Control of Hybrid System of Wind/Hydrogen/Fuel Cell/Supercapacitor

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Abstract. Because of the intermittent power out of Photovoltaic (PV) and wind, the model and strategy of wind/PV hydrogen hybrid system is proposed in this paper. The model of wind, PV, electrolyzer (EL) and supercapacitors (SC) are built up. Due to the strategy, the photovoltaic efficiency is improved and system power quality is optimized and the internet power is smoothed. In the PSCAD, the simulation results show that the model and control strategy of PMSG/PV/EL/SC hybrid system are effective.

Introduction

More and more scholars pay attention to clean wind energy. Because of the intermittent power out of Photovoltaic (PV) and wind leads to poor power quality. Wind turbine running with storage is a kind of solving the problem. The hydrogen energy is clean and abundant. By producing hydrogen, the fluctuant power out of wind turbine and PV stabilized is the important direction in the future\cite{1-4}.

Currently, many scholars have conducted a preliminary study for the hybrid system of wind/PV/hydrogen. The model of PV, electrolyzer and fuel cell is built up, and all of units are integrated to the dc-bus. This paper proposes a kind of control strategy to realize dc-bus voltage stabilized and the internet power smoothed\cite{5}. Basing on MPC algorithm, a kind of energy management strategy of hybrid system of wind/PV/ electrolyzer/fuel cell/supercapacitors is proposed. The energy management strategy ensures that energy of hybrid system is distributed reasonably into every unit of hybrid system all the time\cite{6}. Applying coordinated control to hybrid system consisted of PV, wind turbine, electrolyzer and fuel cell is to achieve power balance for power generation system, energy storage system and dynamic load\cite{7}. The paper proposes a control strategy of grid-connected hybrid system, which ensures that the fuel cell can supply the power shortage for the hybrid system and electrolyzer can consume surplus power of hybrid system\cite{8-9}.

The main work of this paper is organized as follows:
Firstly, the model of PMSG, PV, electrolyzer, fuel cell and Supercapacitors are built up in the PSCAD. Then, the structure of hybrid is constructed. Secondly, a kind of control strategy is proposed to 4 running modes for hybrid system. Finally, the simulation results are provided to show the accuracy of model of hybrid system and the effectiveness of the control strategy of grid-connected hybrid system.

The Model of System.

The Model of PV System

The mathematical model of PV is defined by the following expression\cite{10}:

\begin{equation}
I = N_p I_{sc} \cdot \left\{1 - C_i \left[\exp\left(\frac{U - dU}{C_2 N_s U_{oc}}\right) - 1\right]\right\} + dI
\end{equation}

where $U_{mp}$ is voltage of MPPT, $N_s$ is the series connection number, $N_p$ is the parallel connection number.
The Model of Wind Turbine System
The energy of wind turbine is defined by the following expression[11]:

\[
P_{\text{air}} = \frac{1}{2} \rho \pi R^2 v^3 C_p(\beta, \lambda)
\]  

(2)

where \( V_w \) is wind speed, \( \rho \) is the air density, \( R \) is rotational speed, \( \omega \) is rotational speed.

The Model of EL System
The voltage equation is defined by the following expression[12]:

\[
U_{el} = N_{el} \left( U_{el} + \frac{r_1 + r_2 T_{el}}{A_{el}} i_a + (s_1 + s_2 T_{el} + s_1 i_a^2) \log \left( \frac{t_1 + t_2}{T_{el} + t_1 + t_2} \right) \right)
\]  

(3)

where \( U_{el} \) is reversible cell voltage, \( A_{el} \) is electrode area, \( N_{el} \) is the number of electrolyzer cells.

The Model of SC System
The energy absorbing or releasing of SC defined by the following expression[12]:

\[
E = \frac{B}{A} C_t \left[ (AU_1) - (AU_2) \right] = ABC_t \left( U_1^2 - U_2^2 \right)
\]  

(4)

where \( E \) is energy of SC, \( U_1 \) is the starting voltage, \( U_2 \) is ending voltage.

Hybrid System Coordinated Control
Hybrid System Control Strategy
The control strategy of hybrid system is shown in Figure 1.

The figure show that the unit of PMSG and PV realize the maximum power point tracking, and the unit of EL consumes the surplus power of hybrid system, and the unit of SC supplies the power shortage for the hybrid system or consumes surplus power of hybrid system. In a word, the energy of hybrid system is distributed reasonably into every unit of hybrid system all the time, which leads to smoothing internet power.
Hybrid System Power Control Mode

Mode 1
When the output of power of PMSG and PV is more than the AC load demand, the excess power of hybrid system is showed as follows:

\[ P_c = P_w + P_{pv} - P_G \]  

(5)

Then, EL consumes the excess power of hybrid system.

