Y9.GEH1.3: Multi-SST IPM and IEM Applications

Project Leaders: Mesut Baran and Mo-Yuen Chow

Students: Yue Shi, Yuan Zhang, Jie Duan

1. **Project Goals**

   The overall objective of this task is to demonstrate multi-SST IPM and IEM applications based on DGI in the Green Energy Hub. This effort will be broken into two subtasks: (1) Decentralized Volt/Var Control and (2) Real-time Energy Dispatch. The goal of this first subtask is to implement the decentralized volt/var control scheme which has been developed over the last three years for the FREEDM system. Main effort will involve the following: (i) Port the code to the recent DGI platform and run it on the ARM boards and (ii) Develop a test case and implement it on GEH which will allow us to demonstrate the performance of the proposed VVC scheme. The goal of the second subtask is to develop a real-time energy dispatch strategy for FREEDM system to address the forecast uncertainty with the following features: (i) Maintaining system stability by amending the day-ahead scheduling result to meet the system operational constraints with the presence of forecast error, (ii) Fast decision making within 5-minute timeframe, and (iii) Considering the heterogeneous device capabilities, then prioritize and dispatch the DESDs based on their charging/discharging rate, capacities, etc. The real-time energy dispatch strategy will be implemented and tested in the GEH testbed.

2. **Role in Support of Strategic Plan**

   Volt/Var is one of the main real-time system level control functions for the FREEDM system. The energy dispatch closes the control loop for the distributed energy management to remain stable in the presence of forecast errors. Moreover, the energy dispatch project provides a tangible demonstration of how the cooperative distributed energy management should be implemented in GEH testbed.

3. **Fundamental Research, Technological Barriers and Methodologies**

   Volt/Var is currently an active research area as it is the main applications for smart distribution systems. The control function is not unique, but the proposed method is new and it makes use of the additional capability FREEDM provides.

   For the energy dispatch, the fundamental research is to explore a distributed control strategy for the GEH testbed, which adjusts the scheduling commands in response to the forecast errors. The technological barriers include two aspects. Firstly, the distributed decision making process needs to be fast, to meet the 5-minute timeframe requirement. Secondly, the control strategy needs to consider the heterogeneous device capabilities. For example, the adjustments of DESD dispatch commands should depend on their charging/discharging rate, their capacities and their current state of charge (SOC), etc. The methodology being used currently is to incorporate the load balancing algorithm developed in MS&T to do real-time adjustment of the DESD dispatch command when there is a mismatch between the forecasted profiles (DRER generation and demand) and the actual system operation profiles.

4. **Achievements**

   Decentralized Volt/Var Control

   Volt-Var control (VVC) is one of the main real-time control functions on a distribution system. Within the last three years the focus has been on development of decentralized control schemes for VVC [1]. Decentralized schemes make use of the DGI to facilitate actual implementation, and thus achieve the main benefits of a decentralized control [2]. This year's efforts on VVC has focused on migrating the VVC to HIL and GEH testbeds and test the performance of the method. The accomplishments made are summarized below.

The VVC module has been implemented in DGI 2.0. For master-slave control scheme, communication between two DGI nodes has been established. Also, to receive data from the feeder, interface between the DGI software and HIL system is needed. Fig. 1 shows how the VVC on DGI interact with the HIL system. Data exchanges shown in the figure is as follows: (i) Send/receive float number and/or string between a DGI node and HIL system; (ii) Array data exchange between DGI nodes so that Master can send data to Slaves and Slaves can receive the array sent by Master.

The 5 node looped feeder has been simulated on the RTDS. For VVC, the system is divided into three groups and therefore there are three VVO slave DGI nodes and one VVO master DGI node. To test if the VVO can respond to real-time load change, a load profile is scheduled in the HIL system. Fig. 2 shows how the system power loss, voltages and Q_{SST} change as the VVO adjust the control to follow load changes.

