Coordination control of medium-voltage hybrid ac/dc distribution

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Abstract: Hybrid ac/dc distribution has attracted much attention recently. This study presents a medium-voltage (MV) hybrid ac/dc distribution consisting of various distributed generations connecting to the ac and dc loads. Coordination control in hybrid ac/dc distribution is a challenging issue to achieve stability especially when there is a load rejection or loss of the generation. A new decentralised control is proposed to coordinate the hybrid ac/dc distribution even when the inter-station telecommunication is not available. A new control is employed at interlinking converter (ILC) to maintain the power balance between ac and dc subgrids, and to ensure that the power quality is maintained in normal operating condition as well as in an extreme abnormal condition such as island mode. Further, a new control strategy is developed in battery storage system (BES) as a backup device to minimise the power fluctuation in the event of the shedding of the loads or generations. Another advantage of the combination of ILC and BES controllers is to provide a multiple slack terminals in both ac and dc grids, which will enhance the stability in the system. Simulation results have shown that the stability performance can be achieved in various operating scenarios.

1 Introduction

Recently, dc loads such as electric vehicles and data centres have been increasing, and therefore the dc power quality requirement becomes more critical. On the other hand, the system condition of the grid will be changing with high penetration of the renewable generations. Dc distributions have been proposed to address the challenges in dc power quality and the connection of renewable generations. In comparison with ac distribution, dc distribution has advantages of higher power quality, larger transmission capacity and easier access to distributed generations, which make it become an attractive distribution option in future [1–5]. At present, practical engineering projects of the dc distributions have also been applied preliminarily, for example, the Finland Elenia Oy company has built low-voltage dc distribution in rural areas [4], and the campus dc distribution will be completed in Germer Aachen University of Technology before 2020 [5].

Pure dc distributions are not expected to emerge exclusively in power grids, for ac distributions are dominant, and would be so for decades, hybrid ac/dc distributions with dc and ac generations/loads are more possible [6, 7]. The challenge of coordination control is to dispatch real-time power from different power generations to achieve stable dc voltage at the dc link and to achieve stable ac voltage and frequency at the ac subgrid.

The studies on coordination control of hybrid ac/dc distribution are rarely seen, but the control strategy in microgrids is a possible method to be used in hybrid ac/dc distribution [8–14]. In [8], the centralised control is exploited to manage the power in a hybrid microgrid. However, taking the decentralised geographical distribution into consideration, the reliability cannot be ensured for the high requirement on fast inter-station telecommunication. In order to avoid control interconnections, the reliability concerns have propelled the coordination control into the decentralised control, among which droop control gained much attention. A number of droop control strategies concentrate on distributed generation (DG) control [9, 10]. According to the droop characteristics, DG units adjust real-time power to guarantee the power balance. At the same time, improved droop controls are widely used in the design of interlinking converter (ILC). Autonomous operation of hybrid microgrid is investigated in [11] and extended to a hybrid microgrid containing an energy storage system in [12], a modified droop control is developed to control the ILCs by using a normalised bidirectional droop. In [13], the droop characteristic is redesigned based on the relation between dc voltage and power variation. As a matter of fact, microgrid is a sort of low-voltage (LV) distribution, different from the MV distribution in some aspects, particularly in the requirements on reliability under complicated operating conditions, a coordination control with broad applicability and high flexibility is essential.

A hybrid ac/dc distribution is proposed in this paper to eliminate the process of conversion and improve the operation efficiency. Five operating modes are studied. This paper provides a decentralised control scheme, in which each converter will select different operating mode based upon the local information such as voltage and power. This control scheme provides smooth coordination among different slack terminals using droop control strategy of converter stations and battery storage system (BES). By doing this, MV distributions can harness maximum power from renewable generation, guarantee high power quality for dc and ac loads and maintain the stable operation under various operating conditions.

2 System configuration and operation modes

2.1 Grid configuration

Fig. 1 shows the hybrid ac/dc distribution schematic diagram. ILC links the ac and dc subgrids and each of these two subgrids is tied to high-voltage (HV) distribution through transformer and interfacing converter (IFC), respectively. Permanent magnet synchronous generator (PMSG) [15] and photovoltaic (PV) array [16] are connected to the corresponding ac and dc subgrids, respectively, so as to reduce the power loss with the minimum converters. Lead-acid battery is connected to dc subgrid by bidirectional dc–dc converter, which is used to smooth the power fluctuation caused by generations or loads.

