Based on Energy Router Energy Management Control Strategy in Micro-grid

Xuemei Zheng(✉), Zhongshuai Zhang, Haoyu Li, and Yong Feng

Engineering Department, Harbin Institute of Technology, No. 92 Xidazhi Street, Harbin, China
xmzheng@hit.edu.cn

Abstract. As the key part of the Energy Internet (EI), the energy router (ER) needs to achieve the purpose of distribution and balance of power, making the entire power system more safe and stable. This paper proposes several energy management strategies for ER. Photovoltaic array is used as the basic power generation unit, wind power is used as the auxiliary unit, and energy storage unit realized the power balance through charging and recharging. At the same time, the maximum power tracking control and constant power of the photovoltaic power generation system and the wind power generation system are carried out, respectively. At last, simulation and control strategy are verified in the MATLAB simulation platform. The simulation results show the proposed management is effective and correct.

Keywords: Energy router · Power management · Microgrid · MPPT

1 Introduction

Consequently, with the development of large-scale integration of Distributed Renewable Energy Resources (DRERs), Distributed Energy Storage Devices (DESDs) and emerging DC loads, the power network structure has become more and more complex. It also caused a big challenge to the conventional grid. Therefore, inspired by the development of smart grid and information Internet, many experts from various countries put forward the idea of creating the "Energy Internet" (EI) conception. This may eventually shift the power and energy industry from the currently centralized mainframes to a client-based, distributed power infrastructure, and need the power and energy can be controlled and flow reasonably [1, 4, 5].

On the way to the Energy Internet, current research work towards to EI, falls into three major categories: one is focus on the design and development of silicon based Solid State Transformer (SST) [8–13]. Others study about the control strategies of Microgrid. Normally, the DRERs, DESDs and DC loads all connected to the DC-bus, which will connect to the grid through the inverter unit again, thus the stability of the DC-bus control is very important [1, 2]. In reference [3], the working modes of each converter are introduced under various working conditions, and then the setting of DC-bus voltage reference value under this condition is analyzed. Reference [4] proposed an algorithm for stabilizing the DC-bus voltage in an island case, and fuzzy control and

W. Xiang et al. (Eds.): BROADNETS 2021, LNICST 413, pp. 329–339, 2022.
https://doi.org/10.1007/978-3-030-93479-8_24

gain adjustment control are introduced in the control to achieve the control target. Reference [5] proposed a control algorithm for bidirectional converters, and according to different possible operating modes, the control methods of modules such as photovoltaic (PV) and batteries in the system are studied and designed. Besides on DC-side management control, some researchers also focus on AC ports by controlling the power electronic inverter. Traditionally, three control methods are used to control grid-connected inverters., that is the constant power control method [8], the V/F control method [9] and the droop control [10].The others are doing research about the standard based software and communication platform for traditional substations [6, 7].

In this paper, an EI and Energy Router (ER) topology, consisting a PV power generation, a wind turbine (WT) power generation system and Energy Storage System (ESS) is proposed. In the proposed EI system, the PV and WT power system can either switch in Maximum Power Point Tracking (MPPT) control mode or in constant power control mode according to the demands of ER. In order to realize the energy management and control of ER, the paper proposed four operating states control strategy and six energy management strategy according to the sunlight and wind speed to ensure the ER to work in the optimal states and utilize the PV and WT efficiently. At last, simulation verification is carried out in the MATLAB simulation platform to simulate the 6 modes and carry out the desired control strategy. The simulation results show the proposed management is effective and correct.

2 Model and Control for Multi-port ER System

The proposed multi-Port Control (MPC) ER topology is shown in Fig. 1. It consists four ports, one for PV generating unit, one for WT power system, these two units are connected to the common DC-bus through boost converter and realize MPPT and constant voltage control. The battery storage system, which is controlled by charging and recharging control and realize the power balanced. The last port for the grid, which connected the DC/AC converter and Solid State Transformer (SST). The whole MPC ER system can realize the energy exchange to the grid, but also can realize islanded running according to the demands.

