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A Novel Hybrid Non-Isolated Distribution Generating System Based on Wind and Wave Power Generation Systems Using a DC Microgrid



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Abstract:

This paper proposes an integrated wind and wave power generation system fed to an AC power grid or connected with an isolated load using a dc microgrid. A bidirectional dc/dc converter is proposed to achieve the integration of both wind and wave power generation systems with uncertainty and intermittent characteristics. The wind power generation system simulated by a permanent-magnet synchronous generator (PMSG) driven by a wind turbine (WT) is connected to the dc microgrid through a VSC of PMSG. The wave power generation system simulated by an LPMG driven by a linear permanent magnet motor (LPMM) is also connected to the dc microgrid through a VSC of LPMG.

A resistive dc load is connected to the dc microgrid through a load dc/dc converter. To achieve stable power flow (or power balance condition) and load demand control of the dc microgrid under different operating conditions, a battery is connected to the dc microgrid through a bidirectional dc/dc converter, while an AC grid is connected to the dc microgrid through a bidirectional grid-tied inverter and a transmission line.

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: the security of energy supply by reducing the dependence on imported fossil fuels; the reduction of the emission of greenhouse 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 of25%–35% annually over the last decade. Hydrogen technologies, combining fuel cells (FCs) and electrolyzes(ELs) with hydrogen tanks are interesting for long-term 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. 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.

II. PROPOSED HYBRID WIND-FUEL-SUPERCAPACITOR SYSTEM:

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

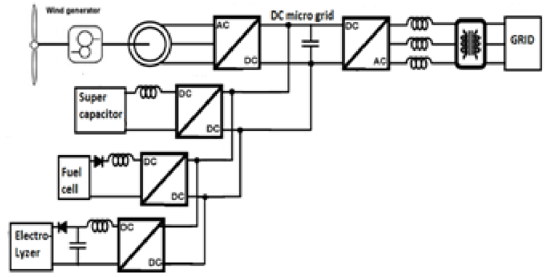

Figure 1: Structure of the proposed wind/hydrogen/SC

In this paper, we use a dc-coupled structure in order to decouple the grid voltages and frequencies from ot her sources. All sources are connected to a main dc bus before being connected to the grid through a main inverter. 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. Fig. 1 shows the configuration of the studied hybrid integrated wind and fuel power generation system connected to an ac grid through a dc microgrid. The wind power generation system simulated by a permanent-magnet synchronous generator (PMSG)driven by a wind turbine (WT) is connected to the dc microgrid through a VSC of VSC_PMSG.

To achieve stable power flow (or power balance condition) and load demand control of the dc microgrid under different operating conditions, a battery is connected to the dc microgrid through a bidirectional dc/dc converter, while an ac grid is connected to the dc microgrid through a bidirectional grid-tied inverter and a transmission line. When available wind power and/or fuel cell power can be injected into the dc microgrid with a fully charged battery, the surplus power of the dc microgrid can be delivered to the ac grid through the bidirectional grid-tied inverter. When no wind power or no fuel cell power is delivered to the dc microgrid with a low-energy battery, the insufficient power of the dc microgrid can be captured from the ac grid through the bidirectional grid-tied inverter.

The power of the resistive dc load RLoad can be obtained from the dc microgrid through the load dc/dc converter only when the dc microgrid has enough power. The load dc/dc converter with the resistive dc load RLoad can also slightly adjust the power balance condition of the dc microgrid. The control functions of the bidirectional dc/dc converter, the bidirectional grid-tied inverter, and the load dc/dc converter must be adequately coordinated with each other to obtain stable operation of the dc microgrid.

III. 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 is designed for each power converter. In this, the drivers with PWM generate the transistors ON/OFF signals from the ideal states of the switching function and the modulation technique determines the switching functions from the modulation functions. The automatic control unit 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 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 Power Control Unit, 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 Hybrid Power System and can be gathered. The purpose of this paper is to present the power-balancing strategies in the Power Control Unit. 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 Automatic Control Units are given in the following paragraphs in order to make the controllable variables of the power conversion systems appear. In this wind/hydrogen/SC HPS, five power-electronic converters are used to regulate the power transfer with each source. According to a chosen power flow, the following power balancing strategy can be implemented. The total power (psour) from the energy storage and the WG can also be used to provide the necessary dc power (pdc) for the dc-bus voltage regulation. In this case, the necessary total power reference (psour_ref) must be calculatedby taking into account the required power for the dc-bus voltage regulation (pdc_ref) and the measured grid power (pg) as disturbanceinput by using the inverse equation of Pow1.

Pow1c: psour_ref = pdc_ref + pg. Then, the total power reference of the storage systems isdeduced by taking into account the fluctuant wind power withthe inverse equation of Pow2.

Pow2c: psto_ref = psour_ref − ˜pwg. This power reference is shared among the FCs, the ELs,and the SCs in the same way as explained earlier (Pow2c,Pow3c, Pow4c, and Pow3c).

In addition, now, the grid power reference (pg_ref) is free tobe used for the grid power control. The microgrid system operatorcan directly set the power requirements (pgc_ref and qgc_ref)for the grid connection system (pg_ref = pgc_ref). Therefore, the HPS can directly supply the required powers for providing the ancillary services to the microgrid, like the regulations of the grid voltage and frequency.