All units in hybrid ac/dc grid can be categorised into two types: power terminal and slack terminal [17]. Power terminals, such as DGs and loads, which are influenced by weather conditions and load consumers, normally operate on their own merits.
Slack terminals, like IFC and ILC, are controlled to maintain the stability of the system by accommodating power variation. When the power is out of limit, this unit will be transformed into a power terminal, no longer maintain the stability. Under normal operating conditions, both dc and ac subgrids should have at least one slack terminal.

Five main operating modes are considered according to the operating states of the breakers in hybrid ac/dc distribution, as shown in Table 1.

2.2 Normal operating mode
When the hybrid grid operates in this mode, both dc and ac subgrids are linked to the HV distributions and interconnected with each other. Power surplus of one subgrid can be transmitted into HV distribution or the other subgrid. The stability of dc voltage is maintained by the combination of ILC with IFC, and ac subgrid synchronises with ac HV distribution. Both PV array and PMSG operates in MPPT modes by regulating the terminal voltage and pitch angle, respectively, and the role of the BES is to operate bi-directionally to smooth the power fluctuation of PV array.

2.3 Abnormal operating modes
In this mode, at least one breaker will trip and the blocking of one or two stations may occur due to faults, overloads or any other abnormal conditions. The hybrid grid loses at least one slack terminal. Furthermore, the mode can be divided into four categories.

2.3.1 AC off-grid mode: The breaker at the HV distribution side trips, ac subgrid no longer synchronize with the HV distribution. In this case, ILC plays a critical role in power management and control, performing as the only slack terminal in ac subgrid.

2.3.2 DC off-grid mode: The breaker that connects the HV distribution and dc subgrid trips, IFC is incapable of delivering the power required for the dc subgrid. The dc voltage is maintained by ILC, which can ensure the dc load supply and the output power of PV array.

2.3.3 Disconnected operating mode: ILC is out of operation in this mode, which results in ac and dc subgrids are split into two independent parts. For dc subgrid, IFC still act as a slack terminal to maintain the dc voltage. For ac subgrid, the ac voltage and frequency are stabilised by the HV distribution.

2.3.4 Island mode: Both HV distributions are out of operation, no power exchange between the hybrid grid and HV distributions. ILC acts as a slack terminal for both dc and ac subgrids, whilst BES is likely to regulate the dc voltage within its state of charge limit. If the stable operation cannot be regained because of the power shortage or the power surplus, load shedding or power reduction of the DGs will be executed.

2.4 Equivalent model of MMC
Both ILC and IFC are designed as modular multilevel converters (MMCs). The MMC is comprised of N sub-modules (SMs) per arm as depicted in Fig. 1, which results in a line-to-neutral voltage waveform with \((N + 1)\) levels. One capacitor and two IGBTs with antiparallel diodes are contained in each sub-module. The inductor \(L_0\) is cascaded on each arm to limit fault currents and arm-current harmonics (Table 2).

![Schematic diagram of hybrid ac/dc distribution](image)

**Table 1** Operating mode categories

| Operating modes        | Breaker action |
|------------------------|----------------|
| normal operation       | closed closed closed |
| abnormal operation     |               |
| AC off-grid            | closed closed open |
| DC off-grid            | open closed closed |
| Disconnected           | closed open closed |
| Island                 | open closed open |

**Table 2** MMC stations parameters

| Parameter                     | IFC   | ILC   |
|-------------------------------|-------|-------|
| MMC levels                    | 30    | 30    |
| capacitance value of SM       | 1000 μF | 1000 μF |
| rated active power            | 5 MW  | 4 MW  |
| rated reactive power          | 0 MVA | 0 MVA |
| droop coefficient             | -0.2 MW/kV | -0.12 MW/kV |
| equivalent resistance in grid side | 0.02 Ω | 0.02 Ω |
| equivalent inductance in grid side | 10 mH | 10 mH |
| arm inductance                | 4 mH  | 4 mH  |
| on-state resistance           | 0.01 Ω | 0.01 Ω |
| trigger frequency             | 2000 Hz | 2000 Hz |

