

Design and Implementation of a Communication Network and Operating System for an Adaptive Integrated Hybrid AC/DC Microgrid Module

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Abstract—This paper proposes an adaptive integrated hybrid AC/DC microgrid module to accommodate a wide range of distributed renewable energy resources (DRERs), distributed energy storage devices (DESDs) and distributed demand resources (DDRs) into the existing distribution systems. This microgrid module is designed to be portable, scalable, easy to deploy, and simple to operate. The modeling of the proposed microgrid module, based on the IEC 61850 standard, is presented. A novel logical node is introduced, which describes functionalities of the bidirectional interlinking converter (BIC) interfacing AC sub-grid and DC sub-grid in a better way. To achieve the target of plug-and-play functionalities, specific microgrid module communication network (MMCN) and microgrid module operating systems (MMOS) are designed and implemented in the hardware prototype built in the laboratory. Experimental results obtained from the lab prototype clearly validate the effectiveness of the proposed design of the microgrid module, communication network and operating system.

Index Terms—AC/DC, Adaptive, communication network, hybrid, IEC61850, integrated, microgrid, operating system.

NOMENCLATURE

AC VRM	AC Voltage regulation mode.
API	Application program interface.
BIC	Bidirectional interlinking converter.
CAN	Controller area network.
DC VRM	DC voltage regulation mode.
DER	Distributed energy resources.
DRERs	Distributed renewable energy resources.
DESDs	Distributed energy storage devices.
DDRs	Distributed demand resources.
EDI	Events driven information.
ESS	Energy storage system.
ECPs	Electrical connection points.

GUI	Graph user interface.
IOUs	Intelligent input/output units.
LN	Logic nodes.
LDs	Logical devices.
MMCN	Microgrid module communication network.
MMOS	Microgrid module operating system.
MUs	Merging units.
OOP	Object oriented programming.
PDM	Power dispatching mode.
SoC	State of charge.
TDI	Time driven information.

I. INTRODUCTION

ONE billion three hundred million people on earth do not have access to electricity. An even higher number do not have access to proper sanitation, including drinking water. In the near term, it is not feasible to access these populations by means of interconnected transmission systems. The solution must be localized network microgrids [1]. The main applications of microgrids include islands, remote villages, emergency situations – earthquakes, tsunamis, refugee camps, remote mining operations, “Fringe” networks, military operations, etc.

Microgrids serve as an integration platform for power supply, storage units and demand resources in local distribution grids. The key benefits of the microgrid include: energy savings, renewable energy integration, improved control and monitoring, and improved system reliability. The microgrid can be primarily categorized into three classes, i.e. AC microgrid, DC microgrid, and hybrid AC/DC microgrid. AC microgrid is the most popular owing to its key benefits of a plug-in approach for all distributed energy resources (DER) and well developed interconnection, products standards and codes [2]. The key challenges of an AC microgrid are additional conversion requirements from DC to AC and back to DC, energy losses in the conversion and the high number of equipment and devices that are required. Recently, the DC microgrid has gained increasing popularity due to the fact that DC loads like LED, LCD, communication devices, computing devices, motors with variable speed drive, etc. are taking a significant portion of electrical loads. In addition, the DC microgrid has lower conversion requirements (reduced number of devices required) and higher efficiencies. The DC microgrid

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is expected to provide energy savings of around 5% to 10% compared with the AC microgrid and is suitable for zero-net energy buildings, and data centers. However, the DC microgrid still suffers from the following shortcomings: 1) Lack of approved/recognized DCLV system architecture (e.g. common bus collecting and distributing power); 2) DC has different safety and protection practices; 3) Lack of approved standards and codes for DC LV equipment, distribution systems and microgrids [3]. On the other hand, most of the infrastructures are based on AC systems, which need to be upgraded from an AC to DC system step-by-step. The hybrid AC/DC microgrid, which is comprised of both AC and DC sub-grids, has been demonstrated to be an effective solution for integration of both AC- and DC-inherent system components. In addition to the similar benefits of the DC microgrid, the hybrid AC/DC microgrid is quite suitable for applications where AC and DC power is produced and consumed [4], [5].

Nowadays, the microgrids have been designed case by case by taking into consideration available energy sources, energy storage, and loads' profiles. Corresponding power conversion modules and system structure are specially designed. Most of the microgrid components are provided by different vendors, using different technologies, which make systematic integration a complex and time-consuming task, not easily replicable from one project to the next. Therefore microgrid applications require a prohibitive amount of expertise and customization for substantial market penetration. There exists a need in the art to design for an integrated microgrid module that adapts to various energy sources, energy storage, and loads [6].

