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Modeling and Simulation of a Hybrid Micro-grid with Back to Back Power Electronic Converters

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Abstract

The necessity of an AC or DC microgrid is governed by available micro sources and connected loads. A hybrid structure can ensure a sustainable configuration blending both the forms. In this paper, a hybrid microgrid structure for a grid connected microgrid with DC connection at back to back (B2B) converters is proposed. While a B2B connection between two AC systems could bestow a reliable, isolated and efficient coupling, an extra DC bus connection can facilitate use of the DC micro sources. The DC bus can supply the local DC loads and can also trade part of the power with the AC grids. The voltage support at the DC link (of the B2B converters) can be used for the DC bus formation. Different power management strategies with fixed power references or decentralized power distribution in AC/DC sides are proposed and validated with simulations in Matlab/simulink.

Keywords: hybrid Microgrid, converters back to back, distributed generation

Introduction

The widespread interconnection of distributed generators (DGs) has created possibility of microgrid, both in AC and DC forms. Combining both AC and DC systems, hybrid microgrid has been proposed by many researchers [1]–[12]. The presence of AC and DC sources requires detail investigation of the control aspects in such systems. The coordination control algorithms are proposed in [1] to balance the power flow between the AC and the DC grids and to maintain both the DC and the AC voltages. Another efficient AC/DC microgrid structure is presented in [2]; where the hybrid grid is consist of AC and DC network connected through multi bidirectional converters. The coordination control algorithms are proposed for smooth power transfer between AC and DC links and for stable system operation under various generation and load conditions. In [3], an assessment and mitigation strategies for system level dynamic interaction (to achieve tight regulation of load requirement) with control power converters is investigated in a hybrid microgrid. An effective control method to reshape the DC side admittance is proposed to improve the system stability. In [4], a real-time circulating current reduction method, for parallel harmonic-elimination pulse width modulation (HEPWM) inverters used to employ power transfer between AC and DC buses in hybrid microgrid, is proposed. The proposed method can provide an extra 15% modulation index range which is a great benefit for power converter applications in this area. The stability issues in a hybrid microgrid are very well addressed in [5], [6]. The proposed control schemes improve the voltage stability in the DC bus and the efficacy of the controller is verified considering the uncertainty of the generators and loads existed in microgrid. In [7], different effective and simple control strategies for hybrid AC-DC microgrid (both grid-connected and islanded operations) are described. The proposed control can keep the power balance and ensures stable AC/DC bus. A decoupled control framework is developed for the hybrid microgrid and the performances are evaluated. The power electronics interfaces and controls for a microgrid with both DC and AC links are investigated in [8]. A general framework to aggregate a wide range of distributed energy resources at several levels with DC, AC, and synchronous links is proposed with variety of power electronics interfaces and control schemes. The energy management system in an AC and DC bus liked microgrid, is described in [9] for different operating modes. The need of frequency and voltage control is identified along with the DC bus voltage. A centralized power control scheme for a hybrid microgrid is proposed in [10]. The proposed scheme control the power flow of the multiple AC-DC bidirectional converters connected in parallel that connect AC and DC buses. The power management system plays a crucial role in any microgrid and can ensure improved steady state performance [11]–[12]. An Energy Management System for the optimal operation of smart grids and microgrids is proposed in [13]. An adaptive algorithm based on advanced control techniques is used to allow energy saving, customers participation in the market etc. A two level architecture for distributed energy resource management for multiple microgrids using multi agent systems (MAS) is proposed in [14]. A central power-management system (PMS) with a decentralized, robust control strategy for autonomous mode of operation of a microgrid is proposed in [15]. A GPS system is used to synchronize the oscillators of the Voltage Source Converter (VSC) DGs. In this paper, a hybrid microgrid structure with DC bus connection at B2B converter is proposed. The main contribution of this paper lies in enabling this new hybrid structure for grid connected microgrid through B2B converters. Control voltage between the microgrid and utility provides a new model system for hybrid microgrid. Different control modes are developed to demonstrate the efficacy of the proposed microgrid structure and associated controls.

System Structure

The basic system structure is shown in "Figure 1".