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simulation is establishing an equivalent mathematics model which is capable of ensuring sufficient accuracy in dynamic simulations. Assuming that the capacitor voltages in each SM are balanced, thus the average values of capacitor voltages are equal, the accuracy of this assumption increases when the number of SMs per arm is increased [18]. Each arm can be modeled by (1), and the equivalent model in ON/OFF states is shown in Fig. 2

\[ v_{\text{arm}} = \frac{1}{N} \sum_{i=1}^{N} S_i v_{C0} + (NR_{\text{ON}}) i_{\text{arm}} \]

where \( N \) is the number of SMs, \( R_{\text{ON}} \) represents the linear conductivity losses, \( C0 \) is the capacitance of each SM, \( i_{\text{arm}} \) is the current of the arm, \( v_{C0} \) is the equivalent voltage of the arm, the switching function \( S_i \) values 0 when the state of SM is OFF, whereas it values 1.

3 New proposed coordination control of the converters

In order to supply the uninterrupted, high efficiency and high quality power to loads in normal operating mode and to ensure the system can return to stable state from abnormal operating modes as soon as possible, the coordination of the controller in multiple converters is used in the hybrid grid. The following section will describe the coordination control method employed in this paper.

Slack terminal priority control method is employed to guarantee the reliability and stability of the system. Under normal operating condition, the operating status in dc subgrid is determined based on the droop characteristic between IFC and ILC. The BES is normally operating in power control mode, however, when the measured dc voltage is outside a certain range, BES will automatically turn into the droop control mode, as shown in Fig. 3. As for the ac subgrid, the ILC will turn into ac voltage and frequency control mode automatically in the event of HV distribution is out of operation.

3.1 MPPT control for DGs

The PV array considered here is connected to the dc subgrid by a boost converter. The control objective is to harness the maximum power under normal conditions, and single-loop voltage control strategy is shown in Fig. 4a, where the voltage reference \( U_{\text{mpp}} \) is calculated by perturbation and observation method [19] (Table 3).

PMSG is connected to the ac subgrid by a couple of VSCs, turbine-side converter (rectifier) and grid-side converter (inverter). The vector control method is described in Fig. 5b, synchronous rotating \( d-q \) reference is oriented by the stator voltage vector. The rectifier is applied to equalise the rotating speed to \( \omega_{\text{ref}} \), derived from the MPPT algorithm [20]. On the other hand, capacitor voltage is maintained by the inverter (Table 4).

3.2 Droop control for IFC

Associated with the HV distribution in dc subgrid, IFC is one of the main factors to stabilise dc subgrid under variable kinds of operation. The following section will describe the operation strategy of IFC.
conditions. The mathematics model in the two-phase synchronous rotating coordinate system is given by

\[
\begin{align*}
\frac{d u_d}{dt} &= u_{dref} - R_i u_d - u_d + \omega L_i q_d, \\
\frac{d u_q}{dt} &= u_{qref} - R_i u_q - u_q - \omega L_i d_d,
\end{align*}
\]

(2)

where the subscripts \( d, q, s, c \) denote the \( d \)-axis, \( q \)-axis, grid and converter, respectively, \( R_i \) and \( L_i \) represent the resistance and inductance, respectively, \( L_1 = L_2 = 0.5L_c \), \( k_s \) is the equivalent inductance of the grid side. Droop control is adopted in the \( d \)-axis outer controller, \( P-U_{dc} \) droop characteristics can be expressed by

\[
P_{IFC} = -\frac{1}{k_{IFC}}(U_{dc_{ref}} - U_{dc}) + P_{IFC_{ref}}
\]

(3)

where \( U_{dc} \) and \( U_{dc_{ref}} \) represent the dc voltage and its reference value, respectively, \( P_{IFC} \) and \( P_{IFC_{ref}} \) represent the active power and its reference value, respectively, and \( k_{IFC} \) is droop coefficient, \( k_{IFC} < 0 \). If the \( U_{dc_{ref}} \) and \( P_{ref} \) are known, \( k_{IFC} \) can be calculated by

\[
k_{IFC} = -\frac{\varepsilon U_{dc_{ref}}}{P_{max} - P_{ref}}
\]

Where \( \varepsilon \) denotes the maximum deviation range of dc voltage, \( P_{max} \) is the maximum power of converter, \( P_{ref} \) is always set to 0 to reduce the imbalance power in case the IFC is out of operation.

