Review on Investigation of Advanced Control Strategies For Power Flow Management In Hybrid AC/DC Systems

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Abstract- *The AC/DC hybrid microgrid has a large-scale and complex control process. It is of great significance and value to design a reasonable power coordination control strategy to maintain the power balance of the system. Based on hierarchical control, this paper designs a reasonable power coordination control strategy for AC/DC hybrid microgrid. For lower control, this paper designs a variety of control modes for each converter in different application scenarios. For the higher control, this paper analyzes the working mode of the system and designs the power coordination control strategy under the grid-connected and isolated island mode. In grid-connected operation, the DC bus voltage can be stabilized by adjusting the operation mode of the DC energy storage and the on-off the secondary load. In isolated island operation, the DC sub-microgrid is the main microgrid, and the DC energy storage is the main power regulating equipment. This is based on the principle of "energy is in short supply in the system, DC energy storage finally discharge, energy supply exceeds demand in the system, DC energy storage gives priority to charging" of DC energy storage. By adjusting the control strategy of the micro-source, the reference power, and the on-o_ of the secondary load, the overall power balance is maintained. The Matlab/Simulink simulation software was used to build the AC/DC hybrid microgrid simulation model, which verified the effectiveness and stability of the proposed power coordination control strategy under various operating conditions.*

Keywords- AC/DC hybrid microgrid; hierarchical control; system working mode; main microgrid etc.

I. INTRODUCTION

The depletion of fossil fuel and their impact on the environment has resulted in the transition toward renewable energy sources (RES) to overcome the global energy challenges. These RESs are great alternatives to power generation to reduce CO2 and greenhouse gas emissions. Some of the most prominent RESs are solar photovoltaic (PV), hydro, wind, geothermal, biomass, etc. Due to the low operating cost, easy installation process, and low maintenance, the PV system becomes the most promising technology to cover future energy demands. In recent years, environmental sustainability, efficiency, reliability, robustness, power management, and some power quality features are some of the benefits that are provided by microgrid (MG) technology. A microgrid is basically a controllable power supply system that interconnects with a group of distributed energy resources (DERs) and loads in a defined electrical boundary. It can operate either in islanded/isolated mode or in grid-connected mode. The simple layout of a microgrid with different energy storage devices and utility grids is shown in Figure.

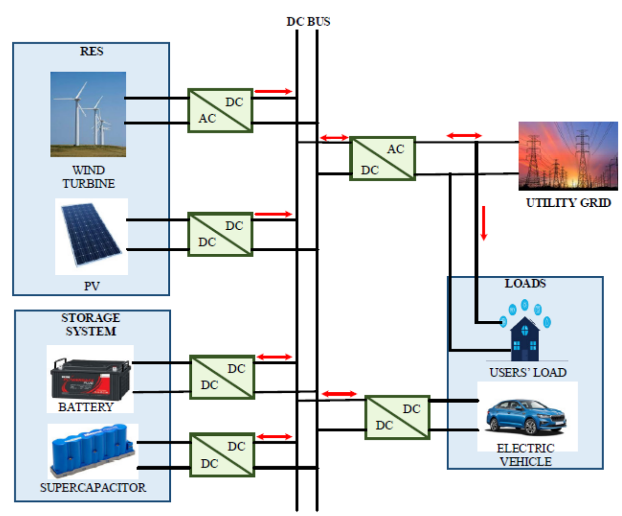

Fig. 1 Outline of Microgrid

The microgrid can be considered as a small-scale low power supply system, but there are a number of factors that differentiate the microgrid from the existing conventional grids. An analytical comparison between the conventional grid and microgrid. The combined operation of these RESs, loads, and storage devices in the MG requires a proper control strategy to get the optimal use of the distributed generators (DGs) to feed the connected loads. Hence, a suitable power management strategy is very important for the MG operation.

