NESTED MICROGRIDS: OPERATION AND CONTROL REQUIREMENTS

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ABSTRACT

Nested Microgrids refers to operation of multiple inter-connected microgrids. It is based on the idea that multiple microgrids can be connected and disconnected depending on the operation and control requirements. The purpose of this paper is to identify the challenges of Nested Microgrids operation with a decentralized microgrid control system. The controller interactions to exchange control parameters and measured network values across microgrids are investigated in this paper. Two key microgrid control functions, islanding, resynchronization are scrutinized to identify the coordinated control and communication requirement among the microgrid controllers and two more, load shed on generator overload and black start are discussed. The implementations of the proposed control functions are validated with time domain simulation in a Nested Microgrids test system.

INTRODUCTION

Historically microgrids were used to supply isolated loads that are not connected to the main grid. Over time, however, they evolved as a solution for the increasing amount of renewable energy integration [1] [2]. Microgrids manage the sources and loads so that from the grids perspective, they appear as a single controllable load. To achieve this, the microgrid assets are controlled locally to account for variations and fluctuations through the use of storage devices [3].

Nested Microgrids (NMs) refer to the operation of multiple inter-connected microgrids. These NMs have capability to remain connected together even when islanded from the main grid. They are also capable of disconnecting from the other NMs. This allows for increased efficiency, reduction of generation costs and reduction required storage capacity for a stable system [4].

The NMs are connected together through the Nested Microgrid Network (NMN) which facilitates the power exchange. The main grid connections can be directly to a microgrid or to the nested microgrids network.

A number of NMs projects have arisen around the world. In the Bronzeville community in the USA, a microgrid is being installed which would connect to the already present, Illinois Institute of Technology microgrid. It would create a system of 22 MW peak demand [5]. It is being funded by the DOE. DOE is also funding the Oncor microgrid, which is composed of 4 NMs able to operate in different configurations [6]. The Yamagata microgrid in Japan is another example of this. It is composed of 3 microgrids utilizing an AC and DC bus bar, as well as a converter to control the incoming power from the main grid [4].

The main contribution of this paper lies in identifying the control and communication requirement for Nested Microgrids operations with decentralized microgrid controllers. Two key control functions, islanding, resynchronization are outlined for nested operation and then simulated in a test case. Function implementation and coordination of the controllers across microgrids are proposed in this paper to identify the new requirements for nested operation.

CONTROLLER INTERACTION IN NESTED MICROGRIDS

The Nested Microgrids discussed in this paper use a decentralized controller solution based on ABB's MGC600 series and Microgrid Plus control system [7]. Each asset within the microgrid has a controller which provides local control as well as communication with the other controllers. The communication between the controllers is all facilitated through ABB's Microgrid Plus system.

A Nested Microgrid is implemented with controllers for the sources and loads. It also has network controllers located at the point of common coupling (PCC) to the other networks. Feeder controllers are located within the microgrid and in nested microgrid network, providing monitoring and protection capabilities. The controllers and their connection through the Microgrid Plus system are shown in Figure 1. Multiple Nested Microgrids are then connected together through the Nested Microgrid Network. Network controllers within the NMN provide control for the PCC to the main grid. Feeder controllers connect different parts of the NMN together. All the NMs have communication and control over the controllers within the NMN through the Microgrid Plus systems of the NMs. Furthermore, communication links are present between all the Microgrid Plus systems. This allows the transfer of information, status and instructions between the Microgrid Plus systems.

FUNCTION IMPLEMENTATION AND SIMULATION VERIFICATION

In this section, the Islanding and Resynchronization functions are outlined for nested microgrid operations