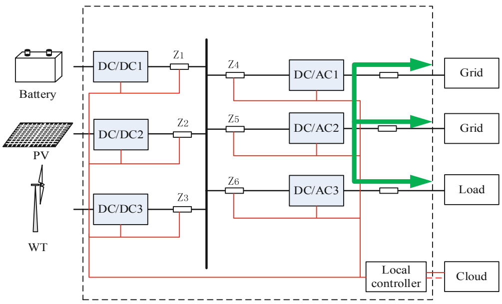

Fig. 1. Topology structure of multiport ER system

2.1 The Model of PV System and Control

In the proposed topology in Fig. 1, PV is the main supply unit, which usually works in the MPPT mode, but in some special cases, it is required to switch to the constant power mode according to the system power requirement. The control system block for PV power unit is shown in Fig. 2. The switching signal decides the operating mode of the system. Based on the state of the switching signal state, the system can switch either from constant power mode to the MPPT mode or vice versa. The PWM remain unchanged for both operating mode.

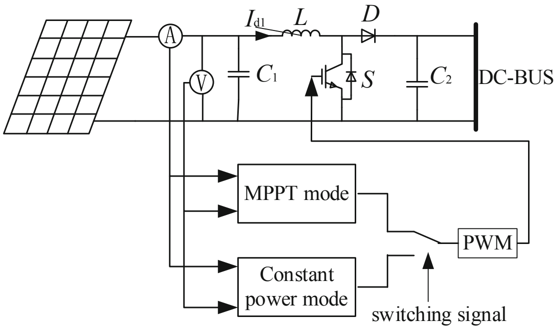

Fig. 2. PV power system control block diagram

2.2 Control of WT System

WT power generation system, works as an auxiliary power supply to support PV power generation system in case the PV and ESS cannot meet the load demand requirement. It usually works in the MPPT mode, but if the ESS cannot be charged, and the PV power generation system is insufficient to preserve power balancing, it is necessary for WT power system to switch from MPPT to the constant power control mode. The reference constant power is determined by the ER depending on the power required by the load and the power generated from PV. So the WT generation system need to work in both operating mode, either in MPPT mode or in constant power control mode according to the actual wind speed changes. The schematic diagram of the specific strategy for WT power system control is shown in Fig. 3.

If WT power system works in the MPPT mode, the pitch angle β is kept at zero. The dq inner current control strategy for PWM rectifier is adopted, where the reference for $i_d = 0$ and the i_q reference is obtained from the outer speed control, which tracks the optimal speed ω_{opt} for maximum power extraction. If WT power system is operating in a constant power mode, it is necessary to continuously adjust the utilization coefficient C_p, by controlling the pitch angle. The deviation between the given power P_{ref} and the actual output power P is fed to the pitch angle controller implemented as a, PI controller, which generates the variable pitch angle β to achieve the constant power.