In this paper, an adaptive integrated hybrid AC/DC microgrid module is proposed to act as an energy hub/energy router to accommodate distributed renewable energy resources (DRERs), distributed energy storage devices (DESDs) and distributed demand resources (DDR) into the existing distribution systems as shown in Fig. 1. Each core part of the microgrid module has been designed to be a compact entity

optimized for rapid deployment and ease of usage. All the external devices including different alternative energy sources (PV, wind turbine, fuel cell etc.), fossil energy sources (diesel generators), energy storages, and loads should be designed following the concept of plug-and-play. Plug-and-play implies that the external device can be automatically detected and managed without user intervention. The plug-and-play concept aims to simplify the integration, accelerate the deployment and lower the cost of hybrid AC/DC microgrids [7]. In addition, the internal power conditioning converter has also been designed to be modular, integrated, and functioning in the way of plug-and-play. The concept of microgrid constellations, which comprised of multiple proposed microgrid modules, is also introduced. This guarantees that the proposed microgrid can be daisy chained to satisfy different specific source/load requirements in the way of microgrid constellations.

The objectives of this paper are to present the design and implementation of the proposed adaptive integrated hybrid AC/DC microgrid module. The detailed architecture is reported in Section II. The information model of the proposed microgrid module based on IEC61850 is presented in Section III. Design examples of the microgrid module communication network (MMCN) and microgrid module operating system (MMOS) are illustrated in Section IV. The design is verified by the experimental results on a laboratory prototype in Section V.

II. ARCHITECTURE OF PROPOSED ADAPTIVE HYBRID AC/DC MICROGRID MODULE

The schematic layout of the proposed adaptive integrated hybrid AC/DC microgrid module is as shown in Fig. 2. The system is comprised of both an AC bus and DC bus. AC loads and diesel generators are connected to the AC bus. The energy storage system (ESS), PV panels and light wind turbine are integrated through respective power electronic converters to the DC bus. A bi-directional interlinking converter (BIC) is installed in-between the AC and DC sub-grids to maintain power balance on both sides. A hybrid AC/DC microgrid module can operate in both grid-tied and islanded modes depending on the availability of the utility grid. The proposed hybrid AC/DC microgrid module is divided into two parts: 1) Core devices, which include the AC bus, DC bus, power conditioning converters (BIC, DC/DC converter), local central controller, communication bus, protection and measurement circuit, power and communication interface, etc.; 2) Periphery devices include renewable energy sources (PV, wind turbine), fossil energy sources (diesel generators), energy storages, and AC&DC loads. All the core devices, including the power electronic converters, are integrated in the hybrid AC/DC microgrid module, forming the main body of the module. All the protection and measurement circuits, power and communication interfaces dealing with corresponding external periphery devices are integrated together and defined as the resource manager (RM).

To facilitate the operation for end users, plug-and-play should be considered for microgrid module periphery device design. The modularized and integrated design offers several advantages: ease of deployment and installation, ease of main-

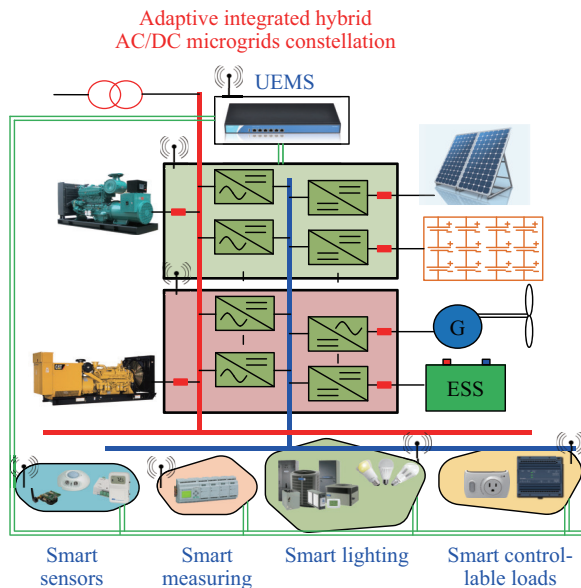


Fig. 1. The distributed power generation system based on the proposed adaptive integrated hybrid AC/DC microgrid module.

