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A Review on Secondary and Tertiary Control Structures for Microgrid

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***Abstract*—** With the large scale integration of Distributed Energy Resources (DERs) into the existing power system, there has been a significant impact on the operation of distribution networks; the major impacts being power quality problem along with congestion and voltage regulation issues. This demands coordinated control approaches which allow Distributed Generation (DG) units to actively participate in voltage and frequency regulation. To realize the same, hierarchical control structures constituting the primary, secondary and tertiary control structures are implemented. These controllers are classified as the centralized or the decentralized type. Thus by employing droop controls or impedance based controls desirable outcomes such as power sharing, non linear load sharing and harmonic reduction is possible thanks to coordinated operation of secondary and tertiary control layers with primary or local layer. This paper aims at establishing a basic understanding of these control layers as applied to AC and DC microgrids along with detailed explanation of modified structures from the conventional control structures in a typical microgrid.

***Keywords*—**Microgrid, Secondary Control, Tertiary Control, Distributed Generation, Droop control, Virtual Impedance Control.

I. INTRODUCTION

A microgrid allows for different power generation technologies of varied power ratings to be integrated with the main grid at the distribution level. The complexity of this arrangement requires the implementation of hierarchical control structure focused on minimizing the operation cost, while maximizing efficiency, reliability, and controllability. To ensure a proper regulation of the point of operation, the hierarchical control of microgrids is formulated into three main layers, i.e., primary, secondary, and tertiary control. The primary control also known as the local control is responsible for controlling the local variables like the frequency and voltage as well as the amount of injection of current. These local controllers involve implementation of dedicated droop and virtual impedance control schemes for power converters in microgrid. The secondary control operates in a centralized fashion to reduce steady state errors in microgrid voltage and frequency apart from controlling the voltage profile long the ac buses in order to keep them within limits. This layer of control requires communications and wide area monitoring systems to ensure coordination among various generation units in a particular area. It has a slow dynamic response as compared to primary control because its time response is in the range of minutes. Finally, the tertiary control level is responsible for controlling the active and reactive power references for each Distribution generation unit thereby optimizing the microgrid operation. The tertiary control level is also in charge of managing eventual congestions, restoring the secondary control reserve and giving support to the secondary control if necessary. From above discussion it is clear that the role of secondary and tertiary control is critical in a microgrid and so the main focus of this paper will be to understand their structures and operations.

The paper has been organised into five sections. Section I deals with the introduction to microgrid and its control layers. Section II and III deals with secondary control strategies for DC and AC microgrid respectively. Section IV elaborates the functioning of tertiary control which forms the top most control layer in a microgrid. Conclusions and future work has been discussed in section V.

II. SECONDARY CONTROL IN DC MICROGRIDS

The secondary control forms the second control layer in the hierarchy which takes care of voltage, power sharing, current and frequency deviations. In a DC microgrid, this layer controls voltage deviation from microgrid reference voltage whereas in AC microgrid, it controls frequency and voltage deviations. Fig 1 shows the block diagram representation of the hierarchy of controls in a DC microgrid and Fig 2 shows a more elaborate description of the role of secondary control as applied to DC microgrid. From Fig 2 it is clear that secondary control sets parameters for primary (droop) control to compensate for deviations. It does so by establishing a comparison of DC bus voltage with the microgrids reference voltage to generate error which is then passed through PI controller thereby reducing the steady state error. In this manner corrective signals are sent to droop controllers which act accordingly to ensure proportional load sharing among various Distributed Generation (DG) units.

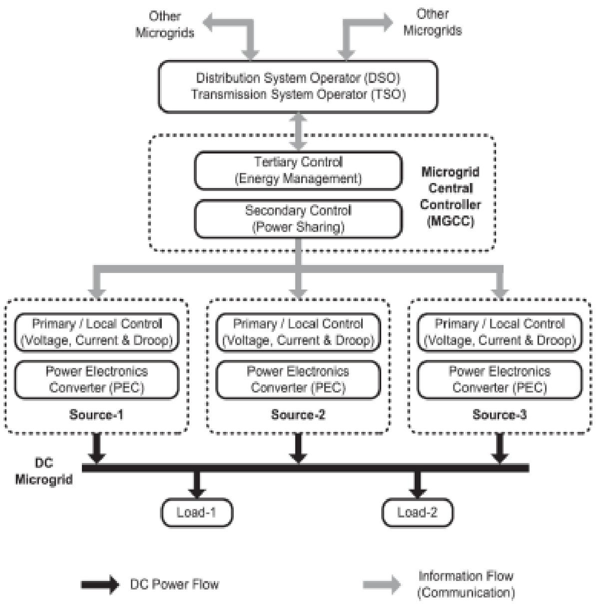

Fig 1 Block diagram Representing Hierarchy of Control Layers in a Typical Microgrid [1].