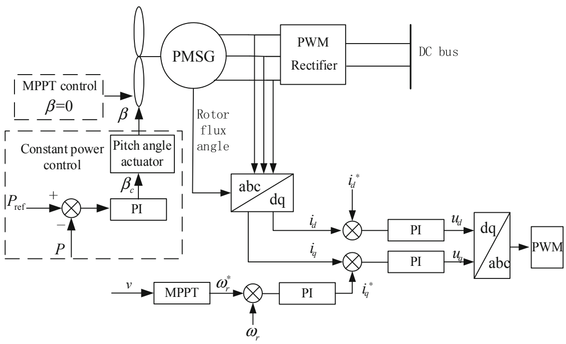

Fig. 3. The schematic diagram of WT power system

3 The Management Control of ER System

3.1 The Control Target of ER

The energy management system ensures the power balance between the power generation unit and the load by regulating the output power of each power generation unit. At the same time, in order to ensure the safe operation of the energy storage unit, it is necessary to monitor the SOC of the battery in real time to maintain the safe operating range of the battery storage. When the battery charges up to the high SOC upper limit, further charging of the battery is prohibited and when the battery discharges up to the lower SOC limit further discharging is prohibited. To guaranty the safe utilisation of the battery energy storage, the SOC monitoring control system must ensure the safe operating region of the battery storage, which relies between the upper SOC and the lower SOC limit. In the existing research, the upper and lower limits of charge and discharge of the ESS are different depending on the consideration. Considering the optimal range of system efficiency, in this paper, the maximum upper limit of SOC = 0.8, and the lower limit of SOC = 0.2 are adopted.

Figure 4 shows the basic block diagram of the energy management control strategy. The power balance relationship can be expressed as:

$$P_1 = P_{wind} + P_{PV} + P_{battery} \tag{1}$$

where P_l is the load power, P_{wind} is the output power of WT power system, P_{PV} is the output power of PV system and $P_{battery}$ is the output power of the battery. For $P_{battery} < 0$ and $P_{battery} > 0$ represents the battery is being charged or discharged.

The logical decision control block uses P_l, SOC and P_{PV} as input, to generate the switching signal PV, required to control PV system. For the WT power system the switching signal wind is obtained from the logical decision that use P_l, SOC, P_{PV} and wind speed V_{wind} as the input. The WT power system generates the power P_{wind}.based on the wind. At the same time, the remained power of P_l-P_{wind}-P_{PV} is sent to the ESS and gets the amount of SOC.

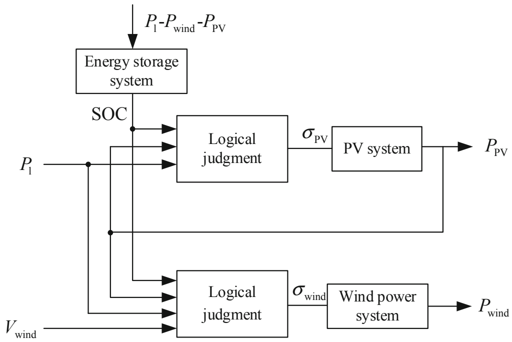

Fig. 4. The control block diagram of energy management system

The proposed system topology provide the following features. 1) It ensures the power balance and stable operation for the ER, and in addition the complete energy management and scheduling is achieved. 2) The stability of the ER is guaranteed in all operating modes and smoothly it can switch from one control mode to the other. 3) the efficiency of renewable energy utilization is maximized, and realize stabilize output power; 4) it ensures that the units of the ER work in the optimal working mode, with high quality of the output power.

3.2 ER'S Working State and Operating Mode

In this paper, the ER is able to operate into 4 states:

1. when all DG units operate MPPT mode, and cannot meet the load demand, the remained power is provided by the ESS, and the renewable energy utilization rate is maximized.
2. when the generated maximum power produced by the DG is higher than the DC load requirement, the excess energy is stored in the ESS.
3. when DG units are in the maximum output power, and cannot satisfy the DC side load demand, and ESS cannot provide energy. The load needs to be cut off from the system, the energy balanced control strategy will be determined according to the specific situation.
4. when DG units are in the maximum output power, and satisfy the DC side load demand, but cannot be charged to the ESS, the distributed generation unit can operate in constant power output state.

It can be seen that the ESS plays a key role in energy balancing. balanced node in the entire energy management strategy. The core of the control system of ER lies on controlling each DG unit to work in specified operating mode by the energy management system. Table 1 shows ER operation 6 operating modes.

Mode 1: with Both PV and WT generation system are all kept in MPPT mode, but still cannot meet the load demand, and the ESS is at its lower limit of discharge state, a part of the load must be disconnected from the ER.

