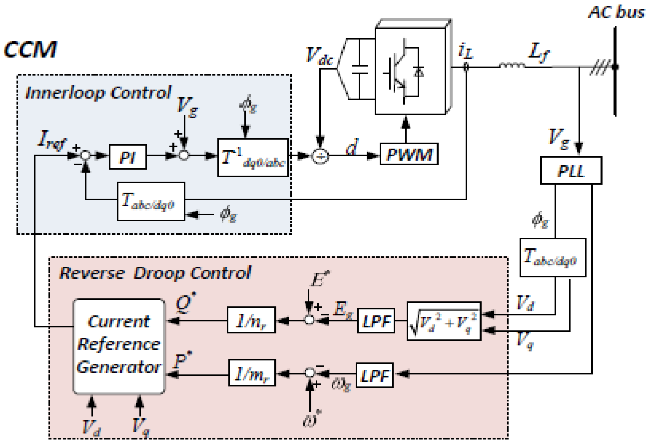

Fig. 2:- Grid connected controller

This includes grid voltage, frequency estimation, and current reference generator. A simple phase lock loop PLL is used for the estimation of grid voltage amplitude and frequency.

$$P^* = (\omega^* - \omega_g)/m_r \tag{1}$$

$$Q^* = (E^* - E_g)/n_r \tag{2}$$

The P^*, ω^*, Q^*, E^* are reference values of active power, frequency, reactive power , voltage of grid voltages at PCC. By assigning proper droop coefficients, the power sharing can be controlled [12] [13].

Reference *P** and *Q** is obtained. The reverse droop coefficient is designed within the limitation of

$$m_r = \frac{\Delta\omega}{P_{\max C}} \tag{3}$$

$$n_r = \frac{\Delta E}{Q_{\max C}} \tag{4}$$

*P*maxC and *Q*maxC are active power and reactive power of CCM DG unit [14] [15]. Active power can be shared among inverters but reactive power can not be shared due to unequal line impedances, which are given by

$$Q_{div} = \frac{E_{div}}{n_r} \tag{5}$$

$$\frac{Q_{div}}{E_{div}} = \frac{1}{n_r} \tag{6}$$

$$\frac{P_{div}}{\omega_{div}} = \frac{1}{m_r} \tag{7}$$

In which *Q*div and *E*div are the reactive power of inverters and voltage amplitude difference over output impedance between two DG units [16] [17]. It can be seen that depending on various reverse droop coefficients, the reactive power sharing and output voltage regulation is done and the direct axis, quadrature axis current references are given as,

$$i_{dref} = \frac{v_{gd}\cdot P^* + v_{gq}\cdot Q^*}{\sqrt{v_{gd}^{\;2} + v_{gq}^{\;2}}} \tag{8}$$

$$i_{qref} = \frac{v_{gq}\cdot P^* - v_{gd}\cdot Q^*}{\sqrt{v_{gd}^{\;2} + v_{gq}^{\;2}}} \tag{9}$$

Where *v*gd and *v*gq are the grid side voltages. *P** and *Q** are the active and reactive powers, regulated from reverse droop control.

- *V-f Control*

Voltage and frequency is to be controlled by the inverter controller in island mode [18] [19]. For this the battery energy storage system is used in VCM configuration, which is shown in Fig.3 below.

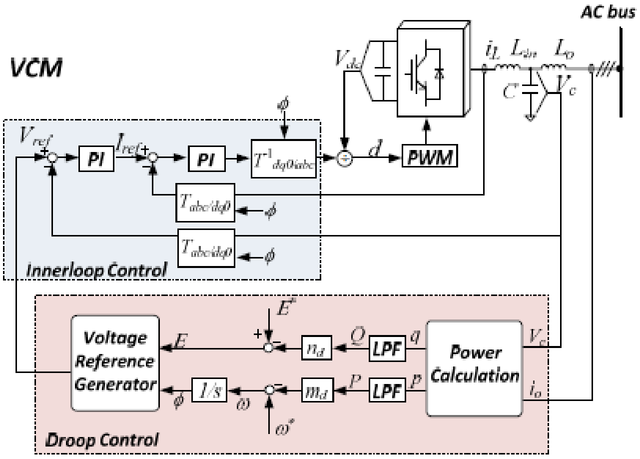

Fig 3:- islanded mode

This controller consists of power calculation block, droop method and voltage reference generator [20] [21]. The instantaneous power p and q to AC bus are given by,

$$m_d = \frac{\Delta\omega}{P_{\max V}} \tag{10}$$

$$n_d = \frac{\square E}{Q_{\max V}} \qquad (11)$$

In which,

$\Delta\omega$ = bus frequency deviation
ΔE = bus voltage deviation
PmaxV = maximum active power of VCM unit
QmaxV = maximum reactive power of VCM unit

