Power Management and Decentralized Control of Interlinking Converter by Interfacing AC and DC Micro grids
Girija .R, Dr.Arivalahan .R

Abstract- Microgrid have been accepted concept widely for the better interconnection of DGs. Corresponding to the conventional power system ac microgrid have been proposed, particularly increasing the use of renewable energy sources generate dc power which need a dc link for the grid connection and as a result of increasing modern dc loads. Dc microgrid have been recently emerged for their benefits in terms of efficiency cost and no of conversion stages. The ac microgrid are dominant in power system, but it doesn't replaced by the dc microgrid, so we are interfacing ac and dc microgrid by interlinking converter (IC) for proper power management and decentralized control, which exploiting the prominent features of both ac and dc microgrid. During the islanding operation of the hybrid ac/dc microgrid, the IC is intended to take the role of supplier to one microgrid and at the same time acts as a load to the other microgrid and the power management system should be able to share the power demand between the exiting ac and dc sources in both the microgrids. This paper considers the power flow control and management issues amongst multiple sources distributed throughout both ac and dc microgrids. The paper proposes a decentralized power sharing method in order to eliminate the need for communication between DGs or microgrids. The performance of the proposed power control strategy is validated for different operating conditions, using simulation studies in the MATLAB software environment.

Keywords: Decentralized control strategy, hybrid ac/dc micro grid, interlinking ac/dc converter, power management.

I. INTRODUCTION

Due to increasing the development of DGs in power system and managing the power from DGs by using the grid is the major concern. So micro grid is the accepted concept for the better interconnection of DGs in to the grid. Corresponding to conventional power system AC micro grid has been proposed. Now a days we are using renewable energy sources which mostly generated DC power which need a DC link for the grid connection, so it emerged the ac micro grid, which increasing the use of modern DC loads for their benefits in terms of efficiency, cost and system that can eliminate the dc-ac, ac-dc power conversion stages and their power losses. Now a days we are purely depends on power grid which are ac type, which is dominant, but the emerged of DC grid does not replace the AC grid totally. So we are interfacing AC and DC micro grid, which are linked by interlinking converter (IC). This is the bidirectional ac/dc converter which establishing a hybrid ac/dc micro grid. Like other micro grid the hybrid ac/dc micro grid can operate in any of these three modes.

Grid connected, Islanding mode, Transition mode. Therefore a suitable control strategy is required to coordinate the operation of dc sources ac sources and IC, which need a fast communication link reliability concern, which uses a decentralized control among which droop control method can be used for which proper power sharing between ac and dc micro grid. During islanding operation the IC act as a role of supplier to one micro grid at the same time act as load to other micro grid and shares the power demand between existing sources. Another challenge is that since the generated power in each micro grid is limited the power management system should be able to share the power demand between the existing ac and dc sources. Therefore a specified droop control method is needed to coordinate the power flows and to cover acceptable power sharing. A two stage modified droop method is used for the bidirectional power control of the IC during different operation modes of the hybrid ac/dc micro grid. By measuring the ac micro grid frequency and the dc micro grid voltage and using proposed droop characteristic. The power management strategy provides the power reference for the IC control to share the power demand between the existing power sources in both ac and dc micro grid. Through this control strategy, the two micro grids can be treated as a unified micro grid in which the demanded load power can be shared between the existing energy sources in this hybrid micro grid. Therefore, the installed power reserve can support the two micro grids commonly and it allows reduced amount of reserve power for each micro grid. The primary contribution of this project during islanding operation IC plays a vital role to manage the demanded power between ac and dc micro grids.

- The positive IC power flow which indicates that the excess power in the ac micro grid will be transfer to the dc micro grid.
• The negative IC power flow which indicates that the excess power in the dc micro grid will be transfer to the ac micro grid.

Power for each micro grid. This paper is organized as follows. In Section II, the hybrid ac/dc micro grid structure and operation modes are described. Droop control strategy for individual ac micro grids and dc micro grids is explained in Section III. Operating states of the hybrid micro grid and the proposed IC control during islanding are discussed in Section IV. In Section V, the performance of the proposed control strategy is demonstrated through time domain simulations; and finally the conclusion is given in Section VI.