Mode 2: The DG operate at the state of MPPT, but still cannot meet the load demand, and The ESS is charged, with SOC lies between the upper and lower limits, the ESS will discharge to provide the remained load power demand for system power balancing.
Mode 3: The ESS is between the upper and lower limits of charge and discharge. If the energy required by the load can be fully supplied by PV system and WT power system, which operate at MPPT state. The ESS switch to the charging mode to save the excess energy..
Modal 4: The ESS is at the upper limit, at this point, distributed generation cannot meet the load demand, and ESS needs to provide the remained energy. The ESS is in discharging state.
Mode 5: The ESS is at the upper limit, if DG is operating at the MPPT state, then select in the MPPT state, and the remained energy is provided by WT power system, at this point, ER is in the constant power state.
Modal 6: The ESS is at the upper limit, at this point, PV can meet the load demand. The PV system is selected to be the same as required by the load.

The above 6 operating modes can guarantee the energy router system in stable operation state. However, since DG is greatly affected by the external weather conditions, and the load demand value of the system will change with the scheduling command value, these external influences will interfere with ER, causing it to switch between different working modes. Therefore, to guaranty the accuracy power management, the real-time monitoring of the electrical quantity of each port is required for accuracy of control system and power allocation for each unit.

4 Simulations

To evaluate the effectiveness, feasibility and the performance of the proposed energy management control method, the simulation model is built in the MATLAB/Simulink platform. The simulation parameters are shown in Table 1.

Table 1. DC power supply simulation parameters

Parameter	Value
U_g/V	380
$U_{battery}$/V	400
U_{dc}/V	750
f/Hz	50
v/(m/s)	8,10
J	0.5
D	20
P_{ref}/kW	2
R_a/Ω	0.032
S/(W/m^2)	800,1000

4.1 Simulation Verification of PV Control

The control algorithm of PV system is Firstly simulated to evaluate the operating capability of the PV in either MPPT or constant power operating mode. To carry out simulation the disturbance observation method is adopted to implement the MPPT control. The solar irradiance and temperature variation are shown in Fig. 5a) and Fig. 5b) respectively. Figure 5c) shows the PV system given power, and Fig. 5d) shows the switching signal of the PV system switch. Figure 5e) shows the output power of the PV system after the switch is on and off. As seen in Fig. 5e), from t = 0.5 s–1.5 s and t = 4 s–5 s, the PV system works in the MPPT mode, while during t = 2 s–4 s, the PV system works in constant power mode. It can be seen from Fig. 5d) and Fig. 5e), the PV system can follow the given power, this indicate effectiveness of the proposed PV system switching control.

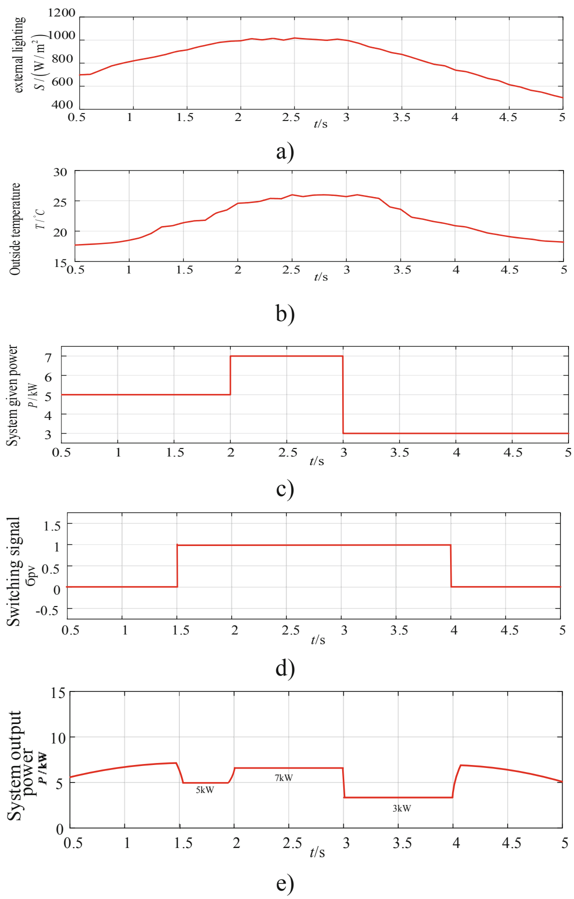

Fig. 5. PV character curve and output power a) Sunlight, b) temperature, c) PV given power, d) switching signal, e) PV output power