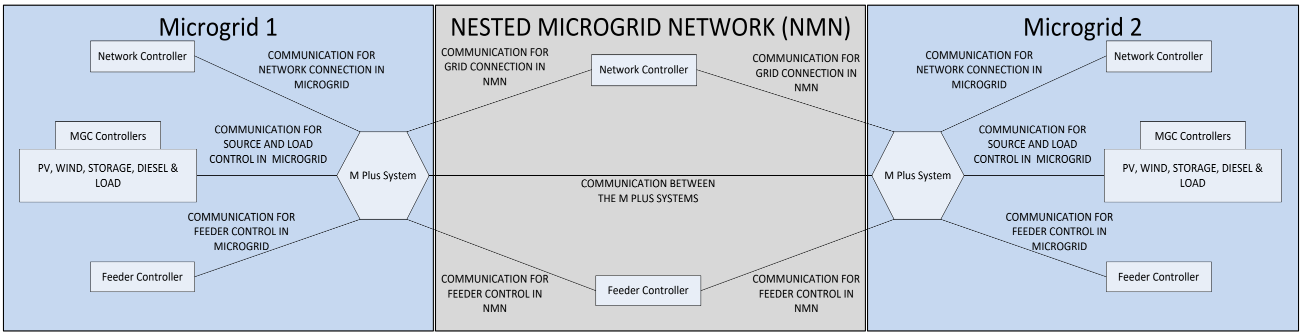

Figure 1: Controller interaction between Nested Microgrids

and followed by the simulation results. The case is assessed using two different variants.

The purpose of the variants is to demonstrate the impact of the selection of PCC to synchronize first. The test case is shown in Figure2. The time domain simulation is carried out in MATLAB-SIMULINK platform.

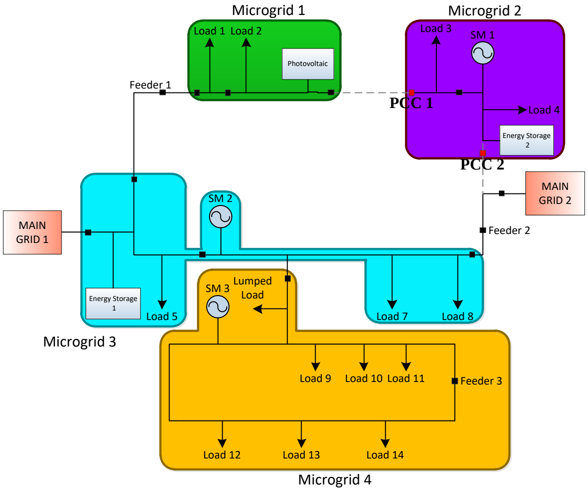

Figure 2: Test system for the islanding and resynchronization case

The main aim of the simulations is to:

1. Verify the system stability when preforming necessary microgrid functions.
2. Compare the placement and order of function operation sequence in the nested microgrid environment.

The test system has four nested microgrids and 2 main grid connections. Only one test case is presented here, but four test cases were carried out in total with multiple variants for each case. The simulation is done with respect to microgrid 2 and its connections to other NMs.

Islanding

In Nested Microgrids, a challenge presents itself in how to involve the different assets of the different microgrids in providing support during islanding.

Figure 3 shows three possible alternatives for communicating messages for coordinating the assets for ancillary support. In this figure the NCs are the network controllers which locally detect islanding cases and communicate them throughout the network.

Microgrid 2 is first disconnected from the NMN. It is islanded through the disconnection of both the tie-lines at the same time. To maintain stability the storage unit is then changed to droop mode. The microgrid is able to maintain stability and reaches a steady-state value as shown in Figure 4.

In order to achieve successful islanding the nested microgrid must fulfill the following communication requirement:

1. Transmit disconnection status to local microgrid management systems
2. Transmit disconnection status to other microgrid management systems
3. Coordinate new droop parameters
4. Coordinate load shedding to ensure adequate power supply