The LPF block represents a low-pass filter for the power calculation which determines the primary loop bandwidth [22] [23] . Finally, the output voltage command which is sent to the innerloop voltage control, generated as $V\,dref$ □□E and $V\,qref$ □□0. [24] [25].

- *Re-synchronization back to Utility grid*

This is not considered in this paper. In the future publication, this will be taken care.

V. MATLAB SIMULATION AND ANALYSIS

This methodology has been tested in Matlab / Simulink and the results are discussed.

- *Matlab Simulation parameters*

To check the correctness and validity of the proposed method, the paper used Matlab /Simulink as per the single diagram of Fig.1.

In this Mmicrogrid two DGs are utilized , one is PV solar (DG1) in parallel with Battery Energy Storage, the parameters are given below,

DG1 (PV):
Pref1=10KW, Qref1=1KVar

DG2:
Pref2=20KW, Qref2=0KVar, utility voltage is 400V,

The grid frequency is 50HZ. In the V/f control strategy parameter,Vdref=380V, Vqref=0V.

DG1 and DG2 line impedances are,
Resistor: R=0.64Ω/km, inductance:
Inductance: L=0.1H/km.

Battery storage, the terminal voltage is 280V,
Rated amp-hour capacity is 70Ah.

Constant power load:
P1=10kW,Q1=1000var;
P2=20kW,Q2=5000Var,
P3=10kW,Q3=0Var.

- *Matlab Simulation Results Analysis and Discussion*

The sampling period is 1 Sec.

Analysis::

1) From 0-0.3s moment, the Microgrid is in grid-connected mode, DG1, DG2 are in PQ control, battery is in SOC,
2) At =0.3s, the utility grid goes through a three phase short circuit fault. Then the Microgrid detects islanding through , SRF-PLL islanding detection method and the Microgrid is isolated at PCC through Static Transfer Switch.The energy storage battery goes to discharge state and is controlled by the V/f improve., taking the droop control method [26] [27].
3) At =0.6s, the Microgrid is stable to re-synchronize to Grid waiting for the command from PLL loop of Microgrid.
4) At =0.65s, the Microgrid is reay in all aspects to switch over to grid-connection mod, which will be discussed in future paper.
5) After resynchronization, energy storage goes into the charging state from discharging mode.