The controller is shown in Fig. 5, double closed-loop control strategy is adopted for IFC. Current reference of \( d \)-axis inner loop controller is calculated by the outer-loop controller based on droop characteristics, the reactive power is regulated by \( q \)-axis outer-loop controller. According to the nearest level modulation strategy [21], IGBTs are driven by pulse signals which are converted from the voltage references \( u_{cd1} \) and \( u_{cq1} \).

### 3.3 New proposed droop control for ILC

ILC plays a critical role in the hybrid grid to achieve smooth operation and share the demanded power between two subgrids [11–13, 22]. The control strategy for the ILC is different from the proposed strategy used for the IFC. In addition to the bidirectional power flow management between ac and dc subgrids, it is necessary to develop a new control strategy for the ILC to maintain the stability of both ac and dc subgrids under various operating conditions. On the other hand, ILC shall maintain the power sharing with other slack terminals in both ac and dc subgrids. As discussed in the previous section, droop control strategy of the IFC is used even when the inter-station telecommunication is not available. The decentralised control can be achieved by modifying the droop control strategy for ILC.

The ILC controller is designed as a double closed-loop control, basically similar to IFC. In order to maintain dc voltage, droop control is adopted in \( d \)-axis outer-loop controller. \( P-U_{dc} \) droop characteristics can be expressed by

\[
P_{ILC} = -\frac{1}{k_{ILC}}(U_{dc_{ref}} - U_{dc}) + P_{ILC_{ref}}
\]

(5)

The stability of ac subgrid is regulated by inner-loop controller. The mathematical model of ILC under the two-phase synchronous rotating coordinate system is similar to (2). For purpose of achieving stable control of ac voltage and frequency, the following equations must be satisfied:

\[
u_{dref} = u_{dref}, \quad u_{cref} = u_{cref} = 0
\]

(6)

Where \( u_{dref} \) and \( u_{qref} \) are \( d \)-axis and \( q \)-axis separately and derived from phase-locked loop, and \( U_d \) and \( U_q \) is the reference voltage amplitude of ac subgrid. By using (6), (2) can be written as

\[
\begin{align*}
\frac{d u_d}{dt} &= u_{dref} - R_i u_d - u_d + \omega L_i q_d, \\
\frac{d u_q}{dt} &= u_{qref} - R_i u_q - u_q - \omega L_i d_d.
\end{align*}
\]

(7)

Both \( u_{dref} \) and \( u_{qref} \) can be tracked by synchronous PI controllers, so the inner-loop controller of ILC can be designed as (8). In theory, PI controllers would keep \( u_{dref2} \) and \( u_{qref2} \) equal to \( U_d \) and 0, respectively.

\[
\begin{align*}
u_{dref2} &= (k_{p1} + \frac{k_{i1}}{s})(U_s - u_{dref2}) + \omega L_i q_d - (k_{p1} + \frac{k_{i1}}{s})(l_{dref - l_{d}}) \\
u_{qref2} &= (k_{p1} + \frac{k_{i1}}{s})(0 - u_{qref2}) - \omega L_i d_d - (k_{p1} + \frac{k_{i1}}{s})(l_{qref - l_{q}})
\end{align*}
\]

(8)

The block diagram for the proposed controller of ILC is shown in Fig. 6. The impact of the proposed droop control for the ILC on the stability regulation in each subgrid is illustrated in ac off-grid and dc off-grid scenarios.

(i) The first scenario is assumed that the ac subgrid is not synchronised with the HV distribution. Upon losing a slack terminal in the ac subgrid, ac voltage and frequency will change rapidly, \( u_{d2} \) and \( u_{q2} \) are no longer equal to \( U_d \) and 0 accordingly. Tracking errors calculated by PI1 and PI2 will change. Meanwhile, \( l_{dref2} \) and \( l_{qref2} \) derived from the outer-loop controller, are basically insensitive. So \( u_{d2} \) and \( u_{q2} \) can be determined by \( u_{dref2} \) and \( u_{qref2} \), respectively. Therefore, the exchange power between ac and dc subgrids will be adjusted to maintain the stability of ac subgrid. In this case, the ILC is the only slack terminal of the ac subgrid.