A low-pass filter-based power management study was presented in to share the total system power requirement between the battery and SC storage system in a PV-integrated hybrid AC/DC microgrid system. In this literature, conventional proportional-integral (PI) controllers are utilized to maintain a simple control structure. A sliding mode controller-based power management control scheme was proposed in for a PV, wind, and fuel cell with HESS microgrid along with linear and nonlinear loads. In, a fixed frequency-based PWM, and in, an adjustable bandwidth-based control structure is implemented by using the sliding mode controller to overcome the issues with high and variable frequency-based operation using conventional PI controllers. A battery energy storage-based microgrid was controlled by using the combination of the fuzzy logic controller (FLC) and the DC bus voltage regulation technique in. Here, the state of charge (SOC) and charging/discharging of the battery were properly monitored by the FLC compared to the conventional droop control techniques. A frequency signaling-based fuzzy logic control is utilized in for an islanded AC microgrid with battery energy storage system.

II. LITERATURE REVIEW

- **Siddaiah and Saini (2016) et al.** proposed a review on hybrid systems, dividing them according to the type of DC/AC or AC/DC static conversion used and the intended use (small such as villages or large such as districts and communities). In addition, the analysis classified the modelling and optimization techniques into classical, artificial intelligence and hybrid, and proposed a further division into economic and energy-based techniques.
- **Olatomiwa (2016) et al.** reviewed the system management strategies of various studies, dividing the techniques into three main types: linear programming, intelligent and software. Each of the techniques was analysed separately for stand-alone and grid-connected systems giving particular attention to the use of the Fuzzy Logic technique. The analysis exposed a dense collection of studies, describing in detail the configurations studied and the conclusions reached by each survey.
- **Goel and Sharma (2017) et al.** presented a sample of studies on hybrid systems divided into four categories: stand-alone systems, grid-connected systems, systems used for rural electrification and charging of electric vehicles using renewable energy. The study highlighted the research results on hybrid systems (until 2017) and dedicated a short space for software optimization.
- **Sawle (2018) et al.** provided a detailed description of hybrid system components, modelling techniques, system control and optimization and carried out a case study aimed at the system economic optimization using HOMER and PSO.
- **Kartite and Cherkaoui (2019) et al.** proposed a rather general review on hybrid systems, reporting their classification according to operating mode, components and system size, main optimization criteria and software used for this purpose. The analysis mentioned several studies related to system optimization through different methodologies (genetic algorithm, economic evaluation through HOMER, optimization through LPSP, etc.).
- **Nema (2009) et al.** presented the sizing process phase by phase, illustrating the pre-feasibility studies, the modelling of components, the system sizing and optimization and the tools for control and management of energy flows in the system, reviewing many studies dealing with these topics. The analysis carried out in 2009 concluded by predicting the system cost reduction considering the increase in the cost of conventional energy, and the diffusion of artificial intelligence techniques to optimize energy management operations.

III. PROPOSED SYSTEM

The configuration of the DCMG system considered in this study. The DCMG system consists of four agents, who are the grid agent, battery agent, wind power agent, and load agent. The grid agent and battery agent can export or import the power from the DC-link, while the wind power agent only provides the power to the DC-link and the load agent only absorbs the power from the DC-link. In this figure, P_G, P_B, P_W, and P_L denote the power from or into the grid agent, the power from or into the battery agent, the power from the wind power agent, and the power into the load agent, respectively. also shows the current direction of each power agent. For convenience, the reference direction of all the currents is taken as out of the DC-link. In order to connect the main grid source to the DCMG system, a transformer and a bidirectional AC-to-DC converter are employed. To supply the power from the wind turbine into the DCMG system, a permanent magnet synchronous generator (PMSG) and a unidirectional AC-to-DC converter are used. A battery is connected with a bidirectional DC-to-DC converter to exchange the power with the DCMG. In the load agent, load shedding or reconnection is achieved through electronic switches.

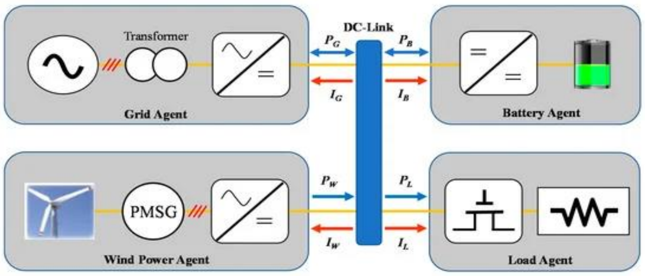

Fig. 2 Configuration of DC microgrid (DCMG).