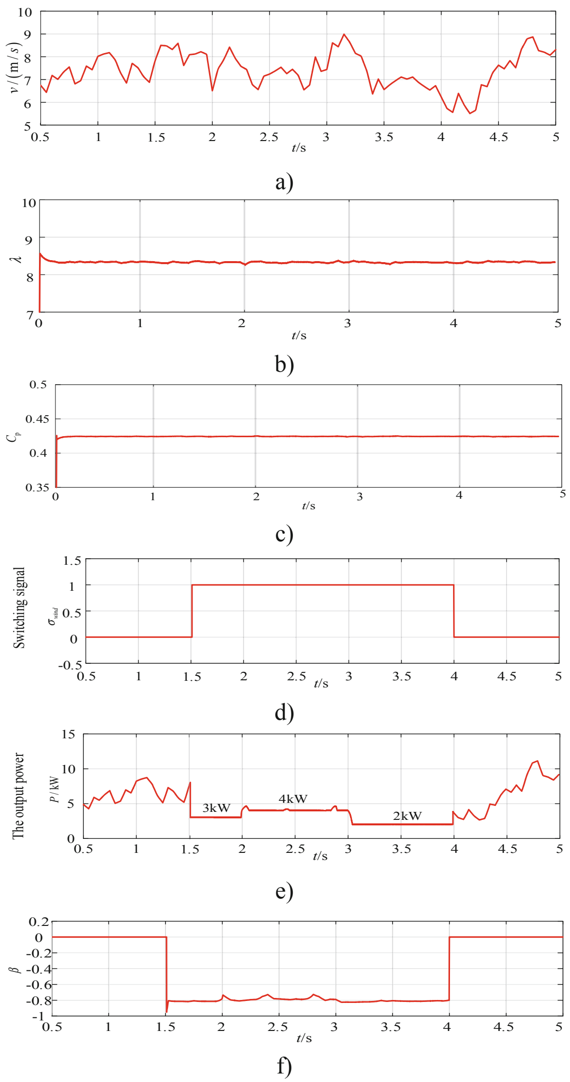

Fig. 6. WT power system input and output curve a) Random speed, b) tip speed ratio, c) Cp curver, d) switching signal, e) WT output power, f) pitch angle curve

4.2 Simulation of WT Power System Control

Next, the control algorithm of WT power system is evaluated. The results are shown in Fig. 6. Figure 6a) shows the input of random wind speed taken from the wind plant. Figure 6b) shows the tip speed ratio of the blade.it can be seen from Fig. 6b) that the optimal value of is $\lambda_{opt} = 8.1$, Fig. 6c) shows the utilization coefficient, which can be kept at $C_p = 0.425$ for the WT operate at MPPT control.

If the switch signal is added in the wind power system, as shown in Fig. 6d), the wind power output power as shown in Fig. 6e). It can be seen from Fig. 6e) that in the time interval of t = 0.5 s–1.5 s and t = 4 s–5 s, the wind power system works in the MPPT mode and in the time interval t = 1.5 s–4 s the wind power system operates at constant power mode. Figure 6f) shows the pitch angle β curve of the wind power system. The value of β is kept at zero in the time interval t = 0.5 s–1.5 s and t = 4 s–5 s, in which the WT operate at MPPT mode as can be observed in Fig. 6f). For time interval t = 1.5 s–4 s the wind power system is under pitch angle control mode, and the pitch angle β changed with respect to the wind speed to enhance constant power control.