NOMENCLATURE
- Power demand of load in dc microgrid
- Power demand of load in ac microgrid.
- Power generated by energy source in dc microgrid.
- Power generated by energy source in ac microgrid.
- Power imported to hybrid ac/dc microgrid from the main grid.
- Power transfer from ac to dc microgrid through the IC.
- Power loss in ac microgrid.
- Power loss in dc microgrid.

II. SYSTEM STRUCTURE AND OPERATION MODES

A simple hybrid ac/dc microgrid is shown in Fig. 1. It consists of an ac microgrid with conventional DG sources, a dc microgrid with two dc type sources and an IC links the two microgrids together. Each of these microgrids also includes their individual loads. Besides, during normal grid operation the hybrid microgrid is connected to the main utility grid through the ac microgrid. Basically, the microgrids are thought to operate in grid connected or islanding modes [1]. In the grid connected operation mode of the hybrid microgrid, the ac microgrid dynamics are governed directly by the main utility grid and the IC primarily regulates the dc microgrid voltage and controls the power balance, as well. In this operating condition the dc sources can generate a constant power or can operate in maximum power point for the renewable energy sources. In the islanding mode of operation, and during light loading of the dc part, the demanded power is shared among the dc sources using the droop characteristics. When overloading happens in the dc microgrid, the interlinking converter will also participate in load sharing using the proposed ac-dc droop control. In the following, the performance of the hybrid ac/dc microgrid is described in either of these two modes.

A. Grid-Connected Mode
While the hybrid ac/dc microgrid is connected to the main utility grid, DG sources in the ac microgrid are expected to either generate a specified real/reactive power, or act as terminal voltage regulator with a specified amount of active power and variable reactive power [5]. On the other hand, the utility grid operates as slack bus to support the difference in the active/reactive power demand and to sustain the microgrid frequency. Similarly, in dc microgrid, DG sources would be controlled to generate a specified active power. However, the utility grid is still responsible for voltage support and power balance through the IC. According to Fig. 1 and neglecting the power losses, this mode can be described,

\[
R_{dc}^{\text{loss}} = \sum i_f p_{dc,i} + P_{dc}^{\text{loss}} \sum_i p_{dc,i}
\]  

\[
P_{\text{grid}}^s = \sum_i p_{dc,i} + P_{dc}^{\text{loss}} p_{dc} - \sum_i p_{dc,i}
\]  

In this mode the renewable energy sources in the microgrid can operate in maximum power point, energy storages can charge and nonrenewable sources can be managed, e.g., for peak shaving purposes, loss reduction or economical goals [4]. In the ac microgrid, DGs could also generate a specified reactive power, regulate terminal voltage or may be used for power quality aims [21]. These power management studies have been studied in dc microgrids [7], [8] and it is not intended to be followed in this paper.
B. Islanding Mode

The more challenging situation is the islanding operation of the hybrid ac/dc microgrid. In the islanding mode, the total load demand should be shared and managed autonomously by the existing DGs in the both microgrids, which involves rapid and flexible active/reactive power control strategies to minimize the microgrid dynamics. A proper load shedding strategy is also required in case of deficiency in local generated power in order to maintain the system stability [7]. This paper adopts decentralized control strategies based on droop control to manage the power sharing among ac sources as well as dc sources, and between the ac and dc microgrid. Different operating states may occur during islanding operation of the hybrid microgrid. For the sake of appropriate performance of the hybrid ac/dc microgrid under different grid conditions, four main operating states are considered in the islanding mode, as follows:

**Islanding state I**: This operation state corresponds to the islanding operation of hybrid ac/dc microgrid during which power generation in ac microgrid and dc microgrid suffices their individual loads (light load condition). The generation units in each microgrid will regulate its power to meet the load. In this state, the IC halts transferring power and can just supply reactive power for the ac microgrid. This state is expressed by,

\[
P_{IC} = 0, P_{grid}^* = 0 \\
\sum_{i} P_{load,i}^{ac} \leq \sum_{i} P_{ac,i} \\
\sum_{i} P_{load,i}^{dc} \leq \sum_{i} P_{dc,i}
\]

