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Design and Analysis of Hierarchical control Structure for Islanded microgrid

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ABSTRACT: This paper presents a distributed hierarchical control framework to ensure reliable operation of microgrid (MG) clusters. This hierarchical control structure consists of primary, secondary, and tertiary levels, and is a versatile tool in managing stationary and dynamic performance of microgrids while incorporating economical aspects. In this hierarchy, primary control is used to regulate the common bus voltage inside each MG locally. A small-signal model is developed to investigate effects of the system parameters, constant power loads, as well as line impedance between the MGs on stability of these systems. In the secondary level, a distributed consensus-based voltage regulator is introduced to eliminate the average voltage deviation over the MGs. This distributed averaging method allows the power flow control between the MGs to be achieved at the same time, as it can be accomplished only at the cost of having voltage deviation inside the system. The proposed distributed controllers on each MG communicate with only the neighbor MGs through a communication infrastructure. Finally, the developed small-signal model is expanded for MG clusters with all the proposed control loops. The effectiveness of the proposed hierarchical scheme is verified through Simulation.

KEYWORDS: Distributed generation, Distributed cooperative control, multi-agent systems, synchronization

I. INTRODUCTION

Recent energy development encourages entry of renewable resources and energy storage device in distribution areas. Due to shortage of conventional fuel like coal, gases and other chemical resources their prices escalating day by day and it's create an Energy crisis in modern Era. Also greenhouse gas emission, acid rain and water pollution find environmental issues with use of conventional fuel. Large network of electricity deviate voltage and frequency at consumer end which affect the power quality & reliability of energy. In modern year increase energy demand with increase comfort level and development .due to all these issues efficiency of conventional energy generation is very poor at consumer end so we need to move on green sustainable energy of resources. These notions emerge a new technology micro grid which is pure green and sustainable source of energy[1]. Distribution level of micro grid Improved sustainability with reliability among desired Energy demand. Effective integration of renewable resources realized with micro grids which facilitate the reliable and sustainable power among distribution consumers .Micro grid is combination of single controllable unit of small distributed generators and loads which provide power and heat at same time. The micro grid located downstream of electrical distribution network which encompasses with various variety of renewable energy resources, distributed storage, different types of load and utility grid. Point of common coupling (PCC) is common point which connect to micro grid with utility grid[2] . conventional electric power systems are facing continuous and rapid changes to alleviate environmental concerns, address governmental incentives, and respond to the consumer demands. The notion of the smart grid has recently emerged to introduce an intelligent electric network. Improved reliability and sustainability are among desired characteristics of smart grid affecting the distribution level. These attributes are mainly realized through microgrids which facilitate the effective integration of Distributed Energy Resources (DER).

II. CONTROL OF MICROGRID

The primary control is designed to satisfy the following requirements [2]-[3], [5]:

- To stabilize the voltage and frequency: Subsequent to an islanding event, the micro grid may lose its voltage and frequency stability due to the mismatch between the power generated and consumed.
- To offer plug and play capability for DGs and properly share the active and reactive power among them, preferably, without any communication links.
- To mitigate circulating currents that can cause over-current phenomenon in the power electronic devices and damage the DC-link capacitor.

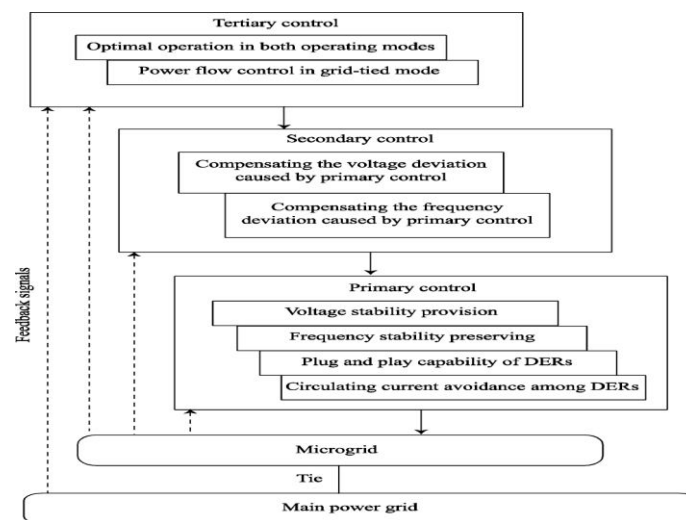


Fig. 1. Hierarchical control levels of a microgrid.