4.3 The Simulation of Energy Management Strategy

In this part, the proposed 6 modes of ER control are evaluated. Firstly, supposed that the demand power of load is given in Fig. 7a). The output power of the PV system, wind power system, and battery are shown in Fig. 7b), Fig. 7c) and Fig. 7d), respectively. Figure 7e) shows the waveform of the SOC of battery.

As can be seen from Fig. 7, the system operates in mode 3 during t = 0.5 s and t = 1 s. The load demand power is 2 kW, at that time the battery SOC is less than 80%, so the battery will be charged. According to the energy management rules proposed in this paper, both PV and wind power systems carry out MPPT control, SOC of the ESS gradually increases Until t = 0.63 s, where the battery SOC reaches the upper limit of SOC (80%). The further charging of the is prohibited. To the system power, the PV switches to the constant power mode and generate 2 KW. During this period, the wind power system does not provide any power, it is deactivated.

Between t = 1 s and t = 2 s period, the system is in mode 6. The system power demand power is 5 kW, which is still less than the maximum tracked power of PV. At this time, the PV system switch to constant power control to maintain 5 kW power demand. The output power of WT power system is kept at 0 kW, and the battery is neither charged nor discharged. It can be seen that the battery provide a 0 kW to the load while its SOC is maintained at 80%. Between t = 2 s and t = 3 s period, the system operates in the mode 5. The system power demand changes from to 12 kW. At this time, the PV can no longer meet the load demand. The PV switches to MPPT mode to generate its maximum possible power And The remained power demand of the load is provided by WT generation system. The battery is neither charged nor discharged at this time. It can be seen that the output power of the battery is still 0 kW, SOC is maintained at 80%.Between t = 3 s and t = 4 s period, the system is in mode 4. The system demand power changes to 20 KW. At this time, PV and WT both switch to MPPT mode, but they are unable to provide enough power required by the load. Therefore. The remained power demanded by load is provided by the battery. It can be seen that the output power of the battery is positive, which means that the battery is discharging to support the PV and WT to meet the load requirement. meanwhile, the corresponding battery SOC continues to decrease, therefore, the system power is balanced, and the energy management rules are satisfied.

Between t = 4 s and t = 5 s time period, the system enter in mode 3. The system demand power is changed to 8 KW. At this time, the battery SOC is less than 80%, and

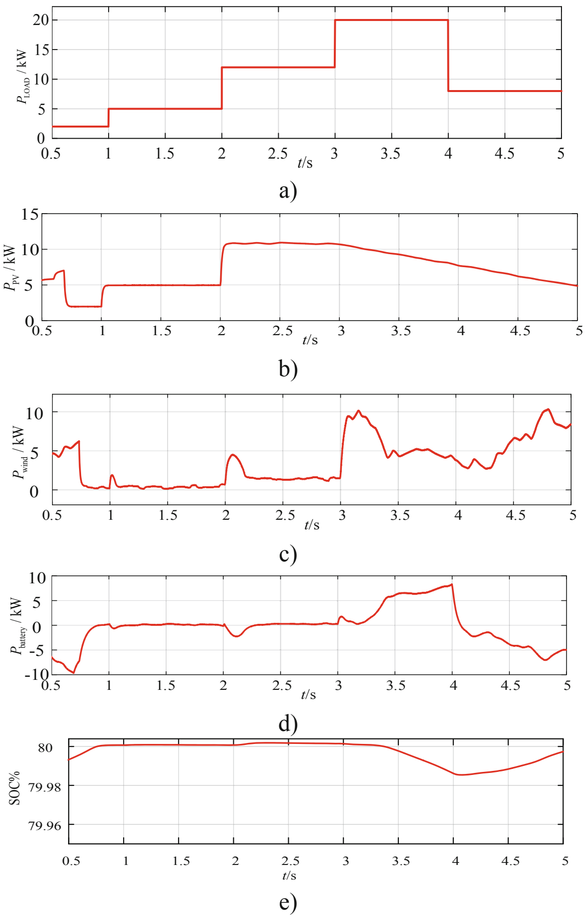

Fig. 7. Power of load, energy router, SOC curve a) Load demand power, b) output power of PV, c) output power of WT, d) output power of ESS, e) SOC curve

PV and WT continue to operate in MPPT state to charge the battery and provide required power to the load.