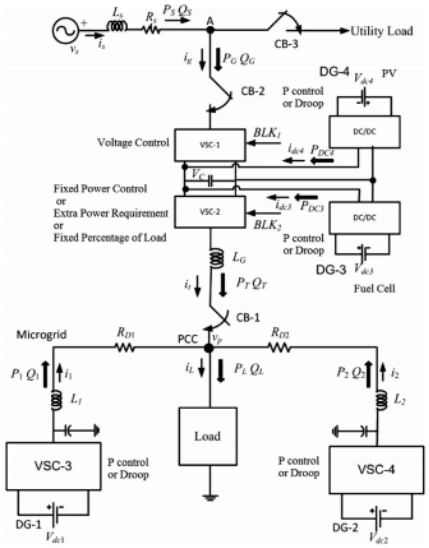


Figure 1: System structure with AC DC microgrids.

The AC microgrid with two DGs (DG-1 and DG-2) and one load is connected to the utility through B2B converters. The DGs are interfaced through VSC-3 and VSC-4. The DG interfacing VSCs (in AC microgrid) convert the DC output of the DGs to AC. The B2B is made of two VSCs (VSC-1 and VSC-2) with common DC link as shown. Two DGs (DG-3 and DG-4) are connected at the DC side of the B2B converters. The DGs in DC microgrid are interfaced through DC to DC converter (DC/DC) as shown in "Figure 1". The DC/DC converter boosts the DC voltage output of the DGs to DC bus voltage level.

In this structure,

• B2B can provide isolation of the AC microgrid and voltage support for the DC microgrid.

• Direct connection of few DC micro sources at the DC bus is achieved.

• Power flow management for the AC and DC microgrid is established.

The interface of the AC, DC microgrids with the utility is shown in "Figure 1". It is possible to supply DC loads from the DC bus as shown and the power output of the DC sources are represented P_{DCi}. The power from the utility is P_G, Q_G and power to the AC microgrid is P_T, Q_T. In this system, set up power flow management can do the following.

• Supply a fixed amount power from utility to AC microgrid or vice versa.

• Supply the extra power requirement from utility to AC microgrid (or excess power from AC microgrid to utility) in Mode-1 operation.

• Provide the DC voltage support for the DC microgrid and supply limited power (based on control limit).

• Supply excess power from DC microgrid to the AC microgrid.

• Supply the excess power from AC microgrid to DC microgrid with the voltage control at the DC bus.

Control of DC microgrid

The control scheme of the DC microgrid is shown "Figure 1". The utility interfacing VSC (VSC-1) controls the DC voltage while the DC micro sources may operate in fixed power control or droop control mode. The current reference of the DC micro sources operating in constant P control can be derived as

$$I_{FCref} = \left(k_{pp} + \frac{k_{ipp}}{s} \right) \left(P_{dref} - P_{dmeas} \right) \tag{1}$$

For droop control operation, the current reference is calculated as

$$I_{FCref} = \left(K_{pd} + \frac{K_{id}}{s} \right) \times \left(V_{drated} - V_{dmeas} - K_{DRP} \left(P_{dref} - P_{dmeas} \right) \right) \tag{2}$$

In this paper fuel cells and PVs are considered as the DC micro sources.

Control of AC microgrid

It is assumed that only VSC interfaced micro sources are present in the AC microgrid. However, the proposed method can also accommodate inertial DGs. It must be noted that the DGs in AC microgrid are VSC interfaced and they are represented by ideal DC sources. In the AC microgrid the power setpoints and measured powers are used to calculate the limited power reference. The power errors are fed to the power controller to derive the current references. The voltage reference is then calculated based on the measured current, measured voltage and current reference values. The frequency and voltage regulation are achieved with measured output powers.

The current references are calculated as

$$I_{dref} = \left(K_{pac} + \frac{K_{ipac}}{s} \right) \left(P_{ref} - P_{meas} \right) \tag{3}$$

$$I_{qref} = \left(K_{qac} + \frac{K_{iqac}}{s} \right) \left(Q_{ref} - Q_{meas} \right) \tag{4}$$

The voltage references are calculated as

$$V_{dref} = \left(K_{vdac} + \frac{K_{ivdac}}{s} \right) \left(I_{dref} - I_{dmeas} \right) + V_{dmeas} + I_{dmeas} R_{tr} + I_{qmeas} X_{tr} \tag{5}$$

$$V_{qref} = \left(K_{vqac} + \frac{K_{ivqac}}{s} \right) \left(I_{qref} - I_{qmeas} \right) + V_{qmeas} + I_{qmeas} R_{tr} + I_{dmeas} X_{tr} \tag{6}$$