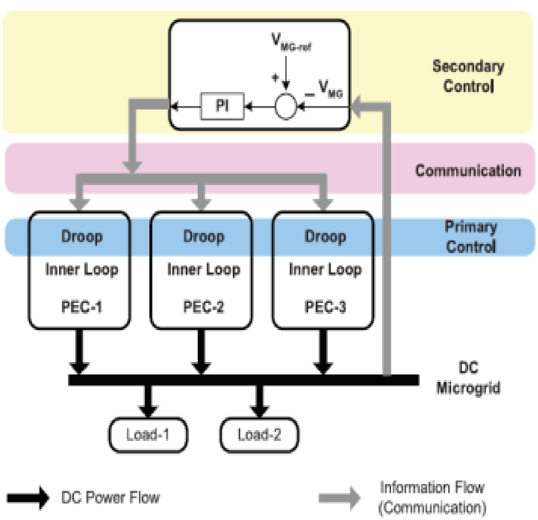

Fig 2 Block Diagram of Secondary Control applied to DC Microgrid [1].

By effectively shifting the droop characteristics on the voltage axis and by adding a suitable factor δv to the droop equation we can maintain the voltage levels in microgrid. The secondary control decides this value of δv as [2][3],

$$\delta v = K_P(V_{MG}^* - V_{MG}) + K_I \int_0^t (V_{MG}^* - V_{MG})dt \quad (1)$$

Where, V_{MG}^*= microgrid reference voltage, V_{MG}= microgrid voltage.The voltage corrections can also be done using current measurements as follows,

$$\delta v = \delta v_1 - \delta v_2 \quad (2)$$

$$\delta v_2 = H(s).\delta i_i \quad (3)$$

$$\delta i_i = \sum_j (i_i^{pu} - i_j^{pu}) \quad (4)$$

Where, H(s) is a PI controller and δv_1 is same as above.

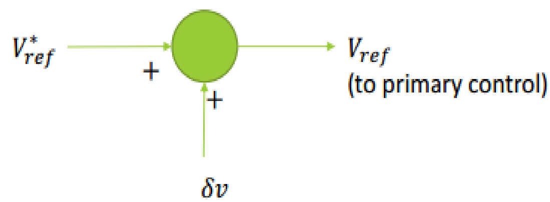

Fig 3 Generation of Voltage Reference for Primary Control.

It is important to realize that the secondary control requires communications. It can either have a centralized or decentralized structure. In centralized topology (Fig 4), the microgrid central controller commands voltage correction to all primary controllers whereas in decentralized or distributed topology (Fig 5) the sources exchange theit voltage and current measurements, compute the voltage correction locally and command their local primary control accordingly. Alternatively, there can be a mix of centralized and distributed secondary control system.

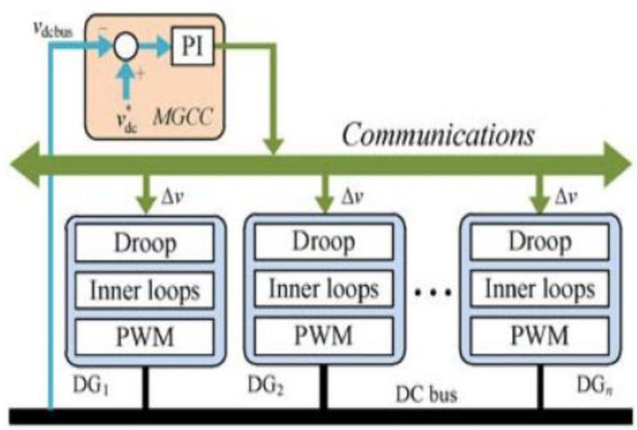

Fig 4 The Secondary Control Centralized Topology for DC Microgrids [4].

Fig 6 shows an improved technique as applied to distributed secondary control in microgrid. The aim is to establish a proportionate current sharing among the DG units by enhancing its dynamic performance using droop controllers. A low bandwidth communication link is employed for transfer of voltage and current signals.

