

# Cloud energy management system for building-scale AC/DC hybrid microgrid

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**Abstract.** This paper proposes a Cloud Energy Management System (C-EMS) for the building-scale hybrid microgrid. The building-scale hybrid microgrid is composed of renewable energy generators, charging piles, dc and ac loads, a diesel generator, energy storage devices, and a power electronic transformer connected to the ac power grid. The C-EMS is in charge of them. With the management of C-EMS, for the power system, the building-scale hybrid microgrid can be considered as a four-quadrant controllable node, which means it can be controlled to either generate or consume reactive and active power to the power system. In addition, based on wireless communication, the C-EMS receives the command of cloud management centre and make the microgrid operate at the assigned power. Therefore, numerous C-EMS can be managed via the cloud manage centre, which improves the controllability of the power system. The proposed C-EMS has been verified by the simulations carried out in Matlab/Simulink.

## 1. Introduction

The increasing demand of electrical energy leads to the requirement of increasing generation part of the power system. The distributed generator (DG), which utilizes the inexhaustible renewable energy to generate power, is considered as an effective solution [1]. In addition, DG can provide electric power to the location near to the customers and eliminate the unnecessary transmission costs [2].

However, since the intermittent characteristic of renewable energy, such as wind and solar, the growing installation of DG will bring problems to the power system [3,4]. Multiple paralleling nearby DG together and form a microgrid with the nearby loads is a feasible approach to resolve this problem. In [5], the authors proposed to use a mode-adaptive droop control method to realize a flexible ac microgrid. In [6], the droop control is further improved to enhance the power oscillation damping. Due to the widely used dc loads and dc characterized renewable energy sources, dc microgrid has emerged for its benefits in efficiency and low cost, and is researched by [7,8]. However, the main grid is still ac type, the ac microgrid is dominant for its convenience, and the pure dc microgrid is not expected to replace the ac microgrid in a short time. The hybrid microgrid, which can exploit the prominent features of both ac and dc microgrids, is proposed [9].

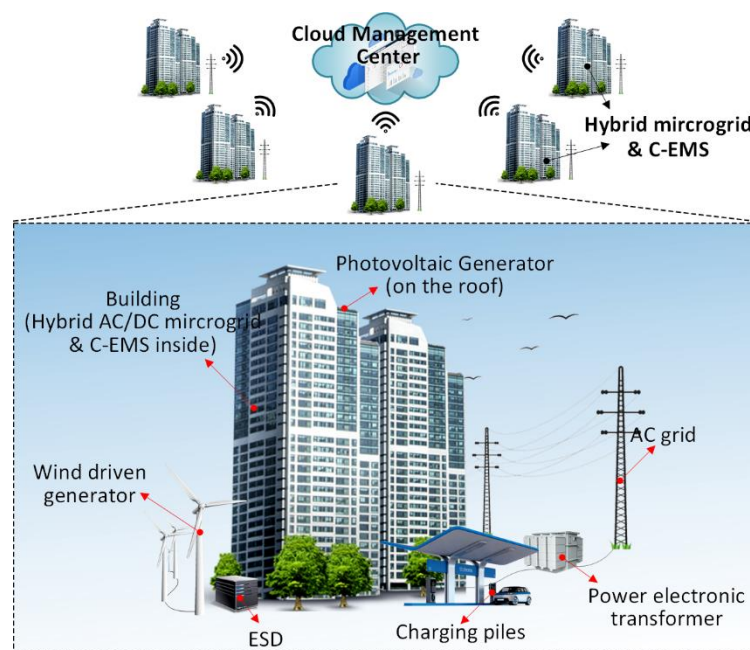
This paper proposes a Cloud Energy Management System (C-EMS) for building-scale hybrid microgrid. The C-EMS manages the energy by controlling the operating condition of the converters in the microgrid. Since the power electronic transformer, linking the microgrid and ac grid, is required to keep the voltage and frequency of ac bus constant, the power transmitted from microgrid to ac grid



cannot be directly controlled. Therefore, the C-EMS is required, which can control the power, transmitted between the microgrid and ac grid, to be a given value in the four quadrants. As a result, each C-EMS and its managed hybrid microgrid is like a controllable node for the power system. These nodes are cloud managed by the cloud management center, which issues the commands (reference power) to the C-EMSs, and the command are obtained according to different objective, such as the least net loss and the best voltage level. If the proportion of C-EMS and its managed hybrid microgrid is increased, on the one hand the intermittency problem of renewable energy can be solved; on the other hand the power system becomes more controllable, and hence the operating performance of the power system can be further improved. Finally, the operation performance of C-EMS is verified by simulations in Matlab/Simulink.