The primary control provides the reference points for the voltage and current control loops of DGs. These inner control loops are commonly referred to as zero-level control. The zero-level control is generally implemented in either active/reactive power (PQ) or voltage control modes [3]. In the PQ control mode, the DG active and reactive power delivery is regulated on the pre-determined reference points. The control strategy is implemented with a current-controlled voltage source inverter (CCVSI). H1 controller regulates the DC-link voltage and the active power through adjusting the magnitude of the output active current of the converter, i_p . H2 controller regulates the output reactive power by adjusting the magnitude of the output reactive current, i.e., i_q [4]. In the voltage control mode, the DG operates as a voltage controlled voltage source inverter (VCVSI) where the reference voltage, v_o^* , is determined by the primary control, conventionally via droop characteristics [5]. The nested voltage and current control loops in the voltage control mode are shown in Figure 1-4. This controller feeds the current signal as a feed forward term via a transfer function (e.g., virtual impedance). To fine tune the transient response, proportional-integral-derivative (PID) [5], adaptive [6], and proportional resonant controllers [7] are proposed for the voltage controller. Power quality of small-scale islanded systems is of particular importance due to the presence of nonlinear and single-phase loads and the low inertia of the micro grid [8]. To improve the power quality for a set of energy sources connected to a common bus, the control structure is used. HLPF (s) denotes the transfer function of a low-pass filter. Each converter has an independent current control loop, and a central voltage control loop that is adopted to distribute the fundamental component of the active and reactive powers among different sources. The reference point for the voltage control loop is determined by the primary control. The individual current controllers ensure power quality by controlling the harmonic contents of the supplied currents to the common AC bus [9]. The DG's control modes are usually implemented using the droop characteristic techniques [3]. The droop control method has been referred to as the independent, autonomous, and wireless control due to elimination of intercommunication links between the converters. The conventional active power control (frequency droop characteristic) and reactive power control (voltage droop characteristic) are used for voltage mode control. Principles of the conventional droop methods can be explained by considering an equivalent circuit of a VCVSI connected to an AC bus. If switching ripples and high frequency

harmonics are neglected, the VCVSI can be modeled as an AC source, with the voltage. In addition, assume that the common AC bus voltage is V_{com} and the converter output impedance and the line impedance are lumped as a single effective line impedance of Z .

Primary control, as discussed, may cause frequency and voltage deviation even in steady state. Although the storage devices can compensate for this deviation, they are unable to provide the power for load-frequency control in long terms due to their short energy capacity. The secondary control, as a centralized controller, restores the micro grid voltage and frequency and compensate for the deviations caused by the primary control. This control hierarchy is designed to have slower dynamics response than that of the primary, which, justifies the decoupled dynamics of the primary and the secondary control loops and facilitates their individual designs [6]. the block diagram of the conventional secondary control with a centralized control structure. Frequency of the micro grid and the terminal voltage of a given DG are compared with the corresponding reference values, f_{ref} and v_{ref} , respectively. Then, the error signals are processed by individual controllers as in [1,5]; the resulting signals (f and E) are sent to the primary controller of the DG to compensate for the frequency and voltage deviations. Frequency controller in [7] to facilitate synchronization of the micro grid to the main grid. In the islanded operating mode, this additional term is zero. However, during the synchronization, a PLL module is required to measure [4]-[8]. During the grid-tied operation, voltage and frequency of the main grid are considered as the references in [9]. The secondary control can also be designed to satisfy the power quality requirements, e.g., voltage balancing at critical buses [10].

Tertiary control is the last (and the slowest) control level that considers the economic concerns in the optimal operation of the micro grid, and manages the power flow between micro grid and main grid [12]. In the grid-tied mode, the power flow between micro grid and main grid can be managed by adjusting the amplitude and frequency of DGs voltages.. First, active and reactive output powers of the micro grid, PG and QG, are measured. These quantities are then compared with the corresponding reference values, ref_{PG} and ref_{QG} , to obtain the frequency and voltage references.

III. PROPOSED METHODOLOGY

The proposed control is based on large-signal nonlinear dynamical model of the DG. The block diagram of an inverter-based DG is contains a primary dc power source (e.g., photovoltaic panels or fuel cells) connected to an inverter bridge.

a)Primary Control

The droop control method is being used in conventional generators of power plants. In autonomous operation of converter based DG systems, this method can be adopted to share total load besides controlling voltage magnitude and frequency in a special range. In this control unit the active power of total load can be shared by drooping the frequency as a function of output active power of converter. Furthermore, one can droop output voltage magnitude of converter against its output reactive power to share total load reactive power. As it is shown in below equation, two coefficients control the slope of change of frequency and voltage against active and reactive power respectively.

$$\omega_i^* = \omega_n - m_{pi} P_{si}$$

$$V_{mi}^* = V_n - n_{qi} Q_{si}$$

Where ω_n and V_n are rated frequency and rated voltage of the system, respectively. m_{pi} , n_{qi} , P_{si} and Q_{si} are active power droop coefficients, reactive power droop coefficient, output active power and output reactive power of converter, respectively.

