Energy Management of Isolated Micro-grid With Wind Turbines and Seawater Desalination Devices

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Abstract—Energy management of isolated micro-grid with wind turbines and seawater desalination devices is of great significance to the use of wind power, the supply of fresh water resources and the economic operation of micro-grid. This paper established isolated micro-grid model including wind turbines, seawater desalination devices, diesel generator and hybrid energy storage consist of battery and super capacitor. On the basis of stable operation, considering the controllability of seawater desalination and the damage difference to the battery between deep charge deep discharge and shallow charge shallow discharge, according to battery life loss under difference SOC and difference discharge power, combined with the seawater desalination production profit, achieved long time energy management aiming at economic operation of micro-grid. Built micro-grid model based on analog hybrid real-time simulation platform PXI and simulated the energy management. The result verified the correctness, feasibility and economy of the proposed strategy.

Keywords-micro-grid; seawater desalination; energy management; hybrid energy storage; real time simulation

I. INTRODUCTION

Along with social progress and economic development, the more and more lack of coal, oil, natural gas and other traditional focus people's attention. Renewable energy possesses the advantage of no pollution and can regenerate, become the best choice to replace traditional energy. In wind power, for example, China's wind power installed capacity in 2013 reached 91.4GW [1-2], become the third largest energy.

The combined operation of off-grid wind turbines and energy-intensive industries will be one of the directions of wind power absorption in the future [3-4]. In island areas, high energy consumption of reverse osmosis desalination system is suitable to operation with wind power. At present, topological structure, coordinated control, energy management and other technical problems aiming at isolated micro-grid has been preliminarily studied. [5] set up micro-grid capacity optimization configuration model including wind power, photovoltaic, diesel engine and energy storage, [6-7] studied coordinated control of isolated micro-grid and verified the feasibility of the proposed control strategy through simulation experiments, but energy management was not mentioned. [8-9] designed the implementation architecture of energy management and determined the status of energy management in micro-grid.

Based on isolated micro-grid including doubly fed induction generator(DFIG), seawater desalination load, diesel engine and hybrid energy storage consist of battery and super capacitor, consider battery life loss under different state of charge (SOC) and different charge power, this paper analyze controllability of desalination load, proposed micro-grid energy management strategy. At last, isolated micro-grid model was built based on analog hybrid real-time simulation platform, long time simulation verify the correctness, feasibility and economy of the proposed strategy.

II. SEAWATER DESALINATION SYSTEM STRUCTURE

Wind power desalination isolated micro-grid system is mainly consist of DFIG, battery, super capacitor, diesel generator and seawater desalination, each equipment connect with 380V AC bus by their own inverter or transformer. Structure diagram of stand-alone micro-grid is shown in Fig.1.

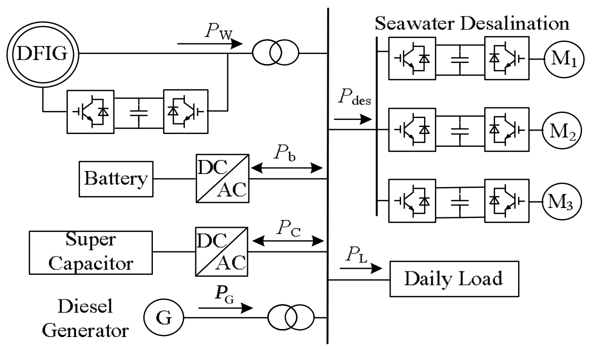

Figure 1. Structure diagram of stand-alone micro-grid

III. MICRO-GRID ENERGY MANAGEMENT SYSTEM INTRODUCTIONS

Micro-grid energy management system (MEMS) is one of the key technologies to ensure isolated micro-grid safe and economic operation. This paper put forward real time energy management strategy of isolated micro-grid. Based on wind speed forecasting results and energy storage state, the strategy determines the state of the system, makes seawater desalination cutting plans and wind power limit orders to ensure stable and economic operation of the system.

A. Wind turbines

This paper adopted DFIG. Under maximum power point tracking(MPPT) control, DFIG possess variable speed and constant frequency operation characteristics, active and reactive power can be independent controlled. In micro-grid, DFIG should be in state of maximum wind capture for long-term to ensure maximum utilization of wind energy. When wind power surplus, unloading load put into use.