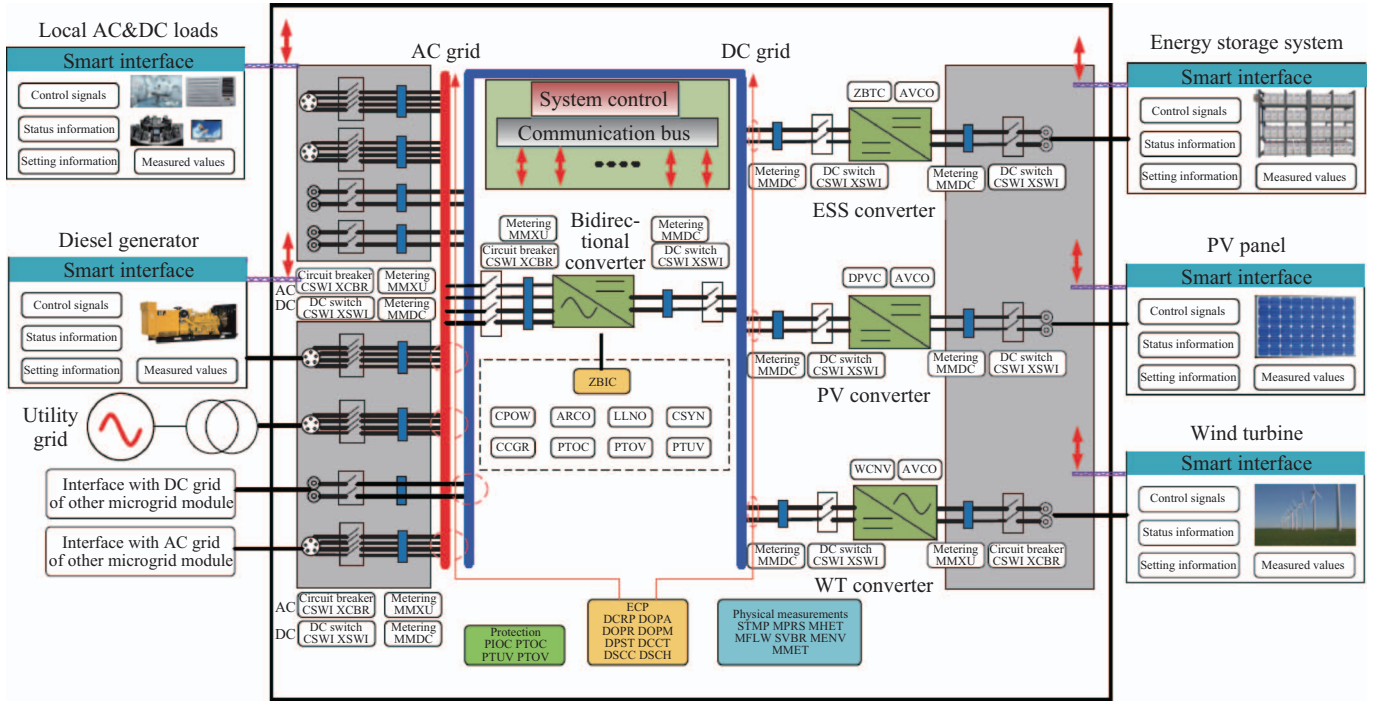


Fig. 2. The information model of the proposed hybrid AC/DC microgrid module.

tenance, highly portable, highly scalable, simple operation and control. As shown in Fig. 1, a couple of hybrid microgrid modules can form a microgrid's constellation through a daisy chain via DC and AC bus interfaces, which adds to the benefits of the proposed design.

III. MODELING OF ADAPTIVE HYBRID AC/DC MICROGRID MODULE BASED ON IEC61850

The information modeling of the proposed adaptive hybrid AC/DC microgrid module is the foundation for the integration of microgrid equipment. IEC 61850 is a dominant international standard of power systems and allows the integration of devices of different types into the microgrid system, which defines the information models to be used in the exchange of information with distributed energy resources (DERs) [8]. IEC 61850-7-420 provides the information model and logical nodes (LNs) for typical DERs, including electrical connection points (ECPs), controllers, generators, power converters, and auxiliary systems (such as measurement devices and protection devices). Other standards including IEC 61850 7-1, 7-2, 7-3, and 7-4 provide the model principles of physical equipment. However, those IEC 61850 models are defined generally based on a relatively preliminary and rigid AC microgrid structure. For the proposed hybrid AC/DC microgrid, information modeling should be modified based on previously mentioned standards [9]–[11].

The overview of information modeling of the proposed hybrid microgrid module is illustrated in Fig. 2. Most of the power devices followed existing predefined logic nodes (LN) in the standard IEC 61850-5 and IEC 61850-7-4 models. The LNs of the hybrid microgrid module core device primarily include: ECP, power converter, metering, circuit breaker, DC

switch, protection and physical measurements. For the sake of simplicity, the data objectives in the LNs of the periphery devices of the microgrid module are not elaborated in detail since they have already been defined in IEC61850. They can be primarily divided into four types: measured values, control signal, status information and settings information.

Definition of a New ZBIC Logical Node: BIC plays a significant role in the power balancing between AC and DC sub-grids in the hybrid AC/DC microgrid module. BIC is designed to have three operating modes, i.e. inverter mode, rectifier mode and power dispatching mode (PDM) to enhance the overall flexibility of the control of the hybrid microgrid module. Inverter mode refers to the operating mode that the AC grid voltage is regulated by the BIC. Rectifier mode refers to the operating mode that the DC grid voltage is regulated by the BIC. For the PDM, BIC's operating power and power flowing direction is managed by its specific references that could be assigned by the local central controller. Standard LNs rectifier (ZRCT) and inverter (ZINV) have been defined to characterize rectifier mode and inverter mode respectively in IEC 61850-7-420. However, neither of them, even the combination, can cover all the necessary functionalities of BIC. Therefore, a new LD named ZBIC has been defined based on standard data of the other already available LNs. The proposed new LN, to characterize the bidirectional AC/DC converter, is shown in the appendix. For the sake of simplicity, only newly defined LNs have been listed in the appendix.

IV. COMMUNICATION NETWORK AND OPERATING SYSTEM DESIGN

The design of the communication network architecture is crucial for the microgrid system to operate continuously and

to achieve optimal performance. As shown by Fig. 3, the designed microgrid module communication network (MMCN) consists of a local communication network within a single hybrid microgrid module and global communication network among multiple modules in microgrid constellations.