(ii) The other scenario is considered when IFC is out of operation. Before IFC loses, if it transfers the power from HV distribution to dc subgrid, a power shortage will arise whilst dc voltage decreases; If it transfer the power from dc subgrid to HV distribution, a power surplus will appear, and dc voltage will increase. When the \( d \)-axis outer-loop controller detects the dc voltage variation, due to the role of PI1, \( l_{dref} \) will be changed. Meanwhile, tracking error calculated by PI1 is fixed. Therefore, \( u_{d2} \) is determined by \( l_{dref} \) and dc voltage is maintained by adjusting the exchange power, which is based on the droop characteristics. It should also be noted that the dc voltage cannot be restored to previous value because of its droop characteristics.

### 3.4 Improved control for BES

The BES is connected to the dc subgrid by a buck/boost converter. The combination of the BES with PV array can achieve constant power control and to minimise the power fluctuation. On the other hand, under extreme abnormal conditions, such as the out-of-operation of IFC or ILC, huge power imbalance will appear in the system. Converter stations will be blocked by the protection, which resulting in the incontrollable of dc voltage. In this case, BES is
under normal operating conditions, the dc voltage is higher than 
\( U_{dcn} \) or lower than \( U_{dcn} \), the buck/boost converter will switch into droop control mode (Fig. 4), operating as a slack terminal to accommodate dc voltage rapidly by cooperating with other slack terminals. The control block diagram for buck/boost converter is shown in Fig. 7a. \( i_{ref1} \), \( i_{ref2} \) and \( i_{ref3} \) are tracking errors of PI1, PI2 and PI3 respectively, \( i_{ref} \) is expressed by

\[
i_{ref} = \text{MAX}[i_{ref1}, \text{MIN}(i_{ref2}, i_{ref3})]
\]

In order to illustrate the improved droop control, three control modes are adopted by buck/boost converter.

### 3.4.1 Mode 1: Under normal operating conditions, the dc voltage is higher than \( U_{dcn} \) or lower than \( U_{dcn} \), the buck/boost converter will switch into droop control mode (Fig. 4), operating as a slack terminal to accommodate dc voltage rapidly by cooperating with other slack terminals.

The control block diagram for buck/boost converter is shown in Fig. 7b. \( i_{ref1} \), \( i_{ref2} \) and \( i_{ref3} \) are tracking errors of PI1, PI2 and PI3 respectively, \( i_{ref} \) is expressed by

\[
i_{ref} = \text{MAX}[i_{ref1}, \text{MIN}(i_{ref2}, i_{ref3})]
\]

In order to illustrate the improved droop control, three control modes are adopted by buck/boost converter.

### 3.4.2 Mode 2: Under extreme abnormal conditions, such as the out-of-operation of ILC, large power shortage will arise and the dc voltage will decrease, while output power of BES is still determined by \( P_{ref} \). dc voltage will decrease constantly, when it dropped lower than \( U_{dcn} \), \( i_{ref} \) will increase. At some point, it will be higher than \( i_{ref2} \). According to (10), \( i_{ref} = i_{ref1} \) is expressed by

\[
\text{MIN}(i_{ref2}, i_{ref3})
\]

The control block diagram for buck/boost converter is shown in Fig. 7c. \( i_{ref} \) is expressed by

\[
i_{ref} = i_{ref2} > i_{ref3}
\]

### 3.4.3 Mode 3: When an abrupt load shedding happens, due to the power surplus, dc voltage will increase, while the output power of BES is still determined by \( P_{ref} \). dc voltage will increase constantly, when it rise higher than \( U_{dcn} \), \( i_{ref} \) will decrease. At some point, it will be lower than \( i_{ref2} \). According to (10), \( i_{ref} = i_{ref3} \), power control mode will turn into dc voltage control mode. With the power decreasing, dc voltage will be maintained in \( U_{dcn} \). The process is shown in Fig. 7c.

### 4 Simulation studies

In order to validate the proposed coordination control, considering the schematic diagram of Fig. 1, a hybrid MV ac/dc distribution under various generations and load conditions are simulated in Power Systems Computer Aided Design/Electro Magnetic Transient in DC System. The rated ac RMS voltage and frequency of ac subgrid are 10 kV and 50 Hz, respectively. Meanwhile, the rated dc voltage of dc subgrid is ±10 kV, rated grid ac voltage in the side of IFC is 6 kV. Other system parameters are presented in Appendix. The measured dc voltage and ac voltage in the following simulation cases are recorded in dc and ac sides of ILC.