B. Energy storage system

Energy storage system use battery and super capacitor hybrid energy storage. It is used to bring down power fluctuations of high wind power penetration, maintain seawater desalination short-term operate and safety shutdown when wind power is insufficient.

Super capacitor is power type storage, can compensate power balance rapidly and don't participate in long time energy management system. Battery use PQ control, transport constant power to micro-grid according to the operation condition. According to the micro-grid power balance, battery changes reference active and reactive power per 30s to help super capacitor maintain system stable.

SOC of battery should be in safe state as shown in (1).

$$SOC_{\min} \le SOC \le SOC_{\max} \tag{1}$$

Considering the battery inverter rated power restriction, battery charge or discharge power should satisfied (2). In (2), P_b is battery power, positive value means discharge power and negative refers to charge power, P_{bN} is inverter rated power.

$$|P_b| \le P_{bN} \tag{2}$$

C. Seawater desalination system

Seawater desalination device is mainly consisting of feed water pump, PX booster pump, high pressure pump, reverse osmosis RO unit and energy recovery device. The main load energy consumption is from feed water pump and high pressure pump.When seawater desalination working in the largest state and all high pressure pump running in high frequency, it reaches in maximum power $P_{\text{des.max}}$, when seawater desalination working in the smallest state and all high pressure pump running in middle frequency, ti reaches in minimum power $P_{\text{des.min}}$. When micro-grid can't satisfied $P_{\text{des.min}}$, seawater desalination stops. During normal operation, seawater desalination power constraints is shown in (3), among them, P_{des} is seawater desalination power.

$$P_{\text{des.min}} \le P_{\text{des}} \le P_{\text{des.max}} \tag{3}$$

D. Diesel generator

Diesel generator as emergency energy system, put into use when wind power can't meet the daily load and battery can't discharge. To ensure the normal operation temperature of engine and extending the service life of generator, diesel generator should at least operate in 30% rated power.It's shown in (4).

$$30\%P_{\text{GN}} \le P_{\text{G}} \le P_{\text{GN}} \tag{4}$$

E. Micro-Grid system

Micro-grid should satisfy power balance constraints shown in (5) when normal operation. This paper mainly analyzed active power balance (reactive power deficiency is small in the system and all provided by super capacitor). In (5), P_{W} is wind power, P_{L} is daily load power and P_{dl} is unloading load power.

$$P_{\text{W}} + P_{\text{b}} = P_{\text{des}} + P_{\text{L}} + P_{\text{dl}} \tag{5}$$

IV. ENERGY MANAGEMENT SYSTEM CONTROL STRATEGY

Energy management system is the basis of micro-grid automatic operation. The micro-grid achieves real time control according to the wind speed prediction and real time measurement data, completes seawater desalination unit cutting, wind power limiting and battery charging and discharging.

In this paper, wind speed forecasting interval is set to be the unit time Δt of energy management. According to wind speed data of each forecasting point and by collecting current system running state including current seawater desalination power, current battery power, current battery SOC, current super capacitor power, current super capacitor SOC, energy management makes seawater desalination load cutting plans to maintain micro-grid stable on the premise of battery SOC is in safe limit.

When wind power can't meet seawater desalination full load operation, we can choose battery discharge maintain seawater desalination running at a relatively high power or battery charge maintain seawater desalination running at a relatively low power. At this time, the more economic choice used as the energy management result. Under the condition of the given wind speed data, operation maintenance cost and equipments life loss of DFIG and super capacitor can be a constant value, it can be ignored when economical comparison. The operation maintenance cost and equipments life loss of seawater desalination converted to water profit. Micro-grid operates in normal state namely diesel engine is not put into use. Analyzing the life loss of battery discharge and seawater desalination water profit, economic operation plans can be obtained.

Battery current SOC is SOC_0, if battery discharges, seawater desalination runs at a relatively high power P_{des1}, after unit time Δt, battery SOC reduce to SOC_1. Equation is shown in (6).

$$\begin{cases} C_1 = k_1 P_{\text{des1}} \Delta t - f(SOC_0, SOC_1) \\ P_{\text{dis}} = P_{\text{des1}} + P_{\text{L}} - P_{\text{W}} \\ SOC_1 = SOC_0 - P_{\text{dis}} \Delta t / C_N \end{cases} \tag{6}$$

In (6), C_1 is system total revenue in Δt, k_1 is water production net income of unit energy consumption (Yuan/kWh) when seawater desalination runs at P_{des1}.