A. Grid Agent

The configuration of the grid agent. In order to damp the harmonic currents caused by the main grid source, an inductive-capacitive-inductive (LCL) filter is placed between the grid transformer and AC-to-DC converter. The parameters R1, R2, L1, L2, and C_f represent the filter resistances, filter inductances, and filter capacitance, respectively. The inverter-side current and grid-side current are denoted as i_1 and i_2, respectively. To regulate the currents in bidirectional way, an integral state feedback current controller with a full state observer is employed based on only the measurements of the grid currents and grid voltages. The detailed control design process and observer implementation for the integral state feedback current controller in the grid-connected inverter is presented. The grid agent has three operating modes in the DCMG system, which are V_{DC} control converter (CON) mode, V_{DC} control inverter (INV) mode, and IDLE mode. The grid agent operates as V_{DC} control CON mode when the wind power cannot supply the load demand, or the wind power cannot supply both the load demand and battery power in the charging mode of battery. In this operating mode, the grid agent maintains the DC-link voltage at the nominal value by injecting the required power from the grid to the DCMG.

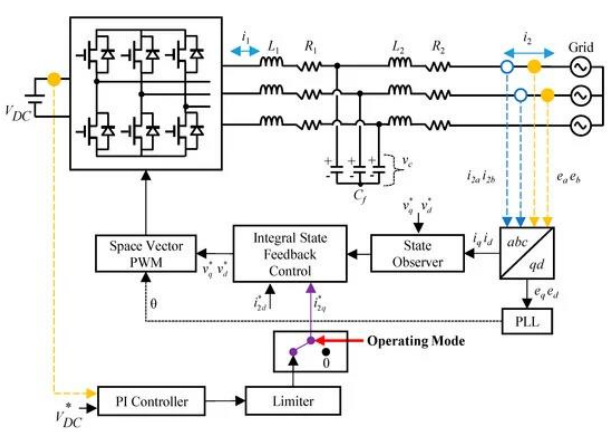

Fig. 3 Configuration of Grid Agent

The second operating mode, namely, V_{DC} control INV mode is used when the wind power is sufficient to supply the load demand. The grid agent also operates in this operating mode when the wind power can supply both the load demand and the maximum charging power of the battery ($P_{B,Max,chr}$). In V_{DC} control INV mode, the grid agent absorbs the surplus power from DCMG to inject it to the main grid, while regulating the DC-link voltage at the nominal value.

B. Battery Agent

The battery is connected to the DCMG system with an inductive (L) filter and interleaved bidirectional DC-to-DC converter for the purpose of reducing current ripples. The battery agent has four operating modes which are V_{DC} control by charging, V_{DC} control by discharging, charge with the maximum allowable current ($I_{B,Max}$), and IDLE mode. The battery agent operates in V_{DC} control mode by charging if a fault occurs in the grid, and the wind power generation P_W is higher than load demand P_L. This operating mode is also chosen when the battery SOC is lower than the minimum SOC level, SOC_{min}, and P_W is lower than P_L. Under the condition that P_W is lower than P_L, and the grid agent cannot operate in V_{DC} control CON mode, the battery agent operates in V_{DC} control mode by discharging. When the battery SOC is less than the maximum SOC level (SOC_{max}) and the grid agent is connected to the DCMG, the battery operates in charge with $I_{B,Max}$. This operating mode increases the battery SOC as fast as possible. The battery agent operates with IDLE mode when the battery SOC is greater than SOC_{max} and other power agents operate with V_{DC} control mode. This operating mode maintains the battery SOC level without exchanging the power with the DCMG.

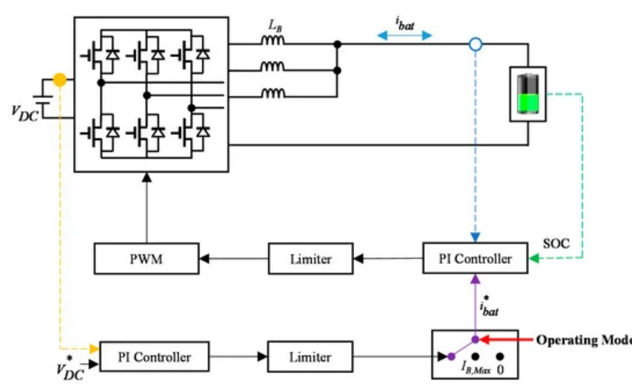

Fig. 4 Configuration of battery agent.