## 2. Structure

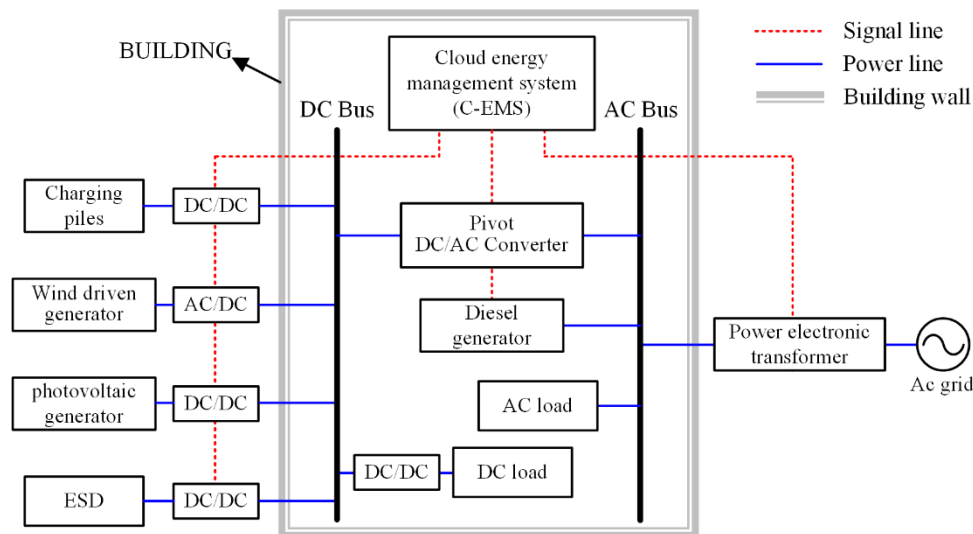
The diagram of hybrid microgrid and C-EMS is shown in figure 1. The renewable energy generator, charging piles and energy storage devices (ESD) are connected to the microgrid. The microgrid receives/generates power from/to the ac grid via a power electronic transformer. The C-EMS is in charge of the operation of the building-scale hybrid microgrid. Through wireless communication, numerous C-EMS are connected to the cloud management center, which adjusts the output power of numerous microgrid every several minutes.



**Figure 1.** Diagram of building-scale hybrid microgrid and C-EMS.

As shown in figure 2, the blue solid line represents the power line, which is used to transmit electric power. The red dashed line represents the signal line, which is used to transmit control signals. The C-EMS is in charge of the electrical equipment by controlling the converters, which connected the equipment to the DC or AC bus. The grey box represents the building wall, and hence the blocks located inside and outside the grey box denote that they are settled inside and outside of the building, respectively.

From figure 2, the inside of the building contains AC and DC buses, which are connected by a pivot DC/AC converter. The DC and AC loads are connected to the AC and DC buses, respectively. In addition, a diesel generator is also connected to the AC bus, and the diesel generator is controlled by the C-EMS the via signal line. Since using the diesel generator pollutes the air and is more expensive than using the renewable energy generator, the use of it should be decreased.

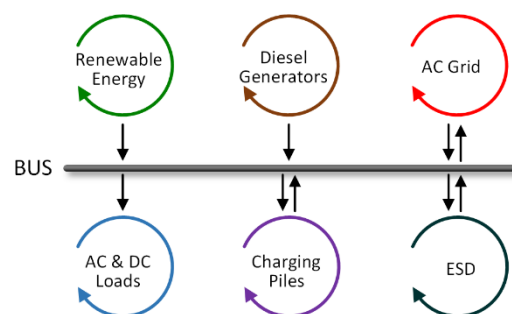


**Figure 2.** Block diagram of building-scale hybrid microgrid and C-EMS.

The nearby renewable energy generators and charging piles are connected to the building-scale microgrid. There are two advantages: First, since the wind and solar energy is intermittent, high proportion of renewable energy will bring difficulties to the stability of power system; by connecting these distributed renewable energies to a controllable hybrid grid, this problem can be solved. Second, connecting the renewable energy and charging piles to the dc bus in the hybrid microgrid can reduce the ac/dc converter, and hence reduce the losses [10,11].