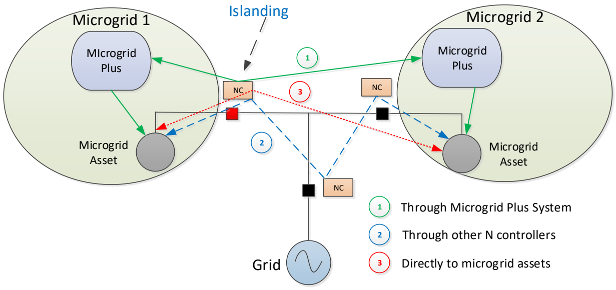

Figure 3: Different communication methods for islanding event

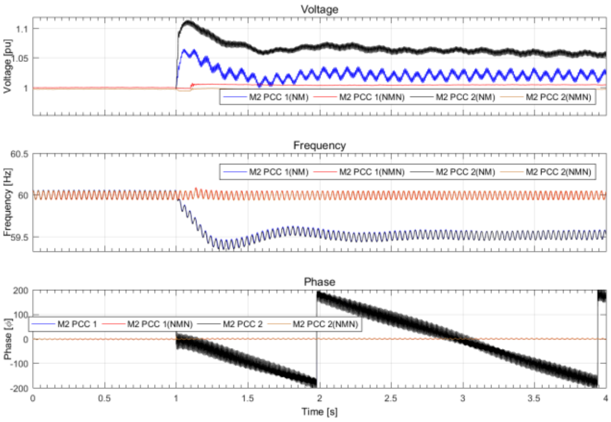

Figure 4: Operation parameters of microgrid 2 and the nested microgrid network

Nested microgrids must collaborate as soon as islanding occurs to ensure there is sufficient ancillary services, as well as reduce the load to ensure it meets the capacity.

Resynchronization

For Grid synchronization the sinusoidal signals on either side of the point of common coupling (PCC) are matched to within a mismatch margin. The upstream frequency is detected and communicated by the network controller. The voltage is then adjusted according to options shown in Figure 5. The phase synchronization is achieved through the use of a slight frequency mismatch causing eventual opening for connection to be formed

The process of resynchronization is initiated after the system has stabilized. This is shown at the 100ms mark. Microgrid 2 has two PCC connections to the NMN as options for first connection.
In variant 1, the synchronization process is carried out at PCC2 first. This performed by utilizing the storage in microgrid 2. The results are shown in Figure 6. PCC2 is connected to a node where there is a main grid connection. Furthermore, the storage providing the control is located at the same node, electrically.

For variant 2, the synchronization process is done at PCC1 first. PCC2 is the stronger of the two connections. The result is shown in Figure 7. PCC1 is located at a connection to another nested microgrid, where the only source is a PV.

In order to achieve successful resynchronization in the nested operation, the nested microgrids must fulfill the following communication requirements:

1. Broadcast its intention to the other nested microgrids
2. Designate primary PCC to first synchronize (if multiple exist) then broadcast it to the other nested microgrids
3. Collaborate with other nested microgrids to synchronize from both sides of PCC (if applicable)
4. Broadcast status to other nested microgrids after successful connection

Some challenges were encountered. In the case of islanding, the following challenges were found:

1. Load shedding delay can have a drastic impact on stability. This becomes crucial during communication between nested microgrid

For the resynchronization function the challenges are that:

1. Location of sources for resynchronization has a big impact on results
2. Choosing the optimal PCC can be difficult
3. Multiple sources participating in re-synchronization process from either side of PCC can lead to instability

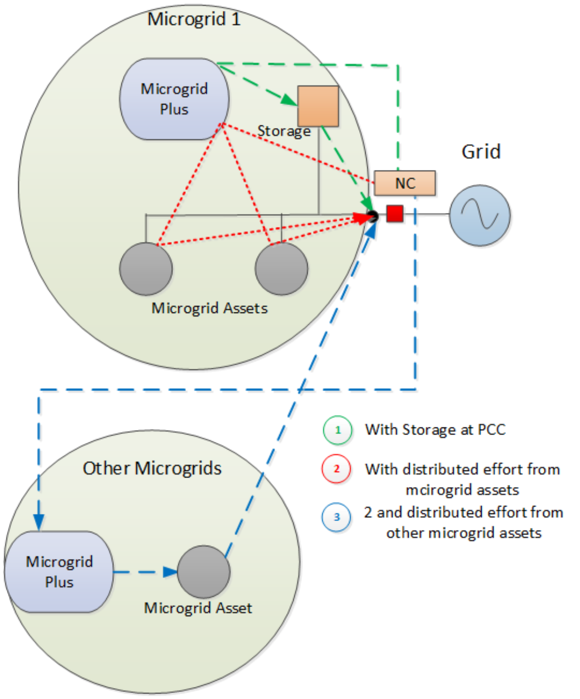

Figure 5: Synchronization of Microgrid 1 to the main grid using different methods