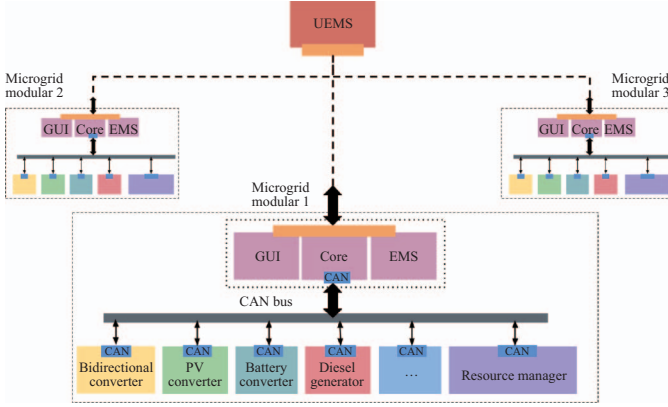


Fig. 3. The communication network of the proposed hybrid AC/DC microgrid constellation.

A. Local Communication Network of a Single Hybrid Microgrid Module

The real time information exchange between all types of power conditioning converters, periphery devices (DRERs, DESDs and DDRs) and a local central controller is realized through the local communication network. As shown in Fig. 2, the grey shaded area primarily consists of metering circuits and relays/circuit breakers interfacing with the periphery devices of the microgrid module. In our proposed design, the grey shaded areas are integrated together and its control and communication is managed by a module defined as resource manager (RM), which significantly simplifies the complexity of the local communication network.

The measured values (like ECP voltage/current/power, physical measurement of temperature, irradiance, etc.), of the status information of the key index and key elements (like periphery devices' operating status information, power converters' operating modes, position status of circuit breaker, etc.) are sent to the microgrid operating system. The operating system will generate control and setting signals (like ON/OFF command, operating modes command, and operating references settings) to the power converters, relays/ circuit breakers, and periphery devices. The communication follows the model defined in Section III. RS485 and controller area network (CAN) [10] are popular standards in the fieldbus system and both of them are equipped with DSP. Compared with RS485, CAN bus is a network with independent controllers and a serial communications protocol that efficiently supports distributed real-time control with a very high level of security [11]. It is a priority driven network [12], having a physical layer and data link layer. It is capable of avoiding data collisions, detecting failures in the transmitted data, automatic repetition of disturbed message and ensuring data consistency over all nodes in a network. In this design example, the CAN bus communication is selected to realize the local communication

network [13]–[15].

B. Global Communication Network Among Microgrids Constellation

The global communication network should be a high-bandwidth backbone communication network that can handle long-distance data transmission with advanced monitoring and sensing applications. It provides a two-way communication network for communication, automation, and monitoring purposes among multiple microgrid modules. Based on the local operation conditions such as ESS state of charge (SoC) and external information such as open market price, the microgrid can automatically adjust the control strategy to fully exploit the use of renewable energy systems and to maximize overall energy efficiency. Internet protocol based communication is shown in Fig. 3. The local central controller can get access to the internet through the built-in 100 M Ethernet, Wi-Fi or 3G/4G cape.

C. Design of Microgrid Module Operating System (MMOS)

As discussed in the section on the communication network, the local central controller is the core component of the microgrid module. It is responsible for identifying and managing all the periphery devices connected to the module, monitoring the system operation status, providing control/setting references or commands to each device (power converters, relays, and periphery devices), providing a local energy management system (EMS), providing necessary data visitation for the users or developers, and also coordinating with other hybrid microgrid modules. As illustrated by Fig. 4, the microgrid module operating system (MMOS) has been designed and embedded in the local central controller, which has been divided into several parts (see Table I): 1) Real time controller: The real time controller is responsible for the processing time critical mission or high priority mission of the microgrid module. 2) Graph user interface (GUI) [12]: The main functionality of the GUI is used to monitor the real-time operating status of the microgrid module and to input user operation preferences and commands. 3) EMS. 4)

TABLE I
ELABORATION OF THE FOUR CRITICAL FUNCTION BLOCK OF MMOS

Items	Critical Functions
Real time controller	Critical situations: system starting-up/shutting-down, adding/removing periphery devices, adding/removing power conditioning converter, etc.
	Emergency situations: loss of periphery devices and loss of power conditioning converters; Overloading/under loading conditions (load shedding, generation curtailment; System fault conditions (fault isolation/system recovery), etc.
	Events driven operation: GUI settings input, System operating mode transitions, etc.
	System operation control: Voltage/frequency restoration, power reference tuning, etc.
EMS	Forecasting, unit commitment, state estimation, optimal power flow, economic dispatch, energy market participation, ON/OFF commands and set points.
Agents	Agents model, agents API
GUI	Display microgrid module operating status Monitor and control of power conditioning converters (for developer)
	Input user preferences or settings