$f(SOC_0,SOC_1)$ is battery life loss (Yuan) when SOC reduce from SOC_0 to SOC_1, specific calculation reference [10]. P_{dis} is battery discharge power. C_N is battery nominal capacity (kWh).

If battery charges, seawater desalination runs at a relatively low power P_{des2}, after unit time Δt, battery SOC rise to SOC_1. Equation is shown in (7).

$$\begin{cases} C_2 = k_2 P_{des2}\Delta t - f(SOC_0, SOC_2) \\ P_{ch} = P_W - P_{des2} - P_L \\ SOC_2 = SOC_0 + P_{ch}\Delta t / C_N \end{cases} \quad (7)$$

In (7), C_2 is system total revenue in Δt, k_2 is water production net income of unit energy consumption (Yuan/kWh) when seawater desalination runs at P_{des2}. $f(SOC_0,SOC_2)$ is battery life loss (Yuan) when SOC rise from SOC_0 to SOC_1. P_{ch} is battery charge power.

If SOC_1 and SOC_2 within the scope of safe limit, by comparing C_1 and C_2, choose max (C_1,C_2) corresponding seawater desalination operation state as cutting plan in Δt. If SOC_1 beyond the limit, choose SOC_2 corresponding seawater desalination operation state; If SOC_2 beyond the limit, choose SOC_1 corresponding seawater desalination operation state.

In order to get long time energy management, it should make multiple Δt seawater desalination plan based on several wind speed forecasting points. If each Δt select $\max(C_1,C_2)$ plan, maybe within some Δt, battery can't discharge due to battery discharge too much in last Δt, which cause total revenue relatively less in all Δt. So, we set all Δt maximizing total revenue goal. Suppose n is the number of wind speed forecasting point, total revenue is shown in (8).

$$C_{total} = \sum_{i=1}^{n} C(i) \quad (8)$$

In (8), $C(i)$ is unit time revenue after No.i wind speed forecasting point, equals C_1 or C_2.

V. ISOLATED MICRO-GRID SIMULATION ANALYSIS BASED ON PXI

This paper verified energy management strategy based on PXI, established micro-grid average model as shown in Fig.1 through MATLAB/simulink and deployed on PXI. In the micro-grid system, wind farm use a set of rated power 150kW DFIG, cut-in wind speed is 3m/s, rated wind speed is 10m/s and cut-out speed is 21m/s. Battery capacity is 42kWh, super capacitor capacity is 5F. Seawater desalination use a set of 5t a day device, specific parameters are shown in TABLE I. Daily load is 4kW. When micro-grid operates, battery changes its reference power every 30s.

TABLE I. PARAMETERS OF 5T SEAWATER DESALINATION EQUPMENTS

Device	raw water pump	PX booster pump	high pressure pump
Capacity	3kw	3.7kw	5.5kw

Based on PXI, real time simulation time is 2h. Initial battery SOC is 50% and its safe operation range is 20%~80%. Initial super capacitor SOC is 60% and the safe operation range is 10%~90%. Wind speed forecasting curve is shown in Fig.2.

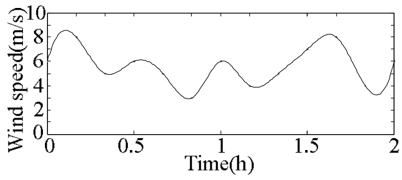

Figure 2. Wind speed forecasting curve

Real time simulation result is shown in Fig.3. I Fig.3, (a) is wind power curve. (b) is seawater desalination and daily load power. In (b), the rapidly increasing at 10min point means new high pressure pump starts within 20s, the rapidly decreasing at 10min point means high pressure pump stops within 20s. In 10min, load small fluctuations means seawater desalination tracks wind power fluctuations. (c) and (d) are battery power and SOC curve, the curve show battery SOC maintain 50%~80% and can counteract wind power fluctuations for long time. (e) and (f) are super capacitor power and SOC curve, (g) and (h) are micro-grid voltage and frequency curve, the curve shows voltage and frequency maintain stable by super capacitor changes its power continually. This can be concluded that seawater desalination can change its power according to energy management to ensure economic operation, battery and super capacitor can maintain micro-grid stable operation within its safe SOC range.