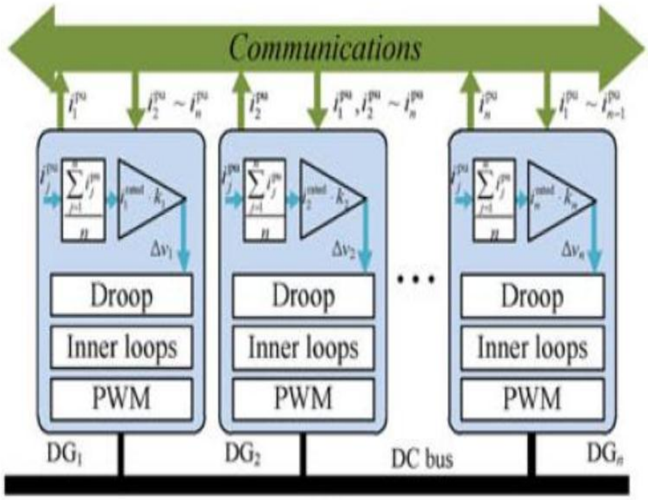

Fig 5 The Secondary Control Decentralized Topology for DC Microgrids [5].

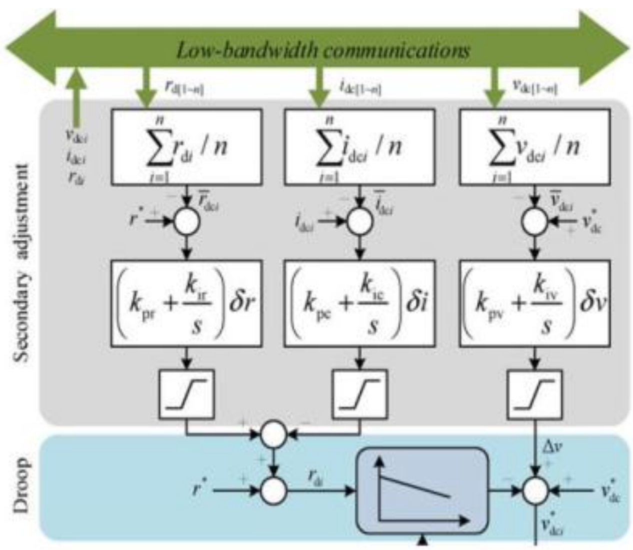

Fig 6 An Improved Technique of Distributed Secondary Control in DC microgrid for ensuring Proportionate Current Sharing among the DG units [6].

III. SECONDARY CONTROL OF AC MICROGRIDS

As discussed above, the secondary control in AC microgrid compensates for voltage and frequency deviations by commanding an additional correction in droop control for frequency and voltage as shown by equations (5) and (6) This is similar to voltage deviation correction in DC microgrid. The control is synchronized with the grid and tackles issue of voltage unbalance and harmonics. Following are the frequency and voltage corrections [7],

$$\delta f = K_{Pf}(f^*_{MG} - f_{MG}) + K_{If}\int_0^t (f^*_{MG} - f_{MG})dt \qquad (5)$$

$$\delta E = K_{PE}(E^*_{MG} - E_{MG}) + K_{IE}\int_0^t (E^*_{MG} - E_{MG})dt \qquad (6)$$

These corrections can be used under any R/X condition of microgrids. The frequency/voltage corrections is common for all distributed energy resources. The system is normally managed by Microgrid Centralized Controller. Even in AC microgrids, the secondary control can be applied as a centralized or a decentralized structure. Fig 7 illustrates centralized scheme and Fig 8 illustrates decentralized scheme both of which employs droop control and virtual impedance for controlling the inverter output.

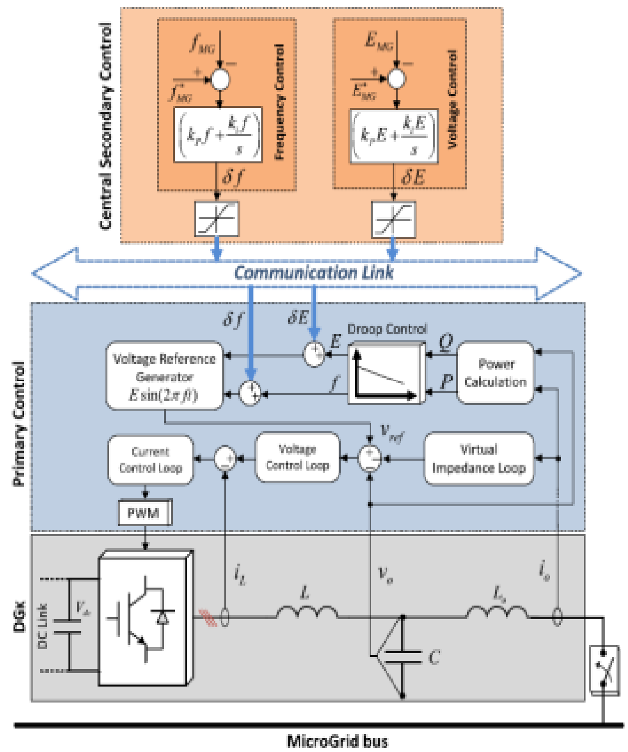

Fig 7 The Secondary Control Centralized Topology for AC Microgrids [7].