- *Simulation Results*

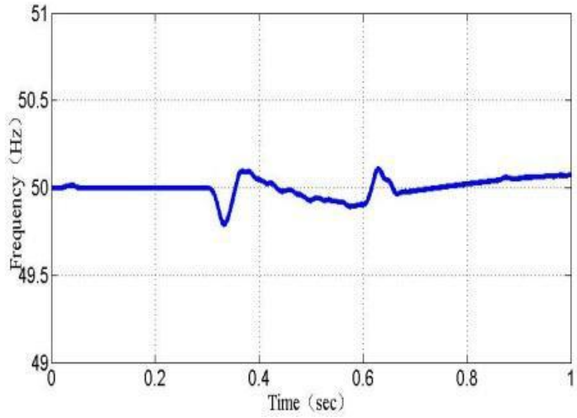

Fig. 4:- Bus Frequency vs Time

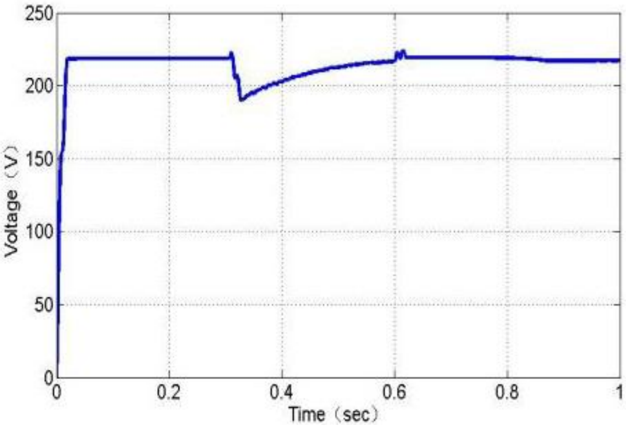

Fig.5:- Bus Voltage vs Time at PCC

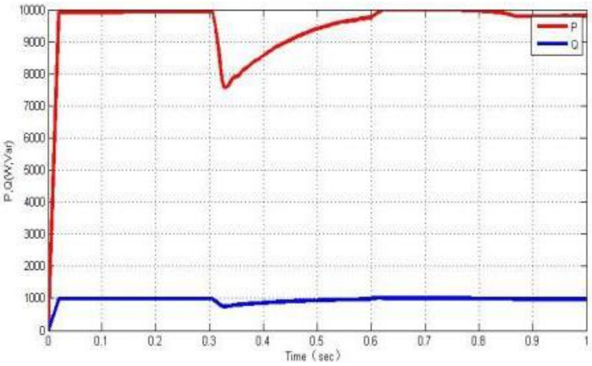

Fig.6 Active and Reactive powers of DG 1

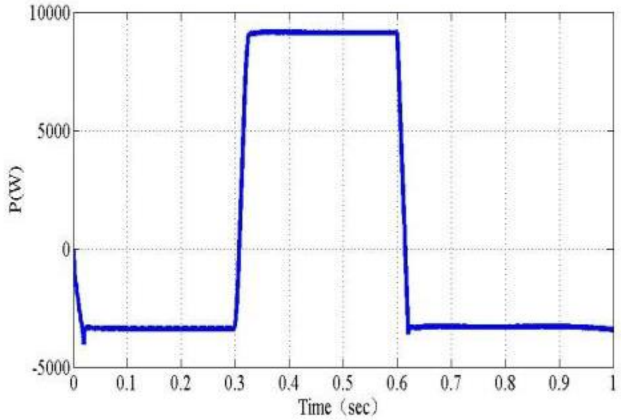

Fig.7 Active power of Battery

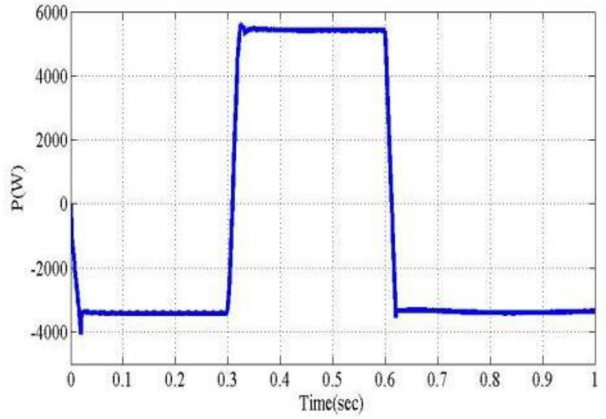

Fig. 8 Reactive power of Battery

VI. RESULTS DISCUSSION

In Figure. 4: The Microgrid and Utility Grid are in synchronism with the steady state mode. The fluctuations of the Microgrid voltage and frequency are within the limits as per IEE 1547 standard. The system could align with the requirements of stable operation.

In Fig.5: As islanding detection activated at 0.3 secs, the voltage and frequency have some deviations, but could quickly to deviation limits, as storage responded.

As shown in Figure 6: DG1 is in PQ control mode and hence output active and reactive powers shared proportionally, following the change of the reference values.

From Figure 7 & 8: Storage has been in a state of charge in grid-connection mode, and when the Microgrid went to island mode, energy storage is in discharge mode with V/f droop control, providing the voltage and frequency to Microgrid to ensure the system stability, and promptly fill the gap of both active and reactive power.

VII. CONCLUSIONS

Microgrid can change over from grid mode to islanding with very little perturbations as per Microgrid definition of DOE, CERTS and IEE 1547 standards. In this paper SRF-PLL methodology adopted which is proved to be effective taking care of internal control and primary droop control loops. The results of the simulations shows the effectiveness and validity of proposal. In this paper the resynchronization back to Utility Grid is not considered, which will be considered in the future paper.

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