The frequency and voltage regulation is implemented as

$$V_{ref} = \mathrm{sqrt}\left(V_{dref}^2 + V_{qref}^2 \right) - K_{drpv} \left(Q_{rated} - Q_{meas} \right) \tag{7}$$

$$\delta_{ref} = \tan^{-1} \left(\frac{V_{qref}}{V_{dref}} \right) - K_{drpp} \left(P_{rated} - P_{meas} \right) \tag{8}$$

Control of back to back converters

There are two VSCs in the B2B connection as shown in "Figure 1". Two three phase H bridge converters are connected through the common DC link. It must be noted that the filter design of each VSC depends on the system

requirements and converter control. The used IGBTs in back to back converter are controllable switches.
VSC-1 controls the voltage in the DC bus to a predefined magnitude (3.5 kV) and control of VSC-1 output voltage angle is achieved as

$$\delta_{ref} = \left(K_{vdc} + \frac{K_{vidc}}{s}\right)\left(V_{dcref} - V_{dcmeas\text{-}av}\right) \tag{9}$$

VSC-2 can be controlled to supply:
• a fixed power from AC microgrid to the DC bus;
• a fixed power to AC microgrid from the DC bus;
• extra power requirement of the AC microgrid in droop control mode.
For supplying fixed power in either direction, the PCC of the AC microgrid is used as the point of reference. The output voltage magnitude and angle references of VSC-2 are calculated as

$$V_T = \frac{V_p^2 + Q_{Tref} X_G}{V_p \cos\left(\delta_T - \delta_p\right)} \tag{10}$$

$$\delta_T = \tan^{-1}\left(\frac{P_{Tref} X_G}{V_p^2 + Q_{Tref} X_G}\right) + \delta_p \tag{11}$$

where P_{Tref} and Q_{Tref} are the power references and the PCC voltage is denoted by $V_p \angle \delta_p$.
In droop control mode, the reference voltage is calculated as

$$\begin{aligned} \delta_T &= \delta_{T\max} - m_T \times \left(P_T - P_{T\max}\right) \\ V_T &= V_{T\max} - n_T \times \left(Q_T - Q_{T\max}\right) \end{aligned} \tag{12}$$

where V_{Tmax} and δ_{Tmax} are the voltage magnitude and angle, respectively, when it is supplying the maximum load. The droop coefficients ensure acceptable voltage and frequency regulations while supplying the powers.

Simulation
The simulation results are presented in this section. Overview of simulation system shown in "Figure 2".

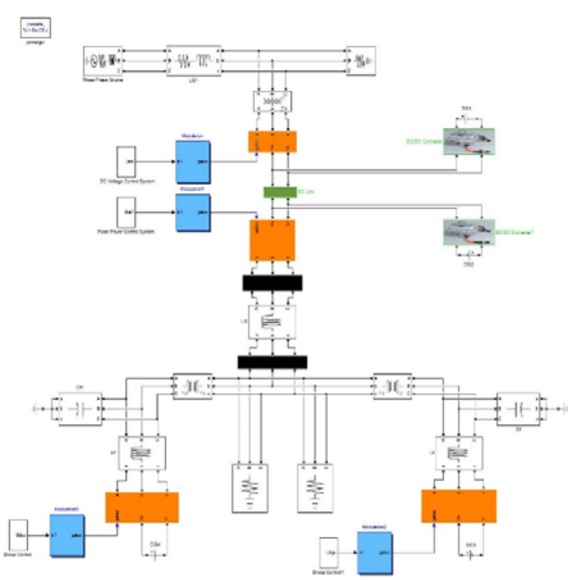


Figure 2: simulation system structure

In this paper, three operating scenarios are considered.
1) Case 1: In this case a fixed power is supplied from the utility to the AC microgrid (or vice versa) and voltage control is achieved for the DC microgrid. As the power from the AC grid is controlled in this case, it is more suitable for a contractual scenario with the AC microgrid.
2) Case 2: In this case, extra power requirement in the AC microgrid is supplied by the utility while the micro sources in the AC microgrid operate on fixed power output. The DC microgrid micro sources may operate with fixed power or droop control.
3) Case 3: The last case considers the possible system contingencies and islanded operation of the microgrid. The variants of case are as follows.
(a) Fault at the back to back DC bus. With the fault at the DC bus, B2B is blocked and the breakers isolate the systems. Loss of utility connection may need change in control mode and load shedding in the microgrids.
(b) Fault at the utility side. Fault at the utility side initiates connected breakers and VSC-1 is blocked. Power exchange between the microgrids is still possible with VSC-2 control mode changed to voltage control.
(c) Fault in the AC or DC microgrid.