Mode 2
The grid load dumps abruptly, that brings about output of power of PMSG and PV being great more than the AC load demand. The excess power is more than rated power of EL. Then, EL produces hydrogen with rated power. At the same time, SC absorbs rapidly the surplus power of hybrid system as follow:

\[ P_{sc} = P_w + P_{pv} - P_G - P_{Nel} \]  

(6)

SC is out of work when its terminal voltage \( U_{dcsc} = U_{dcsc\_max} \), PV abandons light in order to keep the hybrid system power in balance.

Mode 3
Swelling load disturbs the grid result in output of power of PMSG and PV is less than the AC load demand. Simultaneously, SC provides rapidly the shortage power of hybrid system as follow:

\[ P_{sc} = P_w + P_G - P_pv \]  

(7)

SC is out of work when its terminal voltage \( U_{dcsc} = U_{dcsc\_min} \). The power generator in grid increases out of power to keep the hybrid system power in balance.

Mode 4
When PV is in night or cloudy day without sunshine, PV cannot work. Then, the output of wind turbine is slightly more than AC load. And the excess power of hybrid system is defined by the following expression:

\[ P_c = P_w - P_G \]  

(8)

In the same time, EL consumes the excess power of hybrid system to produces hydrogen.

Simulation and Discussion
Basing on PSCAD, the hybrid system of wind/PV/hydrogen/supercapacitors is built up.

The power of hybrid and the running state of SC terminal voltage is expressed as the Figure 2.

![Figure 2. The curve of hybrid system power and supercapacitor terminal voltage.](image)

The picture show the running concrete conditions of hybrid system as follow:
At the time of 2s, SC starts up, absorbing the 45.5kW excess power. At the time of 3.39s, SC is out of work due to the terminal voltage of SC reaching to 0.58kV. Then, PV abandons light in order to keep the hybrid system power in balance.

At the time of 4s, SC starts up rapidly, supply 45.5kW to the hybrid system. At the time of 4.98s, SC is out of work due to the terminal voltage of SC reaching to 0.4kV. Then, the power generator in grid increases out of power to keep the hybrid system power in balance.

**Conclusion**

The paper builds up the mathematical model of PMSG, PV, SC and EL. Adopting the structure of PV, PMSG, EL and SC being linked in the dc-bus leads to reducing cost of hybrid system. Basing on 4 kind of operating conditions of hybrid system, the paper proposes a sort of control strategy, which contributes to improving efficiency of hybrid, stabilizing the DC-BUS voltage and smoothing internet power. In the PSCAD, the simulation results show that the model and control strategy of PMSG/PV/EL/SC hybrid system are effective.

**References**

[1] Chunhua Liu, K. T. Chau. An Efficient Wind–Photovoltaic Hybrid Generation System Using Doubly Excited Permanent-Magnet Brushless Machine [J]. Industrial Electronics, 2010, 57(3): 831-838.

[2] Sushil S. Thale, Rupesh G. Wandhare. A Novel Reconfigurable Microgrid Architecture with Renewable Energy Sources and Storage [J]. Industry Applications, 2015, 51(2): 1805-1815.

[3] K. T. Tan, P. L. So, et al. Coordinated Control and Energy Management of Distributed Generation Inverters in a Microgrid[J]. Power Delivery, 2015, 28(2): 704-711.

[4] Phatiphat Thounthong, Viboon Chunkag, et al. Comparative Study of Fuel-Cell Vehicle Hybridization with Battery or Supercapacitor Storage Device[J]. Vehicular Technology, 2009, 58(8): 3892-3903.

[5] A. Cano, F. Jurado. Sizing and Energy Management of a Stand-Alone PV/Hydrogen/Battery-Based Hybrid System[C], Power Electronics, Electrical Drives, Automation and Motion, Sorrento, 2012:969-973.

[6] Juan P. Torreglosa, Francisco Jurado, et al. Energy dispatching based on predictive controller of an off-grid wind turbine/photovoltaic/hydrogen/battery hybrid system[J], Renewable Energy, 2015, 74(23): 326-336.

[7] Milana Trifkovic, Mehdi Sheikhzadeh, et al. Modeling and Control of a Renewable Hybrid Energy System With Hydrogen Storage[J], Control Systems Technology, 2014, 22(1):169-179.

[8] Caisheng Wang, M. Hashem Nehrir. Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System[J], Energy Conversation, 2008, 23(3): 957-966.

[9] Tao Zhou, Bruno Francois. Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration[J], Industrial Electronics, 2011, 58(1): 95-103.

[10] Djoudi H., Badji A, et al. Modeling and Power Management Control of the Photovoltaic and Fuel Cell/Electrolyzer System for Stand-Alone Applications[C], Mammeri Tizi-Ouzou, 2015.

[11] A. M. Osman Haruni, et al. A Novel Operation and Control Strategy for a Standalone Hybrid Renewable Power System [J], Transactions on Sustainable Energy, 2013, 4(2): 402-412.

[12] Md. Maruf-ul-Karim, M. T. Iqbal. Dynamic Modeling and Simulation of Alkaline Type Electrolyzers[C], Electrical and Computer Engineering, 2009:711-715.