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Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration

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***Abstract*—Classical wind energy conversion systems are usually passive generators. The generated power does not depend on the grid requirement but entirely on the fluctuant wind condition. A dc-coupled wind/hydrogen/super capacitor hybrid power system is studied in this paper. The purpose of the control system is to coordinate these different sources, particularly their power exchange, in order to make controllable the generated power. As a result, an active wind generator can be built to provide some ancillary services to the grid. The control system should be adapted to integrate the power management strategies. Two power management strategies are presented and compared experimentally. We found that the "source-following" strategy has better performances on the grid power regulation than the "grid-following" strategy.**

***Index Terms*—Distributed power, energy management, hybrid power system (HPS), power control, wind generator (WG).**

I. INTRODUCTION

Renewable energy sources (RES) and distributed generations (DGs) have attracted special attention all over the world in order to reach the following two goals: 1) the security of energy supply by reducing the dependence on imported fossil fuels; 2) the reduction of the emission of greenhouse gases (e.g., CO2) from the burning of fossil fuels. Other than their relatively low efficiency and high cost, the controllability of the electrical production is the main drawback of renewable energy generators, like wind turbines and photovoltaic panels, because of the uncontrollable meteorological conditions. In consequence, their connection into the utility network can lead to grid instability or even failure if they are not properly controlled. Moreover, the standards for interconnecting these systems to the utility become more and more critical and require the DG systems to provide certain services, like frequency and voltage regulations of the local grid. Wind power is considered in this paper. Wind energy is the world's fastest growing energy source, expanding globally at a rate of 25%–35% annually over the last decade

However, classical wind energy conversion systems work like passive generators. Because of the intermittent and fluctuant wind speed, they cannot offer any ancillary services to the electrical system in a microgrid application, where stable active- and reactive-power requirements should be attributed to the generators. As solutions, hybrid power systems (HPS) are proposed to overcome these problems with the following two innovative improvements.

1) *Energy storage systems* are used to compensate or absorb the difference between the generated wind power and the required grid power.

2) *Power management strategies* are implemented to control the power exchange among different sources and to provide some services to the grid.

Hydrogen technologies, combining fuel cells (FCs) and electrolyzers (ELs) with hydrogen tanks are interesting for longterm energy storage because of the inherent high mass–energy density. In the case of wind energy surplus, the EL converts the excess energy into H2 by electrochemical reaction. The produced H2 can be stored in the hydrogen tank for future reutilization. In the case of wind energy deficit, the stored electrolytic H2 can be reused to generate electricity by an FC to meet the energy demand of the grid. Thus, hydrogen, as an energy carrier, contributes directly to the reduction of dependence on imported fossil fuel. According to researchers, wind electrolysis is a very attractive candidate for an economically viable renewable hydrogen production system.