**Islanding state II**: This state represents the case where the generated power in ac microgrid is deficient for the ac load demand but there is surplus power in the dc microgrid. Therefore, the required power should be supplied by the dc sources through the IC. In this state we have,

\[
\sum_{i} P_{load,i}^{ac} < \sum_{i} P_{ac,i} \\
\sum_{i} P_{load,i}^{dc} > \sum_{i} P_{dc,i} \\
P_{grid}^* = 0, P_{IC}^* = \sum_{i} P_{ac,i} - \sum_{i} P_{load,i}^{dc} - P_{loss}^{dc}
\]
Islanding state III: This state is similar to state II, except that the power deficit occurs in the dc microgrid and the ac microgrid is in light load condition. Therefore, the ac microgrid supplies the required power for dc microgrid. In this case,

\[ \sum_{i} p_{dis,i} > \sum_{i} P_{dc,i} \]  
\[ \sum_{i} p_{dis,i} < \sum_{i} P_{ac,i} \]  
\[ P_{grid} = 0, P_{IC}^{*} = \sum_{i} P_{dc,i} - \sum_{i} p_{dis,i} - P_{loss} \]  

Islanding state IV: This operation state relates to the case during which the load demand in both ac microgrid and dc microgrid are greater than the maximum available sources capacity (overload condition). In this state, the IC halts transferring power and a proper load shedding strategy must be run to stabilize the grids. This state is described by,

\[ \sum_{i} p_{dis,i} \geq \sum_{i} P_{dc,i} \]  
\[ \sum_{i} p_{dis,i} \geq \sum_{i} P_{ac,i} \]  
\[ P_{IC}^{*} = 0, P_{grid} = 0 \]  

III. DROOP CONTROL STRATEGY FOR INDIVIDUAL MICROGRID

A. Control of DGS in the AC Microgrid

Power management based on droop control is currently well recognized in ac micro grids. Real power generation of a DG is specified based on frequency-droop \( \omega_0 P \) characteristic [4]. Since there is no dominant source to enforce the base frequency in the islanded micro grid, the frequency of the micro-grid varies by means of demanded power variations. The main idea of this control is to increase the active power generation of DGs when the system frequency decreases. Similarly, for reactive power management voltage droop \( V_0 Q \) is exploited. Reactive power generation of a DG is determined based on deviations in the bus voltage. Therefore, the DG source acts in response to the measured local voltage deviations caused by either the system or the local load. \( \omega_0 P \) and \( V_0 Q \) characteristics could be described mathematically by (15)–(18).

\[ \text{Pref} = -\frac{1}{K_{p,ac}}(\omega_0 - \omega) + P_0 \]  
\[ Q_{ref} = -\frac{1}{K_{q,ac}}(v_0 - v) + Q_0 \]  
\[ K_{p,ac} = \frac{\epsilon_{max} - \epsilon_{min}}{\text{pmax}} \]  
\[ K_{q,ac} = \frac{\epsilon_{max} - \epsilon_{min}}{\text{qmax}} \]  

![Fig. 2 Configuration of the IC interfacing ac and dc micro grids](image)
Where \( K_{P,ac}, K_{Q,ac} \) - slope of \((\omega-P)\) and \((V-Q)\) droop characteristics.

By this power control method, during the grid connected mode where the frequency of the system is fixed, real power generation of the DG is controlled by \( P_0 \).

**B. Control of DGs in DC Microgrid**

Alternatively for the dc micro grid the dc voltage droop control method is used for the power sharing between DGS and micro grid:

\[
P_{dc}^{ref} = -\frac{1}{\delta K_{P,dc}} (V_{dc}^2 - V_{dc0}) + P_{dc0}^{ref}
\]

\[
K_{P,dc} = \frac{V_{dc,\text{max}} - V_{dc,\text{min}}}{P_{dc,\text{max}}}
\]

Where, \( K_{P,dc} \) - slope of dc droop characteristics

![Fig. 3 Proposed ac-dc droop characteristic](image)

**IV. PROPOSED IC CONTROL FOR ISLANDING OPERATION**

In addition to the power sharing strategies adopted for the standalone dc or ac microgrids, it is required to develop a proper control strategy for the IC to share the demanded power between these two microgrids. However, the power management for the IC control is different from the proposed strategies currently used for the energy sources in the standalone ac or dc microgrids. In contrast to the ac or dc microgrids, the IC is expected to manage a bidirectional flow of power between the ac and dc microgrids. In addition the IC should cooperate in power sharing between the energy sources in both microgrids with dissimilar droop characteristics. This is due to the fact that at any instant the IC takes the role of supplier to one microgrid and at the same time acts as a load for the other microgrid. These challenging issues can be handled by exploiting a proper control strategy for the IC to transfer the required power between the microgrids. In order to eliminate fast communication links, a modified droop based control strategy is proposed to attain desirable performance. As discussed in the previous sections, during the islanding operation of the hybrid ac/dc microgrid different operating states might arise and the IC should recognize these states and manage the whole hybrid microgrid.