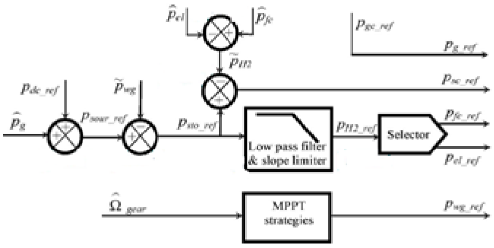

Fig 2: control Strategy for power balancing

IV. SIMULATION RESULTS:

Wind-Wave Hybrid Power System:

To examine the operation characteristics of the studied integrated system joined with the proposed dc microgrid, the results of the laboratory-grade experimental system and the simulated outcomes using the developed system model are compared. Different experiments are carried out, such as a load switching, speed variations of the wind PMSG, speed variations of the force of the wave LPMG, etc. Only the results under a sudden load-switching condition are shown due to page limit. Fig. 13 shows the responses of the studied system when the connected load is switching from 500 to 1000 W at t = 10 s under the rotor speed of the wind PMSG of 450 r/min and the forcer speed of the wave LPMG of 1.2 m/s. In each subplot shown in Fig. 4, the left one is the measured result, while the right one is the simulated dynamic response, where Park's transformation is used to transform the d–q-axis components into a–b–c three-phase components. For observing the output three-phase voltage or current clearly, only a-phase quantity is shown.

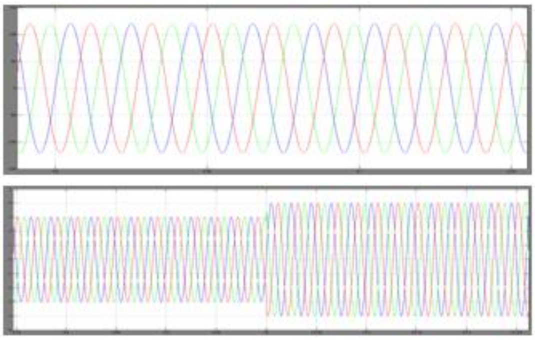

Fig 3: Output voltage, current of PMSG

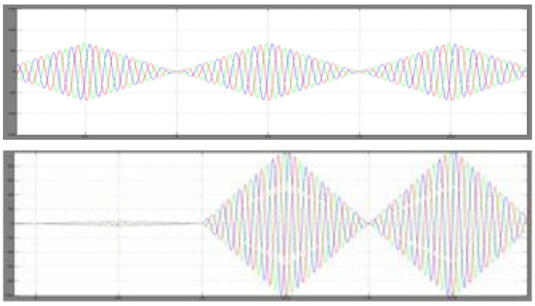

Fig 4: Output voltage current of the wave LPMG

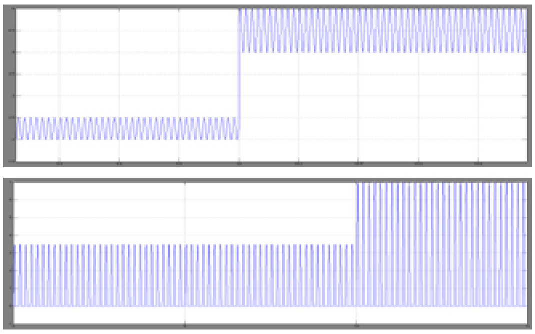

Fig 5: Output dc currents of the wind PMSG and wave LPMG

Win-Fuel cell-Super capacitor Hybrid Power System:

The FC and EL simulators are used to provide the same electrical behavior as the real FC stack and the EL stack. Models of the FCs and the EL have been previously validated through simulated results from models. Therefore, the equivalent capacitor of the SC bank is about 53 F, and the maximal voltage is about 144 V. All sources are connected to the dc bus through different power converters. The dc bus is connected to the grid through a three-phase inverter, three line filters, and grid transformer. The wind power emulator is used to provide the predefined reduced wind power profile pwg (1.2 kW).

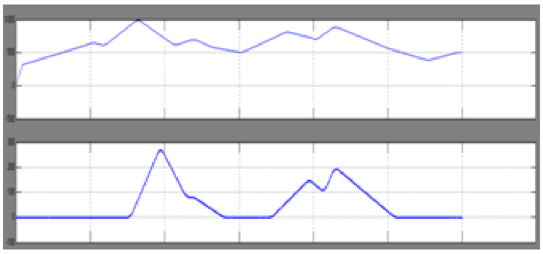

Fig 6: power profiles of wind energy system and super capacitors

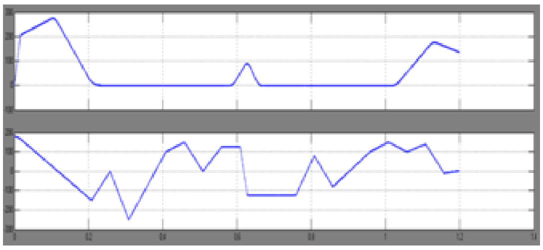

Fig 7: power profiles of fuel energy system and electrolyzer

V. CONCLUSION:

The proposed dc microgrid is derived in detail, including the wind WT-PMSG set with its VSC, the Fuel-Electrolyze set with its DC-DC converter, the bidirectional dc/dc converter with the Super Capacitors, the load dc/dc converter with the resistive load, and the bidirectional grid-tied inverter. The studied integrated system with the proposed dc microgrid can be operated stably under different disturbance conditions.

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