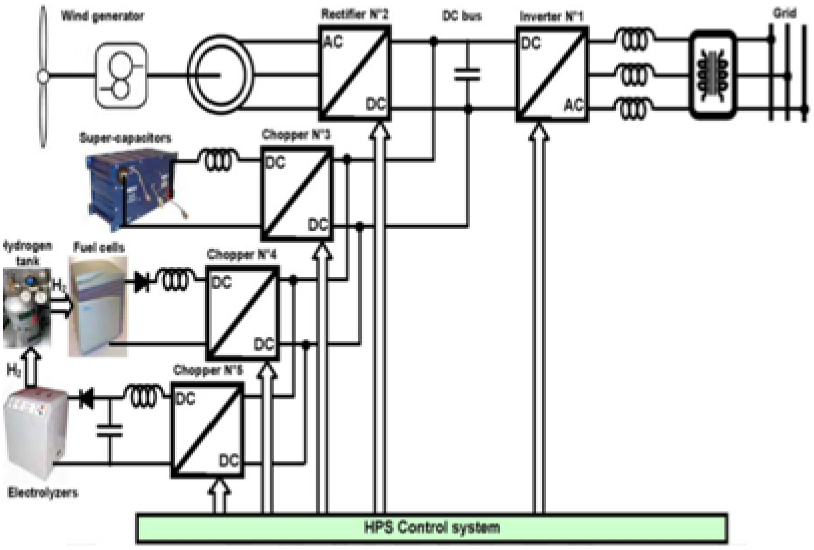

Fig. 2. Structure of the studied wind/hydrogen/SC HPS

However, FCs and ELs have low-dynamic performances, and fast-dynamic energy storage should be associated in order to overcome the fast fluctuations of wind power. Recent progress in technology makes supercapacitors (SCs) the best candidates as fast dynamic energy storage devices, particularly for smoothing fluctuant energy production, like wind energy generators. Compared to batteries, SCs are capable of very fast charges and discharges and can achieve a very large number of cycles without degradation, even at 100% depth of discharge without "memory effect." Globally, SCs have a better round-trip efficiency than batteries. With high dynamics and good efficiency, flywheel systems are also suitable for fast-dynamic energy storage . However, this mechanical system is currently hampered by the danger of "explosive" shattering of the massive wheel due to overload (tensile strength because of high weight and high velocity). SCs are less sensitive in operating temperature than batteries and have no mechanical security problems. In order to benefit from various technology advantages, we have developed a wind generator (WG), including three kinds of sources: 1) a RES: WG; 2) a fast-dynamic storage: SCs; and 3) a long-term storage: FC, EL, and H2 tank. The control of internal powers and energy management strategies should be implemented in the control system for satisfying the grid requirements while maximizing the benefit of RESs and optimizing the operation of each storage unit. The purpose of this paper is to present the proposed power management strategies of the studied HPS in order to control the dc-bus voltage and to respect the grid according to the microgrid power requirements. These requirements are formulated as real- and reactive-power references, which are calculated by a centralized secondary control center in order to coordinate power dispatch of several plants in a control area. This area corresponds to a microgrid and is limited due to the high level of reliability and speed required for communications and data transfer . In Sections II and III, the studied HPS structure is presented.

The structure of the control system is adapted in order to integrate power management strategies. Two power management strategies are presented in Section IV. The experimental tests are presented to compare their performances in Section V, and conclusions are given in Section VI. Hierarchical control structure of the HPS.

II. HPS AND CONTROL SYSTEM

A. Structure of H

P
S

In this paper, we use a dc-coupled structure in order to decouple the grid voltages and frequencies from other sources. All sources are connected to a main dc bus before being connected to the grid through a main inverter (Fig. 2) . Each source is electrically connected with a power-electronic converter in order to get possibilities for power control actions. Moreover, this HPS structure and its global control system can also be used for other combinations of sources.

B. Structure of Control System

Power converters introduce some control inputs for power conversion. In this case, the structure of the control system can be divided into different levels .

The ***switching control unit (SCU)*** is designed for each power converter. In an SCU, the drivers with optocouplers generate the transistor's ON/OFF signals from the ideal states of the switching function {0, 1}, and the modulation technique (e.g pulsewidth modulation) determines the switching functions from the modulation functions (m).

automatic control unit (ACU) is designed for each energy source and its power conversion system. In an ACU, the control algorithms calculate the modulation functions (m) for each power converter through the regulation of some physical quantities according to their reference values.

The ***power control unit (PCU)*** is designed to perform the instantaneous power balancing of the entire HPS in order to satisfy the grid requirements. These requirements are real- and reactive-power references, which are obtained from the secondary control center and from references of droop controllers . In a PCU, some power-balancing algorithms are implemented to coordinate the power flows of different energy sources. The different power-balancing algorithms correspond to a number of possible operating modes of the HPS and can be gathered.

The purpose of this paper is to present the power-balancing strategies in the PCU. In order to focus on the power-balancing strategies of the HPS, the control schemes of the power conversion systems through different power converters will not be detailed in this paper. However, some explanations of the ACUs are given in the following paragraphs in order to make the controllable variables of the power conversion systems appear.

C. ACU

1) The ***EL power conversion system*** is controlled by setting the terminal voltage (*u*el) equal to a prescribed reference (*u*el_ref) through the dc chopper N◦5. The EL stack is considered as an equivalent current source (*i*el).

2) The ***FC power conversion system*** is controlled with a reference of the FC current (*i*fc_ref) through the dc chopper N◦4. The FC stack is considered as an equivalent voltage source (*u*fc).

3) The ***SC power conversion system*** is controlled with a current reference (*i*sc_ref) through the dc chopper N◦3. The SC bank is considered as an equivalent voltage source (*u*sc).

4) The ***wind energy conversion system*** is controlled with a reference of the gear torque (*T*gear_ref) by the three-phase rectifier N◦2.

5) The ***grid connection system*** consists of a dc-bus capacitor and a grid power conversion system. The grid power conversion system is controlled with line-current references (*il*_ref) by the three-phase inverter N◦1, because the grid transformer is considered as an equivalent voltage source (*ugrid*).

The dc-bus voltage is described as *C*dc = *du*dc *dt* = *i*dc. (1)

In order to control the dc-bus voltage, a voltage controller must be used. The output of the voltage controller is a current reference *i*dc_ref .