The hybrid microgrid is connected to the power system via a power electronic transformer. Using power electronic transformer to substitute conventional transformer can improve the controllability of the microgrid.

The directions of the power are shown in figure 3. For loads and charging piles, the power flows from the buses to the electrical equipment. For diesel generator and renewable energy generator, the power flows from the electrical equipment to the buses. For ac grid and ESD, the power directions are bidirectional, and are managed by the C-EMS.



**Figure 3.** Power directions of the power electronic devices.

With the management of C-EMS, for the power system, the building can be considered as a node, whose active and reactive power is controllable. If the proportion of this kind of building is increased, the power system becomes more controllable, which can improve the operating performance of the power system.

It should be noted that this paper only focus on how the C-EMS manages the building to realize the above electrical characteristics. In other words, this paper focuses the building-scale management of the C-EMS. For using the cloud management center to control numerous C-EMS so as to optimize the operation of the power system, it will be researched in the future papers.

### 3. Operation

In the normal operation, the pivot DC/AC converter is controlled to keep constant DC bus voltage. The power electronic transformer is used to keep the voltage and frequency of the AC bus stable. Since the energy in the microgrid is balanced, if the losses are ignored, the following power balance equation can be obtained.

$$P_{re} + P_s + P_G = P_l + P_{grid} + P_c \quad (1)$$

where,  $P_{re}$  is the output power of renewable energy generator, which is mainly composed of wind and solar energy;  $P_s$  is the power of ESD;  $P_c$  represents the power of charging piles;  $P_{grid}$  denotes the power transmitted between the microgrid and the ac power grid;  $P_G$  is the output power of the diesel generator;  $P_l$  denotes the DC and AC load in the microgrid.

It should be noted that the power of renewable energy generator ( $P_{re}$ ), ESD ( $P_s$ ), and diesel generator ( $P_G$ ) can be directly controlled by controlling the operation of their converters or the diesel valve. However, for the power of loads ( $P_l$ ), charging piles ( $P_c$ ) and the power transmitted between the microgrid and the ac power grid ( $P_{grid}$ ), they can only be measured and cannot be directly controlled. Therefore,  $P_{re}$ ,  $P_s$ ,  $P_G$  are named as control factors, whose output power can be directly controlled.

The basic operation principle of the C-EMS is to control the output power of control factors, so as to manage the energy in the hybrid microgrid.

**Table 1.** Operating mode in the normal condition<sup>a</sup>.

Operating mode	Control factors			$P_{grid}$
	$P_{re}$	$P_s^b$	$P_G$	
A	$P_{re} = Max$	$-Max \leq P_s \leq Max$	$P_G = 0$	$P_2 < P_{grid} < P_3$
B	$P_{re} = Max$	$P_s = Max$	$0 < P_G \leq Max$	$P_3 < P_{grid} < P_4$
C	$0 \leq P_{re} < Max$	$P_s = -Max$	$P_G = 0$	$P_1 < P_{grid} < P_2$

<sup>a</sup> In the table, “Max” means the maximum power.

<sup>b</sup> when  $P_s > 0$ , the ESD generates power to the microgrid; when  $P_s < 0$ , the ESD consume power from the microgrid.

In the normal condition, the hybrid microgrid has three operating modes. The three modes are shown in Table 1

In the mode A, the renewable energy generator works at their maximum power point, and the diesel generator is disconnected. The power of ESD is controlled to be

$$P_s = P_l + P_{grid} + P_c - P_{re} \quad (2)$$

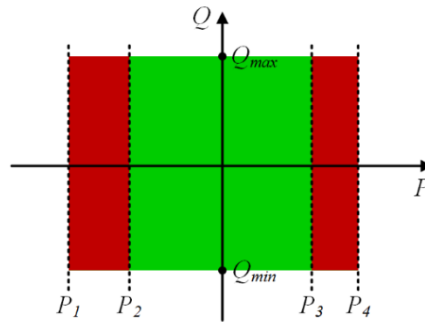
In the mode B, both the renewable energy generator and the ESD work at their maximum power point. The diesel generator generates power to the microgrid, and its power is controlled to be