C. Wind Power Agent

An L filter is interfaced between the PMSG and unidirectional AC-to-DC converter, and the output of AC-to-DC converter is connected to the DC-link. The wind power agent has two operating modes which are the maximum power point tracking (MPPT) mode and V_{DC} control mode. The MPPT mode in which the wind power agent operates mostly aims to draw the maximum power from the wind turbine. On the other hand, when the wind power is higher than the load demand and other power agents cannot absorb the surplus power from the wind power. The wind power agent initiates V_{DC} control mode to maintain the DC-link voltage of DCMG reliably. The V_{DC} control mode is implemented by two cascaded control loops, i.e., the outer loop PI controller for the DC-link voltage regulation and inner loop synchronous PI decoupling current controller. The MPPT mode is implemented by the MPPT algorithm, PI speed controller, and inner current control loop.

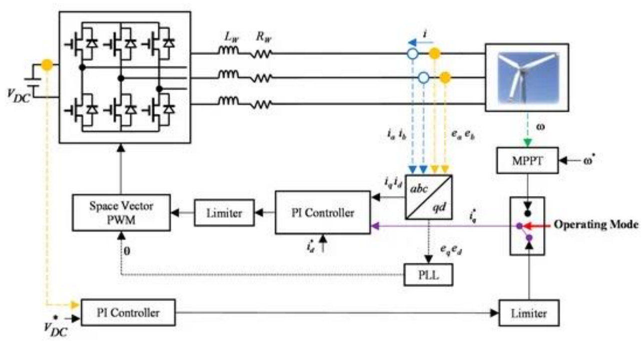

Fig. 5 Configuration of wind power agent.

D. Load Agent

In a critical situation, the load agent can shed unnecessary load to prevent the DCMG from collapsing. After the termination of a critical situation, the load agent may reconnect the shedded load through the load reconnection algorithm. The load shedding algorithm is activated when all the agents cannot provide the demanded power of load. In this condition, the load agent disconnects load one by one from the least important load. This process lasts until the system power balance of DCMG is ensured by supplying the necessary load demand at some point. When the grid is reconnected to DCMG or the battery has a sufficient SOC level, the load reconnection algorithm is initiated to reconnect the shedded load.

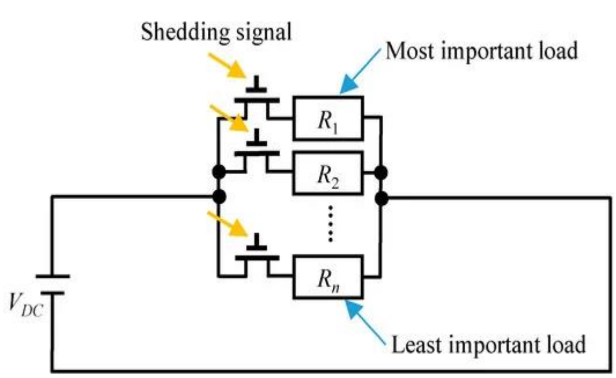

Fig. 6 Configuration of load agent

IV. HYBRID DCMG CONTROL ARCHITECTURE

A. Hybrid DCMG Architecture

In the hybrid control architecture, the centralized and distributed control schemes are combined. In this figure, the blue dashed line represents an HBC link for the centralized control architecture, while the black solid line represents an LBC link for the distributed control architecture. The exchange of information between the CC and power agents in the centralized control architecture is achieved through the HBC link. On the contrary, all the power agents exchange the information with adjacent neighbors in the distributed control architecture by using one-bit binary data format through the LBC link. In the centralized control of DCMG, the CC collects the information from all the power agents, processes the acquired data, and determines the operating modes of all the power agents to achieve a global optimum solution of the DCMG system. On the other hand, the distributed control of DCMG aims to improve the system reliability and robustness against a fault in the communication link.