III. PCU

A. Layout of PCU

The power modeling of the HPS can be divided into two levels: the ***power calculation level*** and the ***power flow level*** . Thus, the

PCU is also divided into two levels: the ***power control level*** and the ***power sharing level***. The PCU enables one to calculate references for the ACU from power references. The power sharing level coordinates the power flow exchanges among the different energy sources with different power-balancing strategies. They are presented here in detail with the help of the Multilevel Representation , which was developed by Peng Li in 2008 .

B. Power Control Level

The power exchanges with various sources are controlled only via the related five references (*u*el_ref , *i*fc_ref , *i*sc_ref , *T*gear_ref

, and *il*_ref . Therefore, the expressions of the powers should be deduced in order to obtain these power references . Only the sources' powers and the exchanged power with the dc-bus capacitor are taken into account here. For the energy storage systems, the powers are calculated by multiplying the measured currents and the measured voltages (***Int3***, ***Int4***, and ***Int5*** in Table I). The references of the controllable variables are obtained by dividing the power reference with the measured current or the measured voltages (***Int3c***, ***Int4c***, and ***Int5c*** . For the wind energy conversion system, a maximal-powerpoint-tracking (MPPT) strategy is used to extract the maximum power of the available wind energy according to a nonlinear characteristic in function of the speed.