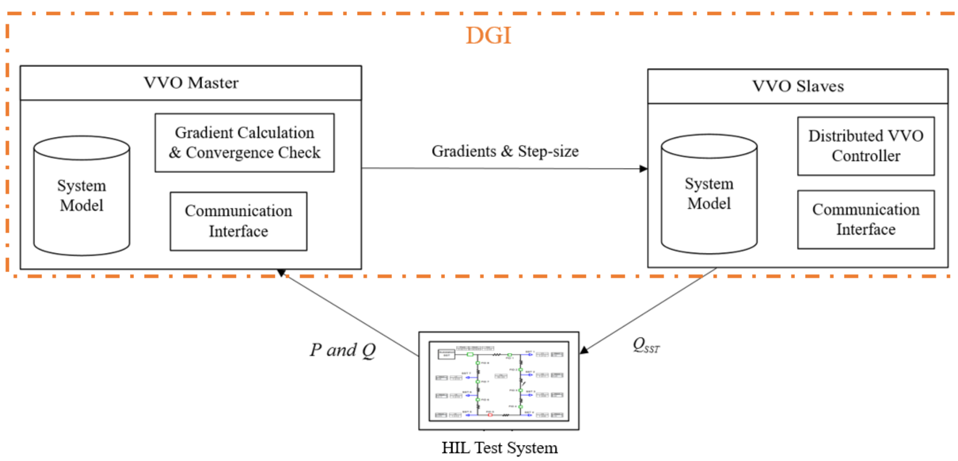

Figure 1: VVC for HIL system

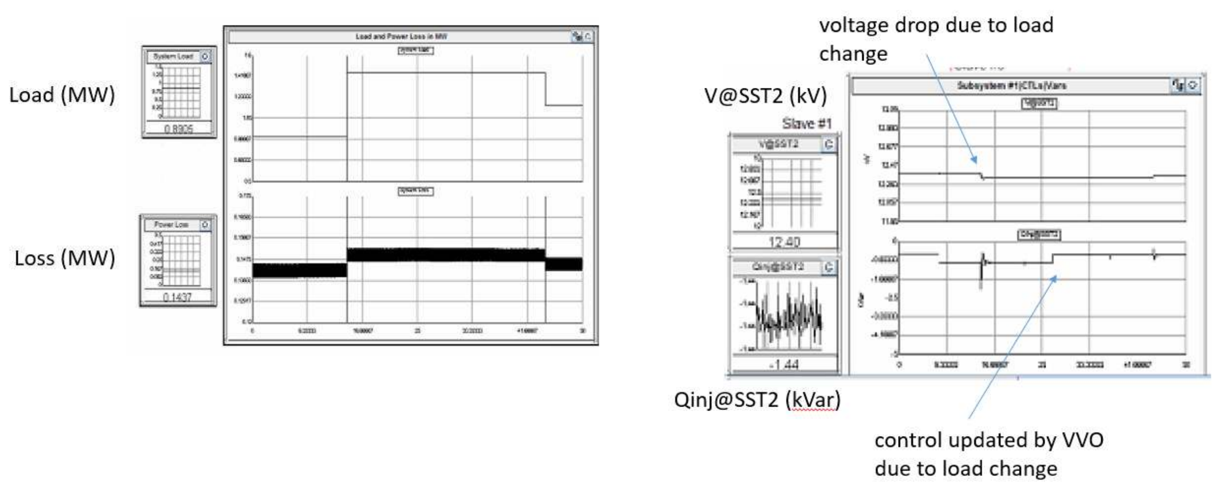

Figure 2: Results of VVO on HIL system

The effectiveness of the VVC has been verified in the LSSS system and the HIL system. As the first step of migrating VVC to GEH multi-SST system, the GEH system designed is being revised to obtain a more realistic feeder for VVC. Fig. 3 shows the topology of this multi-SST GEH system. VVC implementation for GEH is still in progress. The feeder model is to be finalized once the impedance of feeder lines are determined. Then, VVC code will be ported to DGI nodes so that VVC can be tested in GEH.

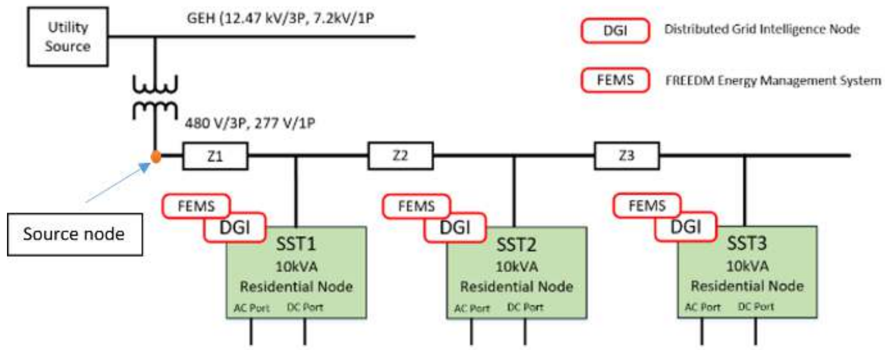

Figure 3: Multi-SST GEH system

Real-time Energy Dispatch

An offline CoDES [3] algorithm has been developed in Y7 to calculate the 24-hours charging/discharging schedules of the DESDs, using day-ahead forecast profile.