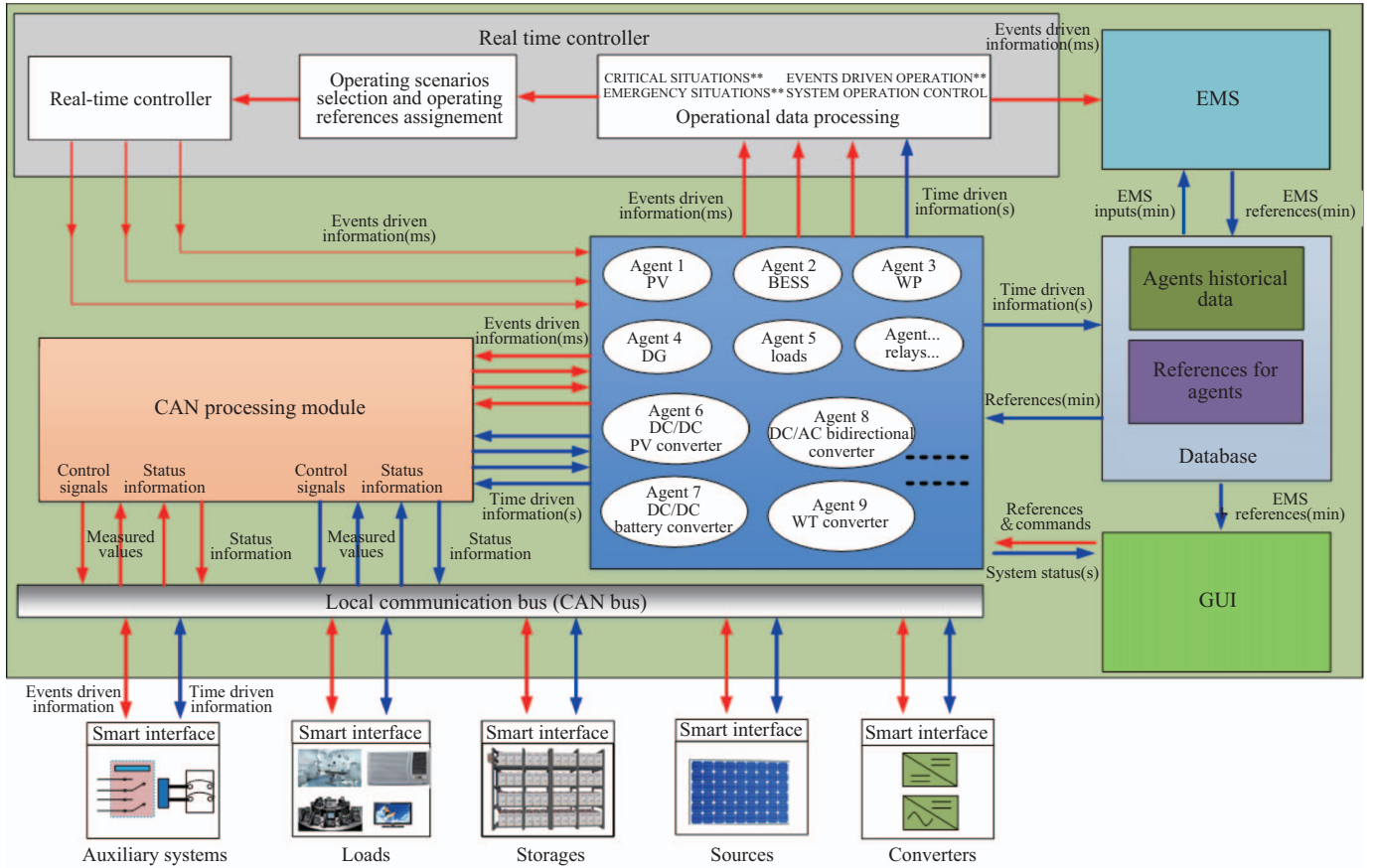


Fig. 4. Information flow and structure of the proposed MMOS.

Agents: Agents correspond to the logical devices (LDs) like periphery devices, power conditioning converters, intelligent input/output units (IOUs), and merging units (MUs). They follow the object-oriented-programming (OOP) concept. Each agent is a state machine running in a local central controller, which can be described as a combination of the agent model and agent application program interface (API). Agent model contains the status (critical parameters, and critical flags) of the LD it represents. The agent API serves as the API of a number of executable functions corresponding to the LD.

The main information flow within MMOS has been demonstrated in Fig. 4. The CAN processing model is responsible for parsing the raw data from the CAN bus and dividing them into two data streams: events driven information (EDI) and time driven information (TDI) (Periodical information). While receiving the real time information, the parameters of the agents' model will be updated. Part of the TDI will be stored in a local database acting as the sources of the inputs EMS module and used to refresh the GUI as well. System operation control function or short term scheduling of the real time controller also take TDI as inputs to implement its functionalities. If EDI is received by agents, operational data processing of the real time controller will be immediately triggered. Depending on the critical events encountered, different operating scenarios will be selected. Then the real time control block will call the agent API following the selected operating scenarios and execute necessary functions with corresponding assigned operating references. Finally these controls signals

and setting information will be sent to the microgrid equipment through the CAN bus communication.