Simulation Design

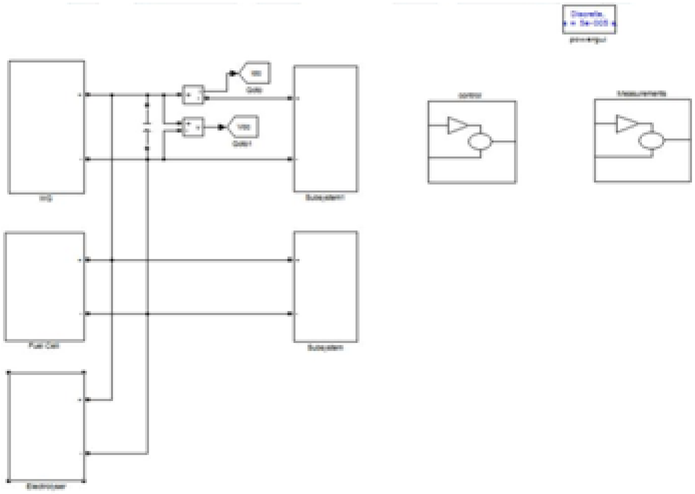

Fig:3 Main Circuit for Grid Following Block Diagram

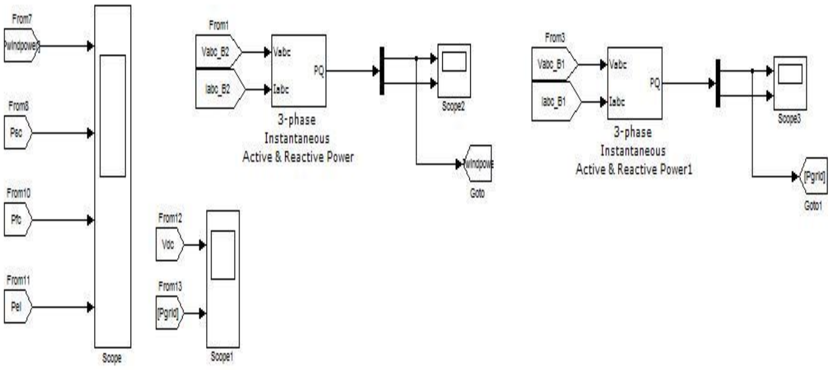

Fig :4 Measurements Block

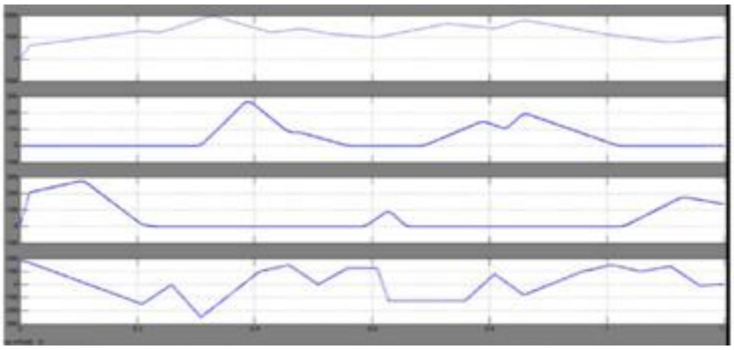

Fig :5 Output waveforms Wind, Fuel and Electrolysis

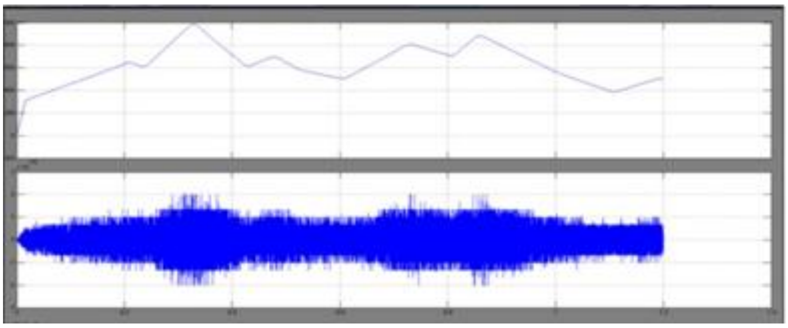

Fig :6 Active and Reactive Powers at bus one

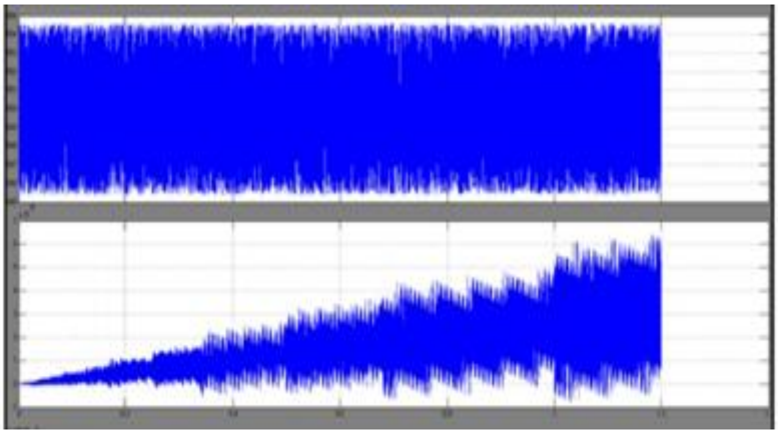

Fig :7 Active and Reactive Powers at Bus Terminal two

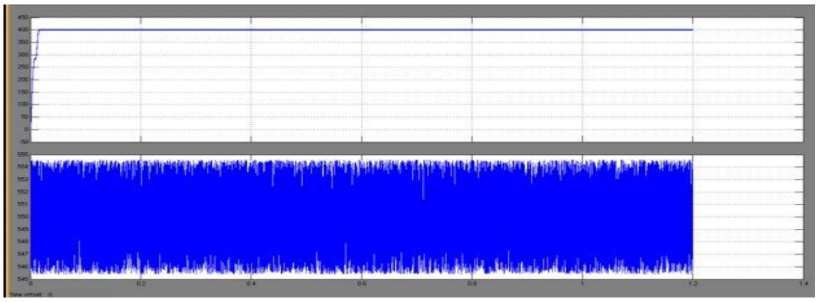

Fig :8 DC Capacitor Voltage and power grid

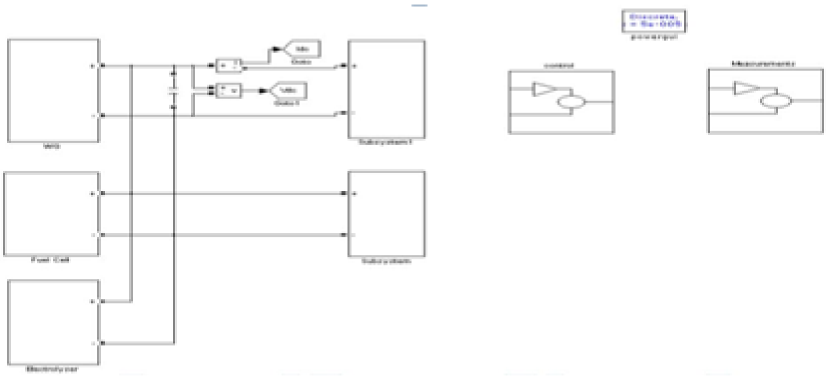

Fig :9 Energy management and power control of HPS

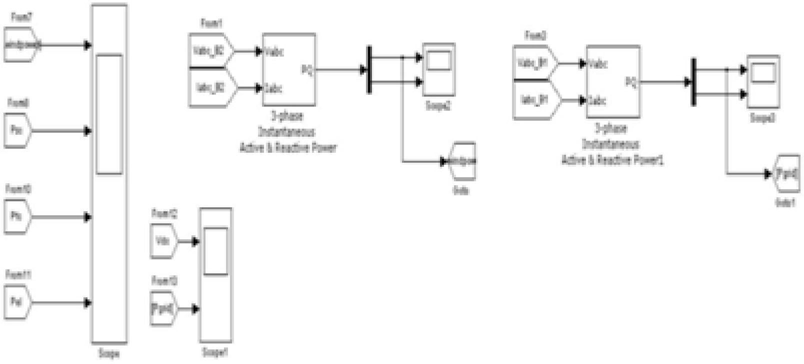

Fig :10 Measurement of DGS system

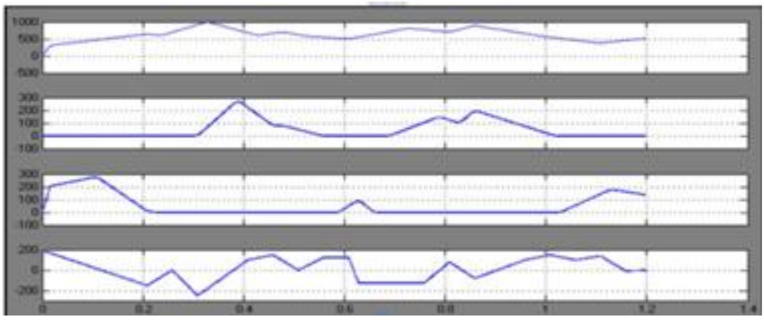

Fig :11 Output wave forms of wind, fuel and electrolysis

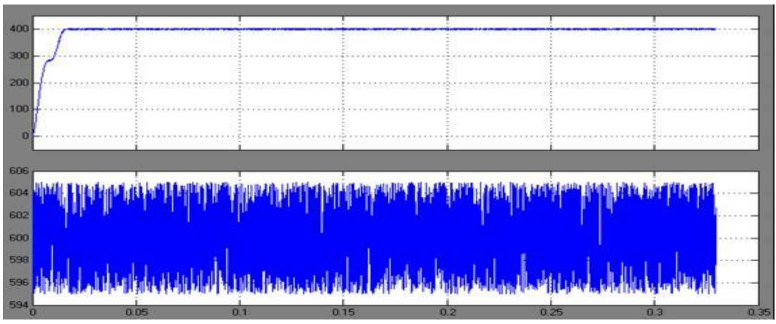

fig :12 DC Capacitor voltage source grid waveform

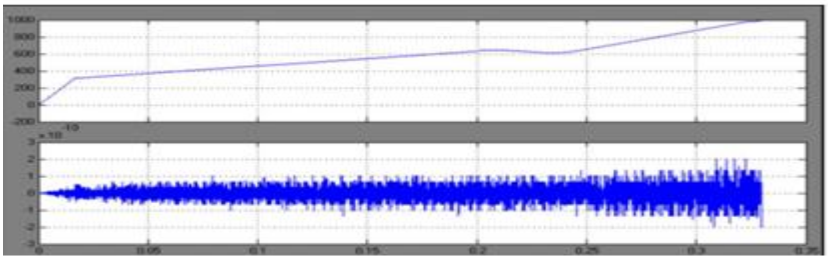