$$P_G = (P_l + P_{grid} + P_c) - (P_{re} + P_s) \quad (3)$$

In the mode C, the diesel generator is disconnected, and the ESD is charged at its maximum power by the microgrid. the output power of renewable energy generator is limited, and is controlled to be

$$P_{re} = P_l + P_{grid} + P_c - P_s \quad (4)$$

The above control method is called the balance power control. With this control method, the output power transmitted from the hybrid microgrid to the ac power grid is shown in figure 3.



**Figure 4.** The output power transmitted from the hybrid microgrid to the ac power grid.

In the above figure 4, the maximal and minimal reactive power ( $Q_{max}$  and  $Q_{min}$ ) are determined by the capacity of power electronic transformer, which also denotes that the reactive power transmitted from the microgrid to the ac power grid is between  $Q_{max}$  and  $Q_{min}$ . The middle green area is the mode A; the right red area is the mode B; the left red area is the mode C. The boundaries  $P_1$ - $P_4$  can be calculated by

$$P_1 = -P_{s,max} - P_l - P_c \quad (5)$$

$$P_2 = P_{re,max} - P_{s,max} - P_l - P_c \quad (6)$$

$$P_3 = P_{re,max} + P_{s,max} - P_l - P_c \quad (7)$$

$$P_4 = P_{re,max} + P_{s,max} + P_{G,max} - P_l - P_c \quad (8)$$

where,  $P_{s,max}$ ,  $P_{re,max}$ ,  $P_{G,max}$  denote the maximum power of ESD, renewable energy generator, and diesel generator, respectively.

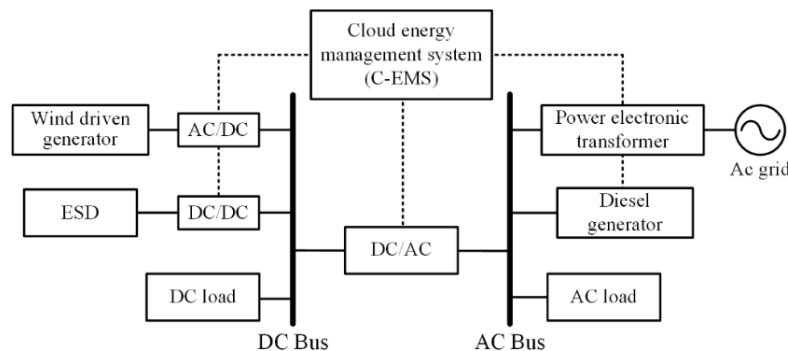
The following two points are noteworthy. First, since  $P_{re,max}$ ,  $P_l$  and  $P_c$  are not constant values, the boundaries  $P_1$ - $P_4$  are not constant values either. Second, the operation mode and the specific transmitted power  $P_{grid}$  are determined by the cloud management centre. The centre can manage numerous C-EMS to optimize the performance of the power system. However, in order to fully utilize the renewable energy and reduce the use of diesel generator, the microgrid should work in the mode A at most of the time. This is because that the renewable energy generators work at their maximum power points and the output power of diesel generator is zero in the mode A.

#### 4. Simulation evaluation

In order to verify the operation performance of the proposed C-EMS for building-scale hybrid microgrid, a simulation model is built in Matlab/Simulink. The simulation parameters and the diagram of the simulation model is shown in table 2 and figure 5, respectively.

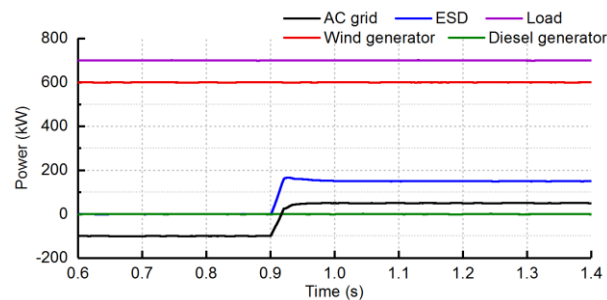
**Table 2.** Simulation parameters.