Hierarchical control based on different time scales is proposed for the system control operation as shown in Fig. 5 [16]. For conventional control techniques [17], [18], deviations of the AC frequency and DC voltage in steady state degrade the system power quality, which results in deterioration of the system units' lifetime operation. This can be eliminated. The proposed hierarchical control can be divided into three layers, namely primary control, secondary control and tertiary control, which can be described in the below equations as elaborated in [16].

$$\left\{ \begin{array}{l} \Delta V_V = G_{VR}(V_n - V) \\ \Delta f_f = G_{FR}(f_n - f) \end{array} \right\} \text{Secondary} \quad (1)$$

$$\left\{ \begin{array}{l} V_{oi} = V_n + \Delta V_V + \Delta V_{PESie} \\ f_{oi} = f_n + \Delta f_f + \Delta f_{Pi} \end{array} \right\} \text{Tertiary}$$

The primary control is realized in the converter controllers. The secondary control and tertiary control is implemented in the MMOS. Converter controllers are able to follow the scheduled operating mode and operating references. All converters in the microgrid module coordinate to realize functionalities like voltage/frequency regulation, maximum power tracking of RESs, power balancing, etc. Real-time power balance is the primary control objective to ensure the stable operation of the system. When sudden load increase/drop occurs in the AC or DC subgrid, the voltage regulator of the respective subgrid will

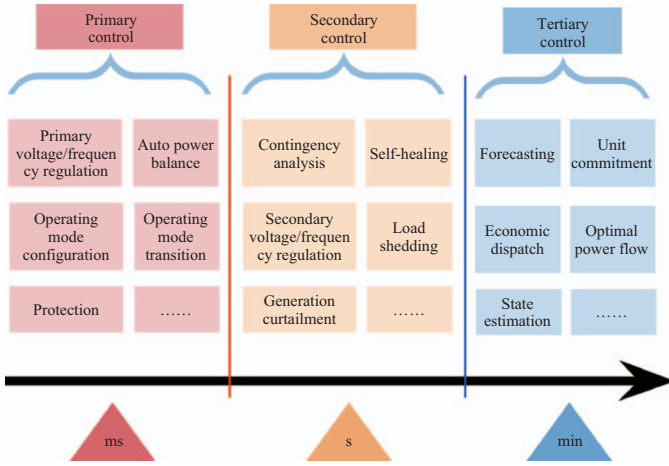


Fig. 5. Schematic diagram for hierarchical control.

change the output power instantly to compensate for the load variations. The response is based on the distributed control, which shows a high speed of response of milliseconds.

In the primary control, converters operate based on local information. In order to eliminate the control errors which are induced due to line impedance and control inaccuracy, a secondary control is implemented. It is primarily responsible for two objectives: 1) tuning of converter operating references to enhance power quality and control accuracy; 2) eliminate or solve critical issues like load shedding, generation curtailment, etc. The secondary control is implemented in second(s) due to the communication delay involved. The microgrid is a weak system due to its limited capacity and inertial. There is a maximum communication delay (delay margin), beyond which the system might be unstable. Therefore, the communication system should be designed so that the communication delay is within the delay margin [16].

Tertiary control is proposed to economically realize systematic optimization. Forecasting of load consumption, RES generations based on algorithms like artificial neural network, extreme learning machine, etc. are implemented to indicate the future situation. Unit commitment, economic dispatch and optimal power flow are executed to generate the long-term operating references for all sources. The tertiary control is usually executed every several minutes.

V. EXPERIMENTAL RESULTS

A preliminary adaptive integrated hybrid AC/DC microgrid module prototype based on silicon carbide devices has been built to verify the proposed design. The specifications of the major components of the microgrid module are given in Table II. Several typical operating scenarios of the proposed hybrid AC/DC microgrid module have been listed in Table III. As mentioned in the above Section, BIC has three operating modes: Inverter mode or AC voltage regulation mode (AC VRM), rectifier mode or DC voltage regulation mode (DC VRM), and PDM. For the energy storage system (ESS) converter, normally it has two operating modes: DC VRM and PDM. The experimental results of several typical operating scenarios and the transitions between them have been

demonstrated to validate the above designed communication network MMCN and MMOS.

TABLE II
MAJOR COMPONENTS OF THE EXPERIMENTAL PROTOTYPE

Specification	Parameter
DC grid voltage	380 V, DC
AC grid voltage	3-phase 110 V, 50 Hz
BIC converter	Rated power rating: 5 kW Rated DC voltage: 380 V Rated AC voltage: 3-phase 110 V, 50 Hz
Battery	Lead Acid Battery, 20 kWh.
PV	Polycrystalline silicon PV 3 channel, each channel 1.5 kW
Battery/wind turbine DC/DC converter	Rated power rating: 5 kW Rated input voltage: 150–250 V Rated output voltage: 380 V
PV DC/DC converter	3 channel interleaved DC/DC converter Each channel rated power rating: 1.67 kW Rated input voltage: 150–250 V Rated output voltage: 380 V

TABLE III
LIST OF THE OPERATING SCENARIOS OF THE PROPOSED HYBRID AC/DC MICROGRID MODULE

Scenario Number	ESS Converter	BIC	Diesel Generator	Utility Grid
#1	DC VRM	PDM	Idle	Tied
#2	DC VRM	PDM	AC VRM	Isolated
#3	DC VRM	AC VRM	Idle	Isolated
#4	PDM	DC VRM	Idle	Tied
#5	PDM	DC VRM	AC VRM	Isolated
.....				