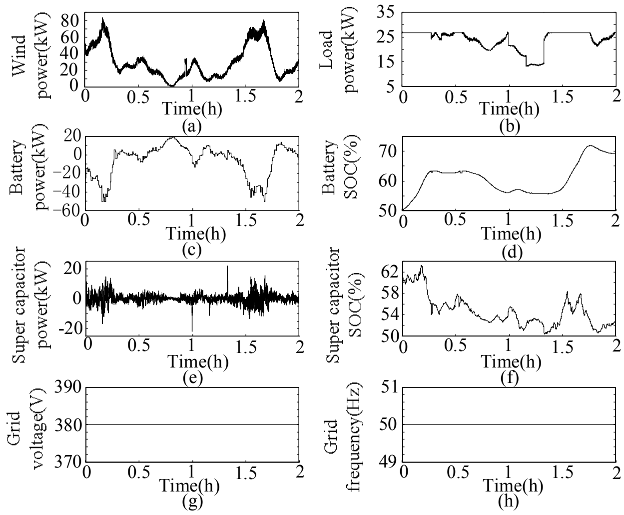

Figure 3. Simulation results in real time

VI. CONCLUSIONS

This paper established isolated micro-grid model including wind turbines, seawater desalination devices, diesel generator and hybrid energy storage consist of battery and super capacitor. On the basis of stable operation, according to battery life loss under difference SOC and difference discharge power, achieved long time energy management aiming at economic operation of micro-grid. Built micro-grid model based on PXI and simulated the energy management. The result shows seawater desalination can stable and economic operate according to cutting plan, battery and super capacitor can maintain micro-grid voltage and frequency stable. Simulation results verified the correctness, feasibility and economy of the proposed strategy.

REFERENCES

[1] Global wind statistics 2013. Brussels: Global Wind Energy Council, 2014.

[2] Zhang Liying, Ye Tinglu, Xin Yaozhong, Han Feng and Fan Gaofeng, “Problems and measures of power grid accommodating large scale wind power,” Proceedings of CSEE, vol.30, Sep.5, 2012, pp.1-9.

[3] Oh H J, Hwang T M and Lee S, “A simplified simulation model of RO systems for seawater desalination,” Desalination, vol.238, 2009, pp.128-139,.

[4] Geisler P, Krumm W and Peters T, “Optimization of the energy demand of reverse osmosis with a pressure-exchange system,” Desalination, vol.125, 1999, pp.167-172.

[5] Zhang Jianhua, Yu Lei, Liu Nian and Xiao Rui, “Capacity configuration optimization for island microgrid with wind/photovoltaic/diesel/ storage and seawater esalination load,” Transactions of China Electrotechnical Society, vol.29, Feb. 2014, pp.103-112.

[6] Liu Mengxuan, Guo Li, Wang Chengshan, Zhao Bo, Zhang Xuesong and Liu Yun, “A coordinated operation control strategy for hybrid isolated microgrid including wind power, photovoltaic system, diesel generator and battery storage,” Automation of Electric Power System, vol.36, Aug.10, 2012, pp.19-24.

[7] Liu Xia, “Control strategy of microgrid containing various distributed generators and storages,” Zhejiang: Zhejiang University, 2012.

[8] Li Yang, Liu Haitao, Wu Ming, Ji Yu and Yu Hui, “Development and application of microgrid energy management system,” East China Electric Power, vol.41, May. 2013, pp.1072-1074.

[9] Niu Huanna, Huang Xiuqiong, Yang Rengang, Tang Yunfeng, Feng Xiaoming and Ynag Minghao, “Research and design of functional architecture system in microgrid energy management system,” Renewable Energy Resources, vol.31, Jun. 2013, pp.47-51.

[10] Chen Jian, Wang Chengshan, Zhao Bo and Zhang Xuesong, “Economic operation optimization of a stand-alone microgrid system considering characteristics of energy storage system,” Automation of Electric Power System, vol.36, Oct.25 2012, pp.25-31.