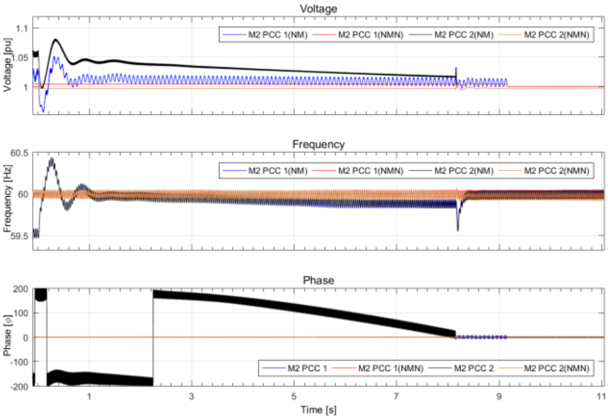

Figure 6: The difference in synchronization signals on either side of the PCCs where the first connected PCC was PCC2.

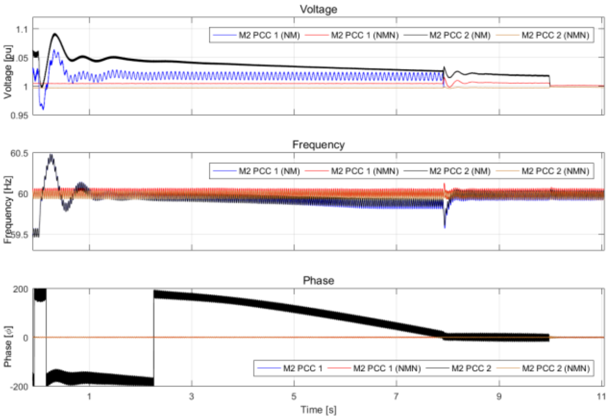

Figure 7: The difference in synchronization signals on either side

DISCUSSIONS

Significant changes are essential in the microgrid control functions to adopt the nested operation. To achieve this, modification of existing controllers' structure, communication interface and functions used in single microgrids is essential. Nested operation requires change in controller interaction, implying input and output parameters from the controllers. As a result the communication structure is also changed to accommodate exchange of information in nested operation.

The network controller manages the PCC connection and the tie-line between the microgrids. It would change in the following ways:

1. Receive instruction from other Microgrid Plus systems
2. Transmitting status to other Microgrid Plus systems
3. Resynchronization and Islanding done in cooperation with other Microgrid Plus systems

In nested operation the new communication requirements are for:

1. Communication between the Microgrid Plus systems
2. Communication between the network controllers

Feeder controllers offer monitoring and management of the feeders in the network. In nested operation, the feeders would have the following requirements:

1. Receive and transmit the parameters monitored. This includes, generation capacity, spinning reserve etc.
2. Coordinate circuit breaker closure timings and delays with other microgrids
3. Collaborate for power rerouting
4. Work together to implement load shedding
5. Communication facilitated through Microgrid Plus system

Table 1: Controller Modifications

	Modifications	
Controller Type	Control Input	Communication Interface
Microgrid Plus System	Yes (with other microgrid plus system)	Yes (at system level)
Network	Yes (with other microgrid assets)	Yes (various options exists)
Feeder	Yes (with other feeder, generator and network controllers)	Yes (asset level or in microgrid plus level)
Asset	Yes (with other microgrid network controller)	Yes (asset level or in microgrid plus level)

Overall, it is necessary to upgrade the controllers in a microgrid to enable nested operation. It can be seen in Table 1 that all of the controllers will have additional inputs and the required communication interface.

CONCLUSIONS

The control challenges for NMs operations are presented in this paper and some solutions in decentralized control approach are proposed. To be able to operate within NMs, the controllers within microgrids must be modified in the following way:

1. Function process updated to coordinate with other microgrid controllers
2. Additional controller inputs/outputs added to exchange information for open and close loop controls
3. New communication channels are added for intra microgrid communications

This leads to the controllers' structure and communication interface becoming more complex. However, NMs can work together to increase system efficiency and to reduce the requirement of generation capacity and storage units. Power supply security is improved through power exchange between the microgrids.

Two essential microgrid control functions are verified in nested microgrid operations. Time-domain simulations validate system stability during nested operations.

It is also possible to implement nested microgrid control concepts in a centralized controller. The required modifications for nested operations can be performed on the central controller instead of the different asset controllers.

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