Results and Discussion
In this section, a few of the simulation results (for the cases described in Previous Section) are presented. The system and controller parameters are given in Table 1–3.

A. Case 1
In this case, a load change (1.05 MW to 0.5025 MW at 0.1 s and then back to 1.05 MW at 0.35 s) in AC microgrid is simulated while the power flow through the B2B is kept constant. It is desired that the change in power requirement in AC microgrid is compensated by the DGs in AC microgrid. The system response is shown in "Figure 3". It can be seen that the DC bus voltage remain undisturbed. The DGs in the AC microgrid share the remaining power requirement. In a different scenario, a fixed percentage of the load power requirement in the AC microgrid is supplied through the B2B. The system response is shown in "Figure 4". The DC bus voltage show a stable system operation.

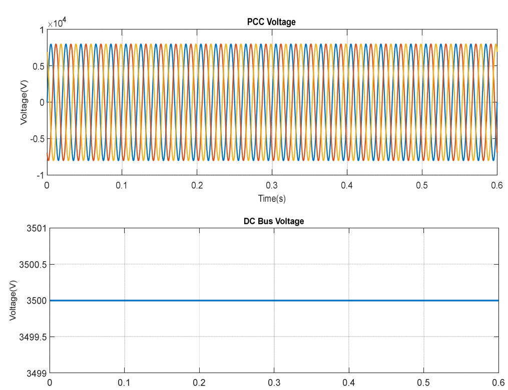


Figure 3: Case 1: Change in AC microgrid load. PCC poin voltage; and DC bus voltage.

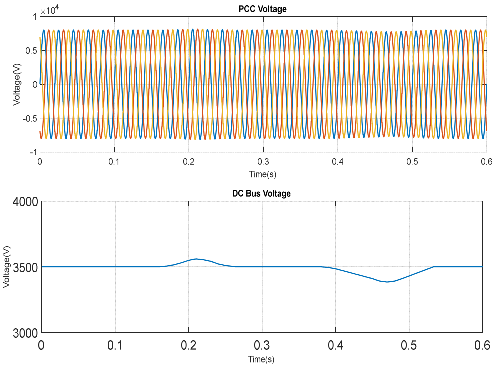


Figure 4: Case 1: Change in AC microgrid load and power flow from B2B. . PCC poin voltage; and DC bus voltage.

B. Case 2

In this case, the DGs in the AC microgrid produce fixed power (maximum available) and the B2B supplies the extra power requirement. Any change in AC microgrid power production must be taken care by the utility. To validate the control efficacy in loss of a DG power, shutdown of DG-3 is simulated at 0.2 s. It can be seen that the extra power requirement is picked up by the B2B. The PCC voltage and the DC voltage exhibit stable system operation "Figure 5"

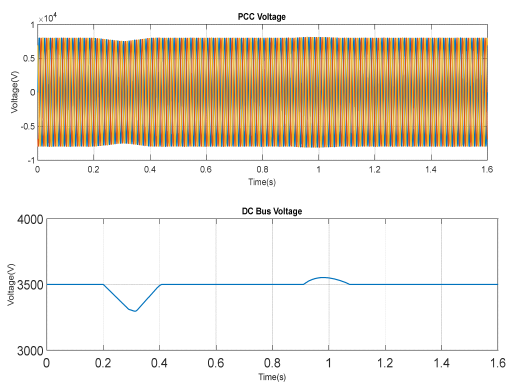
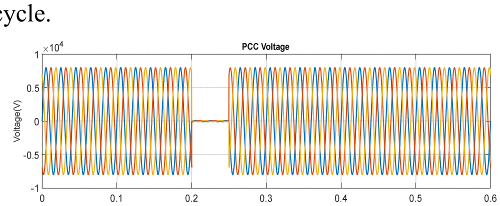


Figure 5: Case 2: DG power limit. PCC voltage ang DC bus voltage.

Case 3(a) is about fault in the DC bus which would lead to island operation of the microgrids. This is a very common microgrid operation mode and not discussed further here.