The transition of the converter's operating mode can be classified into two types: 1) Unscheduled transition. The transition happens based on protection schemes like over-voltage/power/frequency, *etc.* to ensure stable operation of the system. 2) Scheduled transition. The transition is triggered by the local central controller according to the schedule of control strategies of EMS. The former is realized based on the converter local information, thus the speed of response is much faster, but it may not be the systematic optimized solution. The latter relies on the communication link with the local central controller. The transitions of the following case studies fall into the scheduled transition type.

A. Case 1

1) For interval $t_0 < t < t_1$, the microgrid module is operated at scenario #1. The ESS and its converter are regulating the DC sub-grid while BIC is working on the PDM mode. The utility grid is tied and regulates the AC sub-grid voltage.

2) At time instant $t = t_1$, GUI is used to set the power reference as 2 kW (DC to AC is defined as positive). As shown in Fig. 6(a), once the BIC agent model receives the reference from GUI and corresponding BIC, API will instantaneously trigger an EDI signal. After passing through the CAN processing module, the reference setting signal will be sent to the digital controller (DSP) of the BIC within 0.1 ms. Under the control of DSP, soon the BIC will take 2 kW from DC to AC. The DC sub-grid voltage is maintained stable by the ESS converter.

3) At time instant $t = t_2$, the same process as $t = t_1$ repeats except the power reference varies from 2 kW to −2 kW.

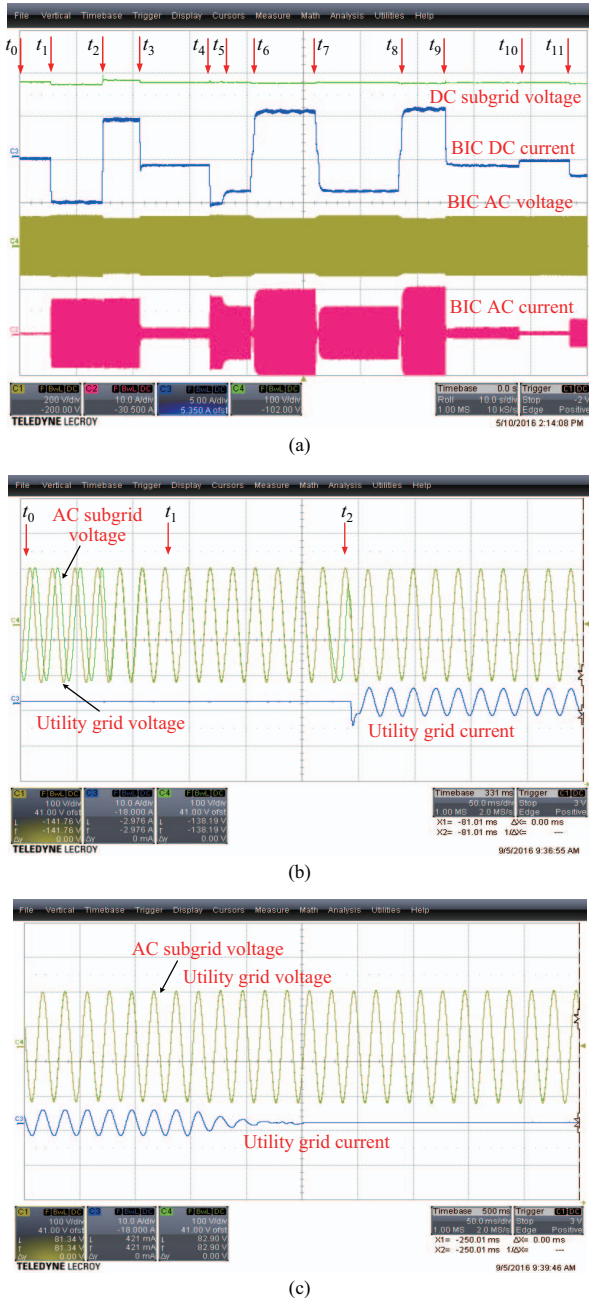


Fig. 6. Experimental waveform of the proposed hybrid AC/DC microgrid module. (a) Operating scenario #1 and #4 and the transition between them. (b) Operating scenario #1 and #3 and scenario transition from #3 to #1. (c) Operating scenario transition from #1 to #3.

Case 1 is used to simulate the process that the BIC receives the setting reference from EMS's economic dispatch assignment (the GUI control is manually used during the experiment).

B. Case 2

1) At time instant $t = t_3$ (Fig. 6(a)), under the control of GUI, the BIC transfers from the operating mode PDM to DC VRM. Shortly after that, the ESS converter goes to PDM. Then the microgrid transfers from scenario #1 to scenario #4.

2) At time instant $t = t_4$, GUI is employed to control the power reference of the ESS converter as 2 kW (discharging is

defined as positive). The BIC will immediately take over the discharging power to keep the DC sub-grid constant. Since, there is a dc load connected to the DC sub-grid, the power transferring to the AC sub-grid is a bit lower than 2 kW.

3) At time instant $t = t_6$, the power reference of the ESS control converter changes from 2 kW to -2 kW to charge energy from the DC sub-grid under the control of GUI. The BIC will inject power from the AC sub-grid to the DC sub-grid.