### 4.1 Case 1: power variation of loads and DGs

Fig. 8 shows the waveforms of the simulation results during loads and DGs power variation. It is assumed that the predictive power of PV array is 2 MW while the initial active power of PV array and PMSG are 1.35 MW and 0.93 MW separately, so battery discharges 0.65 MW to ensure the power is kept constant. The output power of PV array increases 0.6 MW at 2 s with the increasing of light intensity. The 'peak-shift' control of buck/boost make BES change the output power. The wind speed increases and output power of PMSG varies from 0.93 MW to 1.02 MW at 4 s. Due to that ac subgrid is still synchronised with the HV distribution, no ac voltage and frequency fluctuation appear. The initial dc load and ac load are 2 MW and 1.5 MVA (cosφ = 0.95) separately. When \( t = 6 \) s, ac load increases 0.9 MW, as well as the power transferred from HV distribution increases 0.9 MW. The ac voltage drops a little and recovers quickly. The dc load increases 1 MW at 8 s, dc voltage drops to 19.9 kV due to the droop characteristics, when ILC and IFC detect this decrease, both of them will increase transmission power and the dc voltage is stabilised.

It can be seen that the proposed control strategy can effectively manage the power imbalance by regulating the exchange power of the slack terminals.

### 4.2 Case 2: disconnected operation with variable loads

The hybrid ac/dc distribution model in disconnected operating mode is simulated as shown in Fig. 9.
Similar to case 1, the hybrid grid initially operates in normal operating mode. At 4 s, the breaker QF3 trips and the trigger pulse of ILC is blocked, the transmission power drops to 0. However, the power reference of ILC is 0, little power variations occur in both ac and dc subgrids, hence huge transient impact on dc voltage and ac voltage is avoided.

To verify the stability of hybrid grid furtherly, dc and ac loads are increased, respectively. The dc load increases 0.4 MW at 6 s, at this time, IFC acts as the only slack terminal in dc subgrid, when the voltage drop is perceived, it will transmit more power from HV distribution to dc subgrid based on the droop characteristics, dc voltage is maintained stable after about 0.5 s. Then, ac load is increased 1 MW at 8 s, for the ac subgrid is still synchronising with the HV distribution, there are no significant changes in ac voltage and frequency.

Meanwhile, DG output power is not influenced during this whole transient process, MPPT control is ensured all the time.

4.3 Case 3: both ac and dc subgrids are off-grid successively

Simulations results when dc and ac subgrids are off-grid successively are shown in Fig. 10.
When \( t = 3 \) s, the IFC is blocked after breaker QF1 trips. Dc voltage has no fluctuation because of the power reference of IFC is 0. When \( t = 6 \) s, breaker QF2 trips and the exchange power between the ac subgrid and the HV distribution drops to zero. In this case, the hybrid grid operates in island mode. Ac voltage and frequency changes rapidly because of the large power shortage. When ILC detects the change of ac voltage, more power will be transferred from dc side to ac side, the ac voltage and frequency are gradually recovered.

However, in the presence of the power shortage in dc subgrid, dc voltage drops a lot. When the dc voltage drops to 19 kV, the BES detects the drop and changes the operating mode to discharge more power rapidly to slow down the trend of dc voltage drop. In order to achieve the power balance of dc subgrid, dc load is cut by 0.5 MW at 6.6 s, then the dc voltage rises gradually until it maintains stable. Finally, the BES will return to the original state and operate in ‘peak-shift’ mode.

In this case, the recovery stability of the system under extreme abnormal conditions can be realised rapidly, power quality of loads and DG output power are ensured.

5 Conclusion

A new MV hybrid ac/dc distribution has been described and comprehensively investigated in this paper. This hybrid distribution architecture can improve overall efficiency and reduces the power loss. DG units operate in MPPT modes to improve the utilisation of new energy, meanwhile, BES can minimise the impact on system from the randomness of PV power. The new control strategy of ILC can keep the power balance between ac and dc subgrids and ensure the power quality in both ac and dc subgrids, even it is in island mode. The BES acts as a backup slack terminal,
automatically switches into dc voltage control mode under the extreme abnormal operating conditions, accordingly reducing the transient impact. At last, this coordination control ensures multiple slack terminals for two subgrids. Simulation studies are conducted to demonstrate that the stability performance can be achieved under various operating conditions such as power variation, off-grid and island mode.

Apart from the stability control, optimal operation of the hybrid distribution is an essential issue. A comprehensive control scheme by combining the decentralised control and optimal dispatch is under investigation by the authors for the future study.

6 References

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