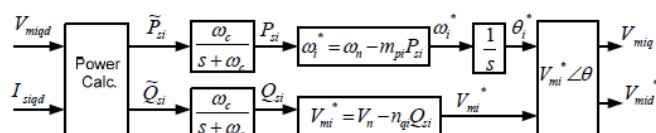


Fig.2. Block diagram of Primary Control

the amount of droop coefficients are defined. The active power droop coefficient is based on maximum change of frequency that is considered 1% against maximum change of active power of converter which is nominal power of the converter. Fig. 2 shows the primary control unit in details. First the instantaneous output active and reactive power of the converter are calculated using measuring output current of the converter and load voltage. The outputs of droop control are voltage magnitude and angular frequency which define the reference angle of the load voltage using an integrator.

b) Secondary Control

1) Voltage Control

To follow the load reference voltage, produced from primary control, a PI voltage controller is designed. From Fig. 2 and dynamic equation of the system in Laplace format:

$$C_{di} p V_{miq} = I_{siq} - I_{ijq} - I_{Liq} - I_{iq} - I_{iNonq} - \omega_{si} C_{di} V_{mid}$$

$$C_{di} p V_{mid} = I_{sid} - I_{ijd} - I_{Lid} - I_{id} - I_{iNond} + \omega_{si} C_{di} V_{miq}$$

$$C_{di} p V_{miq} = k_{miq}(s)(V_{miq}^* - V_{miq}) = \sigma_{miq}$$

$$C_{di} p V_{mid} = k_{mid}(s)(V_{mid}^* - V_{mid}) = \sigma_{mid}$$

For a fast voltage control response a small time constant is needed; but it shouldn't be very small like smaller than the switching time interval. Using the output of voltage controller, the reference output current of converter can be defined.

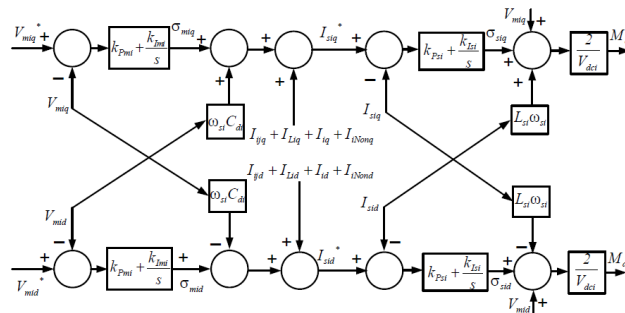


Fig.3. Block diagram of Secondary Control

2) Current Control

After controlling the load voltage magnitude and defining the current reference, the current controller will follow its reference. The advantage of inner current control is that one can put a limiter in the reference current so as to apply an inherent current protection to the system, especially the power electronic converter which has a limited rated capacity. The inner current controller is designed, using qd axis dynamic equations of the system as follows:

$$L_{si} s I_{siq} + R_{si} I_{siq} = M_{qi} \frac{V_{dci}}{2} - V_{miq} - L_{si} \omega_{si} I_{sid}$$

$$L_{si} s I_{sid} + R_{si} I_{sid} = M_{di} \frac{V_{dci}}{2} - V_{dmi} + L_{si} \omega_{si} I_{siq}$$

Therefore one can calculate the PI controller parameters of current controller using the time constant of controller, resistance and inductance of output transmission line of converters. Because current controller is the most inner control unit, it should be the fastest controller. Therefore its time constant is chosen to be half of the voltage controller or five times of switching frequency time intervals.

c) Tertiary Control

This level is an interface level that can realize load sharing among MGs automatically as well as enable the plug-and-play capability of each MG. In addition, the proprietary information of each MG can be well protected by introducing this level. The droop control is modified to control the output power through the PCC of MGs

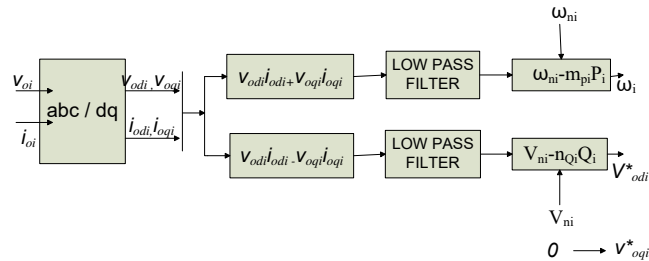


Fig. 4. Block diagram of Tertiary control

The Tertiary controller block diagram shown in Fig. 4. with droop technique which provides the voltage references v_{odi}^* and v_{oqi}^* of the voltage controller and operating frequency ω_i to the inverter bridge

IV. SIMULATION AND RESULT ANALYSIS

To verify the operation of the system and controllers, the autonomous system with the three converters as DG units is simulated in MATLAB/Simulink software. To show the process of load sharing when DG units have different nominal powers, the rated power of converter are show below.