The following decentralized control strategy is adopted for this purpose. The power management should determine the amount of active power that the IC must transfer from one microgrid to the other. In order to provide the power reference command, the dc bus voltage of the IC and the frequency of the ac microgrid are utilized as input to the power management system. Considering Fig. 2, the electrical energy stored in the dc capacitor is,

\[
W_{dc} = \frac{1}{2} C_{dc} V_{dc}^2
\]

Neglecting the switching losses in the converter \( P_{dc} \approx P_{ac} \), the dynamics in the dc capacitor energy is the difference of power transfer between ac and dc micro grids. Therefore,

\[
\frac{d}{dt} W_{dc} = \frac{1}{2} C_{dc} \frac{d}{dt} V_{dc}^2 = P_{dc} - P_{ac} = \Delta P
\]

On the other side, considering the \( \omega_P \) characteristic in the ac micro grid,

\[
\Delta \omega = \omega^0 - \omega = K_{\omega} \Delta P
\]
According to (22) and (23), using the forward Euler approximation with sampling period $T_s$ [22] and assuming that the microgrid frequency is constant in this interval, a new droop characteristic for the IC called “ac–dc droop” is defined as,

$$(\omega^0 - \omega) = k_\omega \{ (V_{dc}^0)^2 - (V_{dc})^2 \}, \quad k_\omega = K_\omega \frac{\delta \omega}{\tau_s} \quad (24)$$

The “ac–dc droop” characteristic is shown in Fig. 3. $\delta \omega$ and $\delta V$ are the dead zone bands for the allowable variation of angular frequency and dc voltage, respectively. Dead zone is utilized in the proposed “ac–dc droop” in order to prevent any power transfer during light load operation of individual micro-grids. During such operation condition the generating units in each micro grid will regulate the generated power to supply the corresponding microgrid load using the relevant $V_{dc}^0$ or $\omega^0P$ droop characteristics. $V_{dc}^{min}$ and $\omega^{min}_P$ are respectively the minimum dc voltage and ac microgrid frequency drop in dc and ac microgrids that the system is supposed to undergo load shedding.

Furthermore, since the IC is not the mere frequency or dc voltage controller in the hybrid ac/dc microgrid, it is necessary to participate in power sharing between ac and dc sources. To implement this scheme, the output of the ac–dc droop is fed to the $V_{dc}$ and $\omega_P$ droops of the IC. It is necessary to mention that since positive sign for power transfer in the IC is considered to be from dc to ac, the power for $V_{dc}$ and $\omega_P$ droop should be regarded with negative sign. Finally, according to $V_{ref}$ and $\omega_{ref}$ the amount of power to be transferred via the IC is determined by the two reference power calculated through these two loops. A schematic block diagram of the proposed power management strategy for the IC is depicted in Fig. 4. The impact of the proposed droop control for the IC on the power sharing of sources in each microgrid is illustrated within two load increase scenarios in each microgrid.

![Proposed real power controller for the IC.](image)

1) In the first scenario it is assumed that the dc microgrid is near overloading and there is excess power in the ac microgrid. Upon increasing the load in the dc microgrid, the dc voltage will accordingly decreases. If the voltage drop is beyond $\delta V$, referring to the proposed ac–dc droop (Fig. 3) this voltage deviation produces a new reference angular frequency $\omega_{ref}$. This $\omega_{ref}$ will then determine the reference power for the IC power controller using the conventional $\omega_P$ droop. This is the amount of power to be transferred from ac to dc microgrid. Therefore, the IC treats as a source for the dc microgrid and partly restores the voltage of the dc microgrid. On the other hand, the IC takes the role of a load for the ac microgrid and increases the power generation of the ac sources.