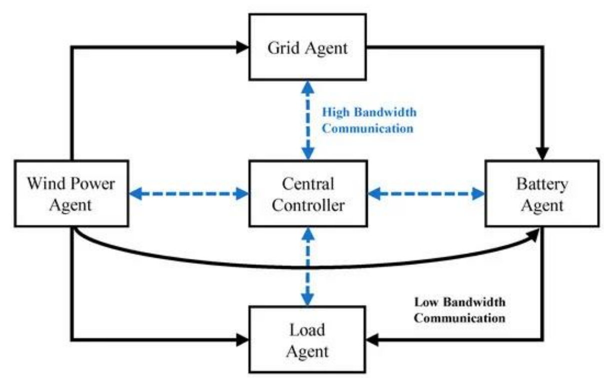

Fig. 7 Concept of the hybrid DCMG control architecture.

In this study, the control mode transition between the centralized control and distributed control is determined based on the availability of the CC. It describes the control mode transition in the hybrid DCMG architecture. During the normal condition without the CC fault, the CC operates the entire DCMG system by the centralized control architecture. Once a fault occurs in the CC, the distributed control takes control to operate the DCMG system.

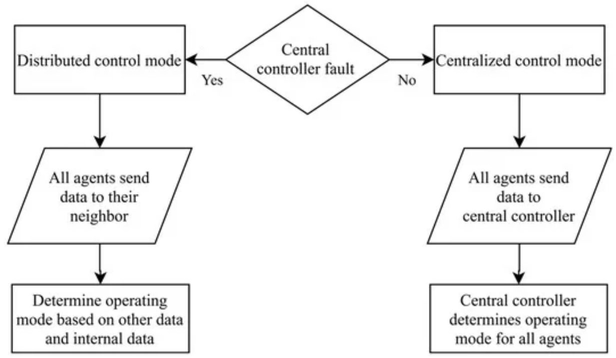

Fig. 8 Control mode transition in the hybrid DCMG architecture.

In the centralized control mode, the data is exchanged between the CC and all power agents. All the power agents send specific data to the CC through the HBC link. At the same time, the CC also investigates the electricity price condition from the external sources like the internet. Based on the acquired information, the CC makes the best decision for the operating mode of all agents. Finally, the CC sends data which contains the agent operating mode along with a control signal (CS) to all the agents. Each power agent uses the CS value to determine the operation by the centralized control mode (CS signal is high) or distributed control mode (CS signal is low). When the CS signal is high, all the agents obviously use the operating mode given by the CC. On the other hand, when the CS signal is low, all the agents determine the operating modes based on the agent internal data and received information through the LBC link. In the distributed control mode, all the agents send specific data in a one-bit binary format to the adjacent neighbors. In this scheme, the data transfer by the HBC and LBC methods is accomplished every control period.

V. ADVANTAGE & DISADVANTAGE

Advantage

- Sources can be placed far apart
- Low cost as costly communication lines are absent
- More reliable than communication-based system
- High efficiency with reduced losses
- Better voltage and frequency regulation
- Information communicated to each source without delay
- Provide efficient, low-cost, clean energy
- Improve the operation and stability of the regional electric grid
- Critical infrastructure that increases reliability and resilience
- Reduce grid “congestion” and peak loads
- Enable highly-efficient CHP, reducing fuel use, line losses, and carbon footprint
- Integrate CHP, renewables, thermal and electric storage, and advanced system and building controls
- Make RTO markets more competitive
- Offer grid services including: energy, capacity, and ancillary services
- Support places of refuge in regional crises and first responders
- Use local energy resources and jobs
- Diversified risk rather than concentrated risk
- Using electric and thermal storage capabilities, a microgrid can provide local management of variable renewable generation, particularly on-site solar

Disadvantage

- Coupling between real and reactive load sharing
- Accuracy dependent on locally measured variables
- Needs secondary control to reduce the steady-state error
- Increased cost and complexity
- Communication failure can compromise stability
- Requires security protocol

VI. CONCLUSIONS

The review focused on current work on hybrid micro-grid integrated with renewable energy sources. The primary problem, especially for those operating in the islanded mode, is power management and control strategy. This is mostly owing to the microgrid's necessity to control voltage, frequency, and power delivery in addition to power supply. In the literature, many methodologies for analysing power-sharing possibilities for AC and DC microgrids have been given. The authors highlight three major study areas: hybrid microgrid convergence, system control, and distribution network modelling. This research investigated power management strategies in hybrid microgrids, as well as the benefits, difficulties, and solutions interfaces together AC microgrids and DC microgrids. Such systems' unidirectional/bidirectional power flow capabilities, as well as changes in frequency and methods, were explored.

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