C. Case 3(b)

The fault case is investigated in this case. A three phase to ground fault in the utility is simulated at 0.2 s and the fault is cleared after 50 ms. The system response is shown in "Figure 6". As VSC-1 feeds the fault, DC bus voltage is decreased.The utility PCC voltage recovers within 2–3 cycle.



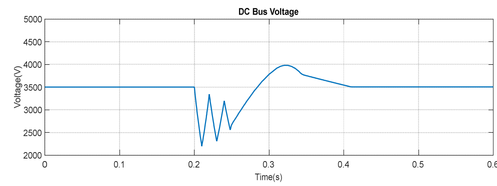


Figure 6: Case 3: Fault at the utility side. three-phase voltage at utility PCC; DC bus voltage

D. Case 3_c

In case of a fault at the AC microgrid PCC, the converter VSC-2 is blocked. The AC microgrid is islanded within 100 ms (the fault is simulated at 0.2 s). The system response is shown in "Figure 7" It can be seen that the PCC voltage and DC bus voltage are restored within 200 ms. As the AC microgrid is islanded, part of the load is shedded to maintain the power balance as shown in "Figure 7".

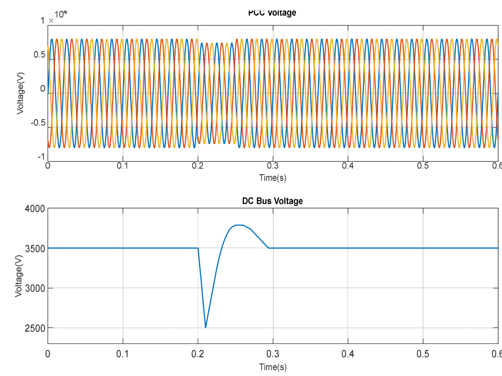


Figure 7: Case 3: Fault and island of AC microgrid.; three phase voltage at utility PCC; DC bus voltage

Island of the DC microgrid following a high impedance fault (far from B2B DC bus) is demonstrated next. It is assumed that prior to the fault the DC microgrid was importing power from the utility. The pole to ground fault is isolated with fast DC breaker within 5 ms. The system response is shown in "Figure 8" and it can be seen that the DC bus voltage recovers within 100–200 ms after fault clearance.

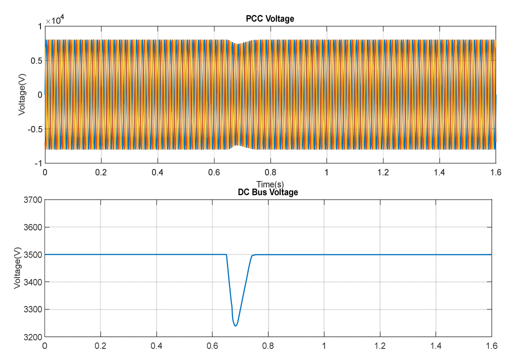


Figure 8: Case 3: Fault and island of DC microgrid. three phase voltage at utility PCC; DC microgrid voltage at DG terminal

It must be noted the proposed structure is suitable for different applications. Few reasonable application scenarios could be:

1) third party microgrid integration to the utility with high reliability;

2) multiple AC DC microgrids integration at common point;

3) DC data centre connection to AC microgrid and utility;

4) active distribution with AC DC sources and loads.

Appendix

Table 1: load in microgrid

Load rating	impedance	Motor load
AC microgrid	0.85MW	0.175MW
DC microgrid	0.5MW	0MW

Table 2: AC microgrid converter and controller

Rated output power of DG	AC microgrid
DG-1	230KW
DG-2	287.5KW
Converter structure	3Ph H-bridge
Converter loss	R=0.1Ω
transformer	1.0/3.5Kv,0.6 Mva,Ltr=4mh
DC voltage	1Kv

Table 3: B2B converter

Converter structure	3Ph H-bridge
Converter loss	R=0.1Ω per phase
LC filter	L_f=35mh, C_f=50μF
DC side voltage	3.5kv

Conclusions

In this paper, a hybrid microgrid structure for grid connected microgrid through B2B is proposed. The proposed control scheme can provide an isolated and reliable system connection. Various control modes of the micro sources in the microgrids are investigated to validate system sustainability in different power flow and system contingencies. A stable system ensures the efficacy of the proposed scheme and control methods.

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