Fig :13 Active and Reactive powers at bus terminal one

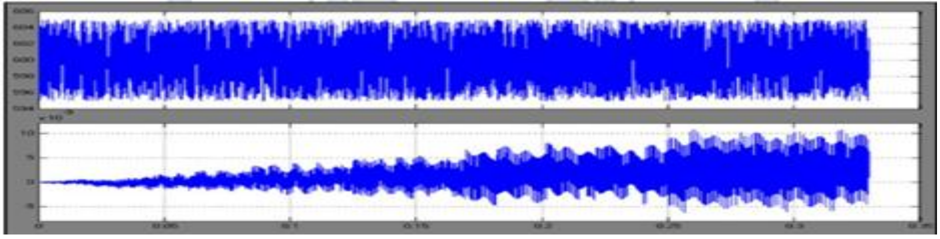

Fig :14 Active and Reactive powers at bus terminal two

CONCLUSION

In this paper, a dc-coupled HPS has been studied with the three kinds of energy sources: 1) a WG as a renewable energy generation system; 2) SCs as a fast-dynamic energy storage system; and 3) FCs with ELs and hydrogen tank as a longterm energy storage system. The structure of the control system is divided into three levels: 1) SCU; 2) ACU; and 3) PCU. Two power-balancing strategies have been presented and compared for the PCU: the grid-following strategy and the sourcefollowing strategy. For both of them, the dc-bus voltage and the grid power can be well regulated. The experimental tests have shown that the source-following strategy has better performance on the grid power regulation than the grid-following strategy.

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