However, when the system approaches real-time operation, the actual device status might deviate from the forecast profiles [4]. In order to handle this mismatch, the Load Balancing algorithm previously developed by MS&T [5] is utilized. The system framework of integration of CoDES and Load Balancing algorithms is shown in Fig. 4.

As shown in Fig.4, the scheduling module uses the day-ahead forecast information to determine the optimal scheduling point for the coming 24 hours (1-hour resolution). When the GEH system approaches real-time operation, the DGI nodes collect real-time system status from the "Data Management Module", and execute the load balancing algorithm to determine the next 5-minute operation status for the SST being controlled. The two different control time frameworks correspond to the day-ahead and real-time energy market, respectively [6].

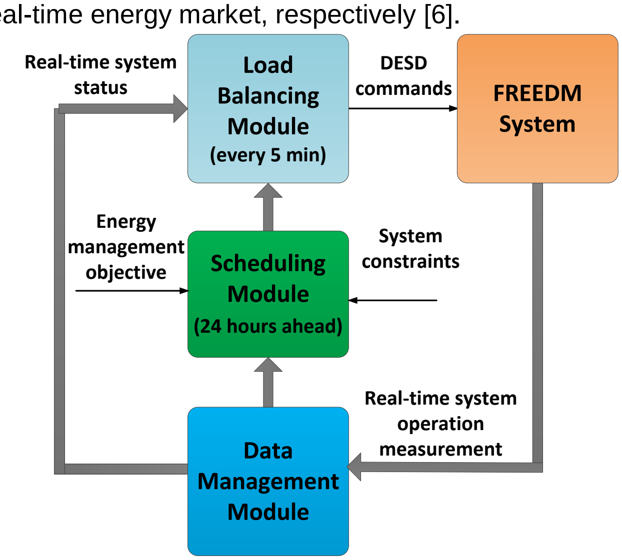

Figure *4:* CoDES algorithm with real-time operation.