Parameter	Value
Voltage of AC grid	10kV
DC Bus	$\pm 400V$
AC Bus (line-to-line)	380V
Wind generator capacity	400kW
ESD capacity	200kW
Diesel generator capacity	500kW



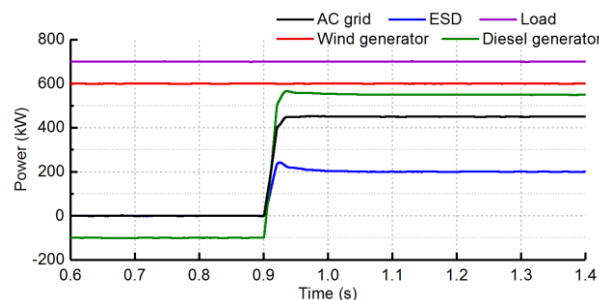
**Figure 5.** Diagram of the simulation model.

In the simulation model, the wind driven generator is the permanent magnet wind generator (PMSG), which is the most commonly used wind generator in the distributed generation. The charging pile is classified as the DC load. The DC and AC load are connected to the DC and AC buses, respectively. The DC and AC buses are connected by a DC/AC converter, which works to keep the DC bus voltage constant. The C-EMS controls the whole microgrid via signal lines.



**Figure 6.** Simulation results in the Mode A.

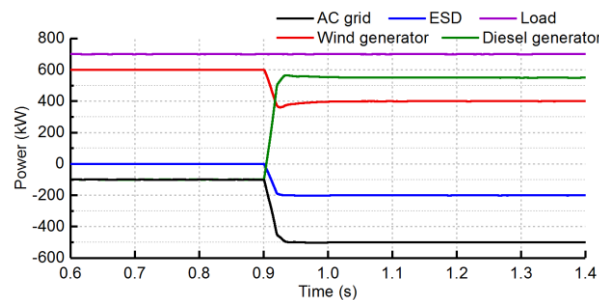
The simulation results in the mode A is shown in figure 6. The sum of the DC and AC load power is 700 kW, and the power of wind generator is 600 kW. In the mode A, the diesel generator is disconnected. At first, the output power of ESD is zero. When the microgrid system is stable, the ac grid supply 100 kW power to the microgrid. At the 0.9 s, the C-EMS receives the command of transmitting 50 kW power from the microgrid to the ac grid. Then, the C-EMS controls the ESD to generate 150 kW power to the microgrid. After approximately 0.05 s, the microgrid becomes stable, and it can be seen in the figure that the output power from microgrid to the ac grid changes from -100 kW to 50 kW, and meets the requirement of the command.



**Figure 7.** Simulation results in the Mode B.



Figure 7 shows the simulation results in the mode B. The initial state of the simulation is the same as the initial state in the mode A. At the 0.9 s, the C-EMS receives the command of transmitting 550kW power from the microgrid to the ac grid. Since only increasing the output power of the ESD cannot meet the requirement, the diesel generator is connected to the microgrid, and it is controlled to generate 450 kW power. When the microgrid is stable, from the simulation results, the output power to the ac grid becomes 550 kW.



**Figure 8.** Simulation results in the Mode C.

Figure 8 shows the simulation results in the mode C. The initial state of the simulation is still the same as it is in the mode A. At the 0.9 s, the C-EMS receives the command of consuming 500 kW power from the ac grid. Then, the C-EMS turns the ESD into the charging state, and its power is -200 kW. The output power of the wind generator is limited to 400 kW by the C-EMS. After approximately 0.07 s, the microgrid system becomes stable, and its output power becomes 500 kW.

From figures 6-8, the simulation results show that by the management of the proposed C-EMS, the output power of the building-scale microgrid is controllable, and hence verify the operation performance of the C-EMS.

## 5. Conclusions

In this paper, an energy management system C-EMS is proposed for building-scale hybrid microgrid. The whole energy management structure contains two parts, which are the cloud management center and numerous C-EMSs. The C-EMS is the focus in this paper. With its management based on the power balance control, the building-scale hybrid microgrid can be considered as a controllable node for the power system. The operation performance of C-EMS is verified in Matlab/Simulink. The simulation results show that the power transmitted between the microgrid and ac grid can be controlled to be a given value within several milliseconds, and the loads can remain stable in the transient process.

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