The problem with the above mentioned schemes is that the reactive power is not controlled in a precise fashion by the E-Q droop control because voltage and phase of DG units and the impedance between DG units may be different. Thus, reactive power is not shared equally. This is similar to droop and current sharing problem in DC microgrids. The problem can be overcome by introducing Q sharing error at individual DG level by [7],

$$\delta E_2 = K_{PQ}\Delta Q_{DGk} + K_{IQ}\int_0^t \Delta Q_{DGk}\, dt \qquad (7)$$

$$\Delta Q_{DGk} = \bar{Q}_{DG} - \bar{Q}_{DGk} \qquad (8)$$

$$\bar{Q}_{DG} = avg_k(Q_{DGk}) \qquad (9)$$

The control structure suggests that every DG unit communicates its value of Q_{DGk} to microgrid central controller which then sends out the correction command.

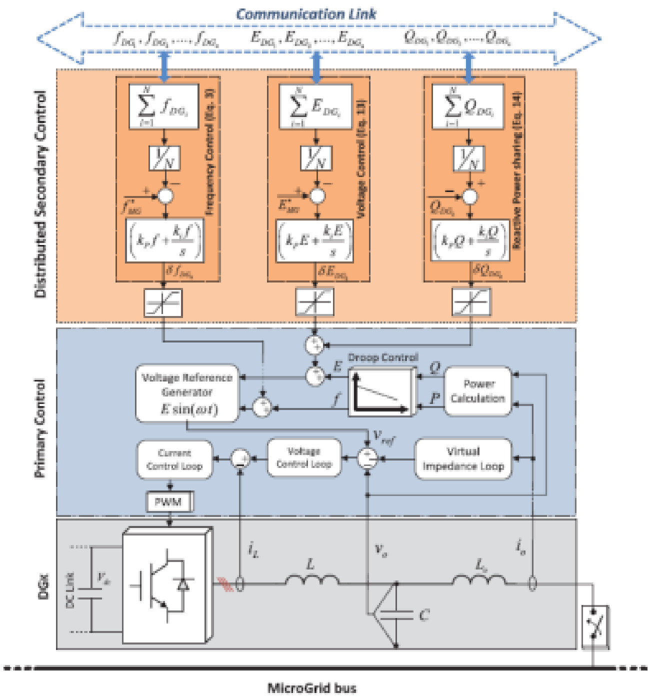

Fig 8 The Secondary Control Decentralized Topology for AC Microgrids [7].

IV. TERTIARY CONTROL OF MICROGRID

Tertiary control of microgrid acts as an energy management unit. It communicates with the distribution system operator (DSO) or Transmission System Operator (TSO) and the secondary control. DSO/TSO decides the power exchange schedule within the microgrid while the tertiary control prepares the source and storage dispatch schedule. It basically looks after the following-

- Power import/export between grid and microgrid in grid-connected mode.
- Power sharing between sources of microgrid in islanded mode.
- Optimization algorithms.
- Commands the microgrid reference or operation points.

The following equation is realized by the controller,

$$\delta V_{MG} = K_{PV_{MG}^*}(I_G^* - I_G) + K_{IV_{MG}^*}\int_0^t (I_G^* - I_G)dt \qquad (10)$$

$$\delta\omega^* = K_{P\omega^*}(P_{MG}^* - P_{MG}) + K_{I\omega^*}\int_0^t (P_{MG}^* - P_{MG})dt \quad (11)$$

$$\delta E_{MG}^* = K_{PE_{MG}^*}(Q_{MG}^* - Q_{MG}) + K_{IE_{MG}^*}\int_0^t (Q_{MG}^* - Q_{MG})dt \quad (12)$$

I_G is the current flowing in/out of microgrid, I_G^* is desired current flow in/out of microgrid. These are the desired deviation in the set point for microgrid voltage and frequency.

V. CONCLUSIONS

The paper discusses hierarchical control structures for AC and DC microgrid for both grid connected and islanded modes. The secondary control using the microgrid central controller is a popular method of centralized control. Microgrid Central Controller is used for the voltage and frequency set-point retrieval as well as for altering the power sharing by considering the line impedance. The main drawback of this centralized control is that if the microgrid central controller fails, the entire system goes down. This problem is then overcome by a decentralized control structure which individually takes care of frequency, voltage, active and reactive power sharing via the droop controllers. Tertiary control is implemented in a centralized fashion, e.g., for economic optimization or communication with the distribution network operator to provide ancillary services. The secondary and tertiary controllers modify the set points of the primary control schemes.Thus the various topologies of controls adopted for AC and DC microgrid has been elaborated in detail.

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Authors Profile

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