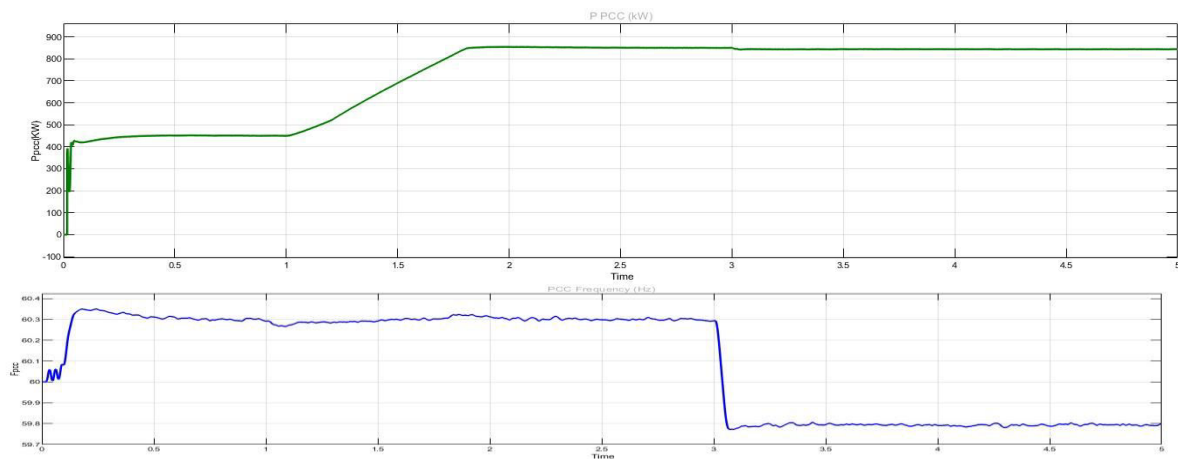


Fig.5 Active power and Frequency response of DG's

As we know, the secondary controller initialization time should be after the time in which the primary controller is reached into its steady state condition. As it is expected the secondary controller should not change the steady state operation point of the system.

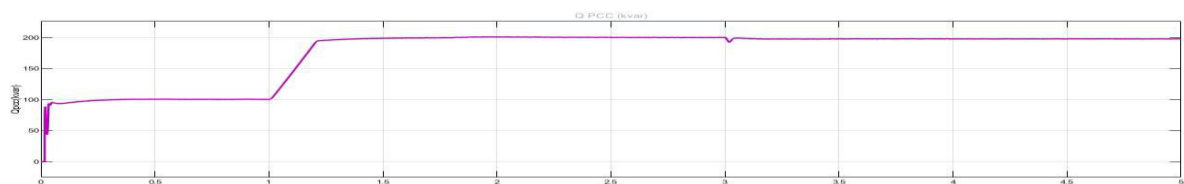


Fig.6 Reactive power response of DG's

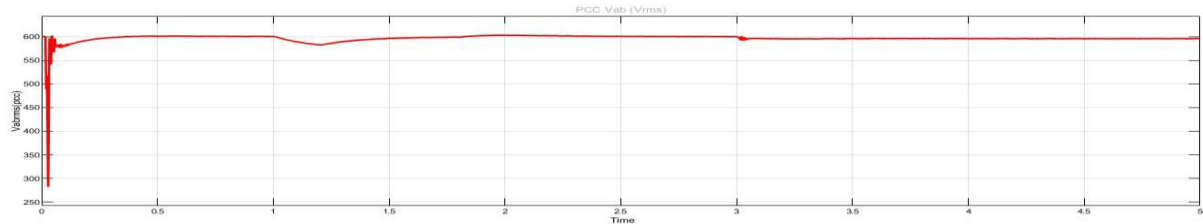


Fig.7 Output Voltage response of DG_s

V. CONCLUSION

As above result we find that distributed control is more stable and suitable for grid connected microgrid .all parameter of voltage and current take as a feedback for distributed control and we take V_{dc} as reference then finalize more conclusions. In this paper, a control approach for improving the transient behavior of islanded microgrid is presented. This inverter-based microgrid employs the secondary controller to equalize the amount of active and reactive while restoring the frequency and voltage of microgrid system. This secondary controller is decentralized and each DG has its own secondary controller. Thus there is no need for any high bandwidth communication link and the reliability of system is improved. The feed-forward loop enhance the stability of system by transferring the dominant eigenvalues to the larger values in left half-plan. The scenario based simulation results show the validity of proposed approach using a typical microgrid derived from IEEE 399 Std. and simulated in MATLAB.

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