4) At time instant $t = t_9$, set ESS converter to DC VRM. And soon after that, BIC goes back to PDM. The microgrid transfers from scenario #4 to scenario #1. At $t = t_{10}$, the BIC power transfer is reduced to zero.

The objective of Case 2 is to simulate the process under the control of the EMS's economic dispatch, the charging and discharging process of the ESS can be precisely managed to increase the overall microgrid module economic value.

C. Case 3

1) Before $t = t_0$ (Fig. 6(b)), the microgrid module is operated at scenario #3. The ESS and its converter is regulating the DC sub-grid while BIC is regulating the AC sub-grid voltage (AC VRM).

2) At time instant $t = t_0$, operating mode transition command from AC VRM to PDM is triggered by GUI and sent to the BIC agent. The corresponding BIC agent transition flag is set and then the operational data processing block will be activated. The events driven operation will be executed and the related predefined operating scenario is selected. Following the operating scenario, the real time control block initiates the phase locking/adjusting process by activating the BIC agent API and the RM agent API. The actual operation of the phase locking is realized by the embedded functions of the real time digital controller of BIC and RM under the control of their virtual API.

3) By the time $t = t_1$, the AC subgrid voltage has synchronized with the utility grid voltage. When the defined synchronization criterion is satisfied, the real time control block triggers a relay turn-on command to the RM agent API after some delay. Neglecting the CAN transmitting delay, the utility grid relay is turned on immediately. And the BIC will switch to PDM almost at the same time. The microgrid module transfers from scenario #3 to scenario #1.

4) The experimental result of the reverse transition from scenario #1 to scenario #3 is demonstrated in Fig. 6(c).

The target of Case 3 is to simulate the transition between the grid-connected operation and islanded operation of the hybrid microgrid module subject to the schedule of the strategies of EMS or the faultless operation of the system. Although all the testing of the three cases are under control of the GUI, the validated functionality can be integrated into MMOS in an autonomous manner collaborating with the local system EMS.

VI. SUMMARY AND CONCLUSION

A novel adaptive integrated hybrid AC/DC microgrid module concept has been introduced in this paper for the benefits

of rapid deployment and ease of usage. The hybrid AC/DC microgrid acts as a smart plug-and-play interface for incorporating and distributing multiple renewable and fossil energy sources, energy storage and micro-grid components, some via the ac port and others via the dc port. To achieve the plug-and-play functionality, the information model specifically suitable for the proposed microgrid module has been studied. On the basis of the information model, two level communication networks have been designed. The local communication network is to monitor the operating status of the microgrid module and

to collect the data from all devices as well as to provide control references to each device. The global communication network is used to exchange information among different microgrid modules within a microgrids constellation to obtain overall optimized performance. A MMOS has been designed and implemented in the local central controller to monitor and control the real time operation of the microgrid module. The microgrid module design concept and its performance have been verified by the experimental results.

APPENDIX

TABLE AI
NEWLY DEFINED LNS

ZBIC Class				
Data Object Name	Common Data Class	Explanation	T	M/O/C
LN Name		Shall be inherited from logical-node class (see IEC 61850-7-2)		
System logic node data				
		LN shall inherit all mandatory data from common logical node class		M
		Data from LLN0 may optionally be used		O
ConvTyp	ENG	Conversion type:		O
		Value	Explanation	
		0	Not applicable/Unknown	
		1	AC/DC or DC/AC	
		2	AC/AC/DC or DC/AC/AC	
		3	AC/DC/DC or DC/DC/AC	
		99	Other	
Status Information				
WDirSt	ENG	Power transferring direction:		O
		Value	Explanation	
		0	AC to DC	
		1	DC to AC	
Settings				
PQVLimSet	CSG	Active curve characteristic curve for PQV limit		M
OptMod	ENG	Operating mode		M
		Value	Explanation	
		0	Rectifier mode	
		1	Inverter mode	
		2	Power dispatch mode	
DVSet	ASG	DC voltage setpoint (only valid when OptMod is Rectifier mode)		O
AVSet	ASG	AC voltage setpoint (only valid when OptMod is Inverter mode)		O
HzSet	ASG	AC frequency setpoint (only valid when OptMod is Inverter mode)		O
WSet	ASG	Operating power setpoint (only valid when OptMod is Power dispatch mode):		O
		Value	Explanation	
		Positive	AC to DC	
		Negative	DC to AC	
VarSet	ASG	Operating reactive power setpoint (only valid when OptMod is Power dispatch mode):		O
		Value	Explanation	
		Positive	AC to DC	
		Negative	DC to AC	
PFSet	ASG	Power factor setpoint as angle (only valid when OptMod is Power dispatch mode):		O
		Value	Explanation	
		Positive	AC to DC	
		Negative	DC to AC	
AALim	ASG	AC side current limit		O
DALim	ASG	DC side current limit		O
AVLim	ASG	AC side voltage limit		O
DVLim	ASG	DC side voltage limit		O

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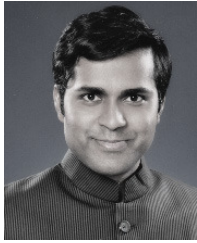
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