2) The other scenario happens when the ac microgrid is near overloading. When the ac load increases again, causes the frequency to decrease below $\delta \omega^0$. Referring to the proposed ac–dc droop a new reference voltage $V_{ref}$ is presented. Finally, by using the $V_{dc}$ droop the required power to be transferred to the dc microgrid is determined. Therefore, according to these two scenarios whenever the load increases in one of the microgrids, the “ac–dc droop” characteristic relates the ac and dc microgrids using the dc link performance and the equivalent frequency droop characteristic of the ac microgrid which is determined by [24].
\[ \Delta P = K_\omega \Delta \omega, \quad K_\omega = \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} \right) + D \] (25)

Where \( R_1, R_2, \ldots, R_n \) are droop coefficient of ac sources and \( D \) is the load damping constant of the ac microgrid. Using this droop characteristic it is possible to relate the different droops of ac and dc microgrid and consequently share the power in the whole microgrid.

The reactive power control of the IC is more straightforward since there is no reactive power in dc microgrid and the IC is designated to play as a voltage support in droop control mode to share the reactive power with other DGs in ac microgrid. The reactive power sharing is based on the conventional droop shown in Fig. 6, the local RMS voltage is measured and using the \( V_{\text{RMS}} \) droop, the reactive power reference is determined.

\[ Q_{\text{ref}} = \frac{-1}{K_{\text{qRMS}}} (v_{\text{RMS}} - Q_0) \]

Finally, a current control scheme [23] is utilized in IC control for tracking the reference active/reactive power calculated by the power management system.

V. CASE STUDIES AND SIMULATION RESULTS

In order to validate the proposed power management control, a hybrid ac/dc microgrid is simulated in MATLAB using detailed switching model for the converters. Considering the schematic diagram of Fig. 1, the ac microgrid includes two gasfired DG units with synchronous generators, excitation and governor control systems. Furthermore, the dc microgrid contains two dispatchable dc sources. System parameters are presented in Appendix. Different operating scenarios, configuration of loads and generation are considered in the simulations for islanding operation in order to validate the performance of the proposed power management method in controlling the IC in the hybrid ac/dc microgrid and sharing the power between the ac and dc microgrids.

[Fig. 8 Simulation diagram for hybrid ac dc micro grid]
**CASE 1: Ac gen 1, ac load 1, dc 2 loads alone [AC light load condition]**

In this case, let us consider that there is no DC power generation and AC Source1 alone produce the power to meet the AC load1, DC load1 and DC load2. In such case, the surplus power from AC Microgrid transfers through the Interlink converter to meet the DC load1 and DC load2. i.e., the power transfers from AC to DC side as shown in below fig 10. Note that, the power transfer through Interlink converter is Positive.

**CASE 2: Dc gen 1, Ac gen 1 – ac load 1, dc 2 loads alone [DC light load condition]**

In this case, let us consider that AC source1 and DC Source1 alone produce the power to meet the AC load1, AC load2, DC load1 and DC load2. In such case, the surplus power from DC Microgrid transfers through the Interlink converter to meet the AC load1 and AC load2. i.e., the power transfers from DC to AC side as shown in below fig11. Note that, the power transfer through Interlink converter is Negative.
CASE 3: TRANSITION MODE
Initially it is operated in the islanding mode. At 0.2s the circuit breaker which closes the switch, so it is connected to the main utility grid and the operation is in grid connected mode. The waveform is shown in fig. until 0.2s the IC power oscillation is high. It feeds the extra power to ac micro grid. After 0.2 the power will be fed to the main utility grid.

VI. CONCLUSION
This paper proposes a decentralized control strategy based on the two stage modified droop method for the control of the IC interfacing dc and ac microgrids. This hybrid micro grid architecture prepares an infrastructure for flexible connection of different ac or dc loads and sources to the grid. By measuring the ac micro grid frequency and the dc micro grid voltage and using proposed droop characteristic, the power management strategy provides the power reference for the IC control to share the power demand between the existing power sources in both ac and dc micro grids. Using the proposed droop method, the IC is able to perform power sharing between the two micro grids during the islanding operation, transition mode of operation, grid connected mode of operation. This makes it possible to decrease the required power conversions stages and hence the system cost and efficiency. The performance of the proposed control strategy considering different operating states was demonstrated through the MATLAB software.

VII. APPENDIX
System Parameters
TABLE I: AC SOURCES PARAMETERS.

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TABLE II: IC PARAMETER

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TABLE III: DC SOURCE PARAMETER

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REFERENCES


AUTHOR BIOGRAPHY

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