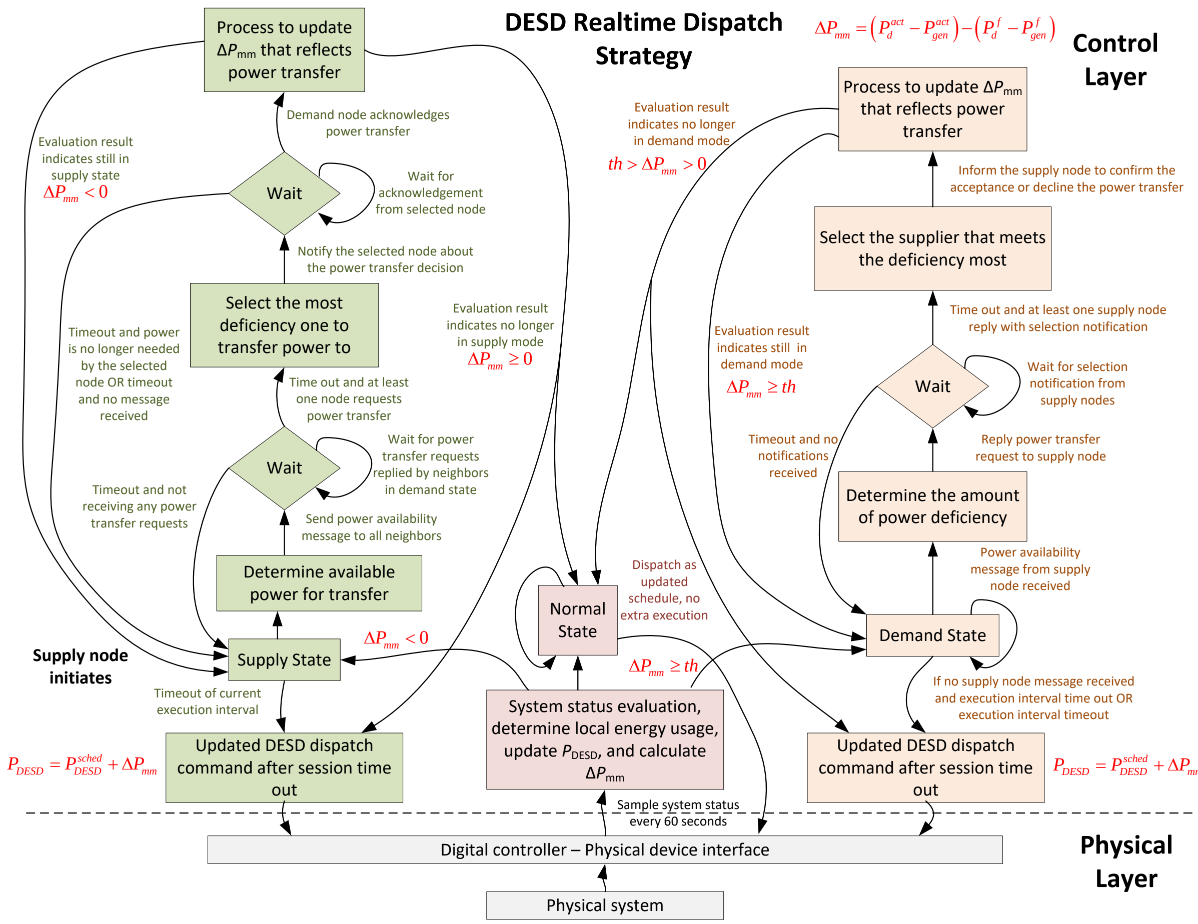

Figure 5: Real-time dispatch strategy.

Fig. 5 shows the process state diagram of a node participating in the load balancing algorithm. As shown in Fig.5, within every 5-minute time framework, each DGI node computes the SST's actual power imbalance, which is defined as:

$$\Delta P_{mm} = \left(P_d^{act} - P_{gen}^{act}\right) - \left(P_d^{f} - P_{gen}^{f}\right), \quad (1)$$

where P_d^{act} and P_{gen}^{act} are the actual load consumption and power generation at the SST, respectively, P_d^{f} and P_{gen}^{f} are the forecast load consumption and power generation, respectively. The DGI node is in a *Supply* state if $\Delta P_{mm} < 0$, meaning that it has excess generation to supply. If $\Delta P_{mm} > 0$, it is in a *Demand* state, and a *Normal* state if $\Delta P_{mm} = 0$.

The load balancing process is triggered if at least one DGI node advertises a change of state from *Normal* to other states. For example, a DGI node, on entering in to a *Supply* state, will advertise a *Draft Request* message to the neighboring nodes. A *Demand* node, on receiving a *Draft Request* message, responds to the sender by sending its demand with a special message called *Draft Age*. The *Draft Age* message includes the demand to be met by the *Supply* node in order to reach a *Normal* state. The *Supply* node, on receiving *Draft Ages* from different *Demand* nodes, will select the most deficient one to transfer power to. After the *Supply* node determines the target *Demand* node, it will send a unique *Draft Select* message, initiate the power migration and update the power imbalance ΔP_{mm} that reflect power migration. The algorithm continues until all the nodes are in *Normal* states.

5. Other Relevant Work Being Conducted Within and Outside of the ERC

Volt-Var control is currently an active research area, also being implemented and integrated into the new advanced DMS systems.

Y9.ET.1.3, with the title "Implementation of Secure Energy Management against Cyber/physical Attacks for FREEDM System".

6. Milestones and Deliverables

Q3 (9/30/2016) – Implement the Volt/Var program on DGI
Q3 (9/30/2016) – Develop the real-time energy dispatch strategy
Q4 (12/31/2016) – Demonstrate Volt/Var on HIL
Q4 (12/31/2016) – A real-time energy dispatch algorithm to address the forecast uncertainty
Q1 (3/31/2017) – Demonstrate Volt/Var on GEH
Q1 (3/31/2017) – A working implementation of real-time energy dispatch algorithm in DGI
Q2 (6/30/2017) – System level demonstration of the real-time energy dispatch algorithm in the presence of forecast error

Deliverable for SV (04/2017):

A working implementation of the real-time energy dispatch algorithm in DGI platform

Final Deliverable (08/2017):

System level integration and demonstration of the developed energy management algorithm in HIL/GEH testbed.
Related publications and reports.

7. Plans for Next Five Years

a) Add more features into the CoDES algorithm, such as microgrid line capacities constraints
b) Formulate the CoDES re-dispatch algorithm as an optimization problem to solve
c) Develop methodologies that improves the CoDES execution efficiency

8. Member Company Benefits

By demonstrating the operation of the CoDES algorithm, the member company will be able to see the potential of the distributed optimization technologies and the GEH hardware testbed, which may be used for commercial applications.

9. References

[1] Z. Shen; M. E. Baran "Gradient based centralized optimal Volt/Var control strategy for smart distribution system", IEEE PES Conf. on Innovative Smart Grid Technologies (ISGT), 2013.

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