5 Conclusion

This paper firstly designed the ER control strategy of the PV system and the wind power system, so that each power generation unit can issue a certain amount of electric energy according to the demand command value. Then, the energy management strategy of the distributed power supply on the DC side of the energy router system is designed, determining the working state and output force of each power generating unit through logic judgment to achieve balanced flow of power. Finally, the simulation model is built in MATLAB/Simulink simulation software to verify the switching of each power generation mode and the proposed energy management strategy. The simulation verifies the correctness and effectiveness of the proposed method.

Acknowledgments. This work was supported by the National Natural Science Foundation of China (62073095).

References

1. Eren, S., Pahlevani, M., Bakhshai, A., et al.: An adaptive droop DC-bus voltage controller for grid-connected voltage source inverter with LCL filter. IEEE Trans. Power Electron. **30** (2), 547–560 (2015)
2. Lazroiu, G.C., Popescu, M.O., Dumbrava, V., et al.: Voltage control system and transient analysis of DG interfaced DC distribution system. In: IET Conference on Renewable Power Generation, Edinburgh, UK, pp. 1–6 (2011)
3. Kakigano, H., Nishino, A., Ise,T.: Distribution voltage control for DC microgrid with fuzzy controland gain-scheduling control. In: 8th International Conference on Power Electronics, Jeju, South Korea, pp. 256–263 (2011)
4. Zhang, L., Wu, T., Xing, Y., et al.: Power control of DC microgrid using DC bus signaling. In: 26th Annual IEEE Applied Power Electronics Conference and Exposition, Fort Worth, TX, USA, pp. 1926–193 (2011)
5. Liu, B., Zhuo, F., Bao, X.: Control method of the transient compensation process of a hybrid energy storage system based on battery and ultra-capacitor in micro-grid. In: IEEE International Symposium on Industrial Electronics, pp. 1325–1329, Hangzhou, China (2012)
6. Wu, D., Tang, F., Dragicevic, T., et al.: Coordinated control based on bus-signaling and virtual inertia for islanded DC microgrids. IEEE Trans. Smart Grid **64**(6), 2627–2638 (2015)
7. Liu, H., Zhang, Y., Mantooth, H.A.: Residential renewable energy distribution system with PQ control. In: 2015 IEEE International Conference on Building Efficiency and Sustainable Technologies, Singapore (2015)
8. Varsha,Y., Arunima, V.: Comparison of VF controlled wind energy system based on different sensing methods. In: 2016 International Conference on Emerging Trends in Communication Technologies (ETCT). Dehradun, India (2016)
9. Xue, X., Li, H., Lv, Z.: Research on new algorithm of droop control. In: 2018 Chinese Control And Decision Conference (CCDC).Shenyang, China (2018)
10. Kang, B.K., Kim, S.T., Sung, B.C., et al.: A Study on optimal sizing of superconducting magnetic energy storage in distribution power system. IEEE Trans. Appl. Supercond. **22**(3), 5701004 (2012)
11. Qian, H., Zhang, J., Lai, J., et al.: A high-efficiency grid-tie battery energy storagesystem. IEEE Trans. Power Electron. **26**(3), 886–896 (2011)
12. Etxeberria, A., Vechiu, I., Camblong, H., et al.: Hybrid energy storage systems for renewable energy sources integration in microgrids: a review. In: 2010 Conference Proceedings IPEC, Singapore (2010)
13. Phatipha, T., Luigi, P., Serge, P., et al.: Nonlinear intelligent DC grid stabilization for fuel cell vehicle applications with a supercapacitor storage device. Electr. Power Enegy Syst. **64**, 723–733 (2015)