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Power management strategies of a Wind/hydrogen/ultra-capacitor based hybrid power system

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Abstract: **The generated power does not depend on the grid requirement but entirely on the fluctuant wind condition. A dc-coupled wind/hydrogen/ultra-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. We found that the "source-following" strategy has better performances on the grid power regulation than the "grid-following" strategy.**
Keywords: hybrid power system (HPS), wind generator (WG), Fuelcell (FC), electrolyzers (ELs), ultra-capacitor (UC)

I. INTRODUCTION

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.[1]
2) *Power management strategies* are implemented to control the power exchange among different sources and to provide some services to the grid.[1][2]
Hydrogen technologies [3], 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 thus, hydrogen; wind power 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. Recent progress in technology makes ultra-capacitors (UCs) the best candidates as fast dynamic energy storage devices, particularly for smoothing fluctuant energy production, like wind energy generators. Compared to batteries, UCs 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, UCs has a better round-trip efficiency than batteries with high dynamics and good efficiency. UCs 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: UCs;[4] 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-power references, which are calculated by a centralized secondary control center in order to coordinate power dispatch of several plants in a control area. Modeling and simulations are performed using MATLAB, Simulink and SimPowerSystems software packages to verify the effectiveness of the proposed system.[5]

II. SYSTEM DESCRIPTION

In this section, the dynamic simulation model is described for the wind/FC/EL/UC hybrid generation system. In this paper dc-coupled structure is used in order to decouple the grid voltages and frequencies from other sources. . Each source is electrically connected with a power-electronic converter in order to get possibilities for power control actions. This HPS structure its global control system can also be used for other combinations.

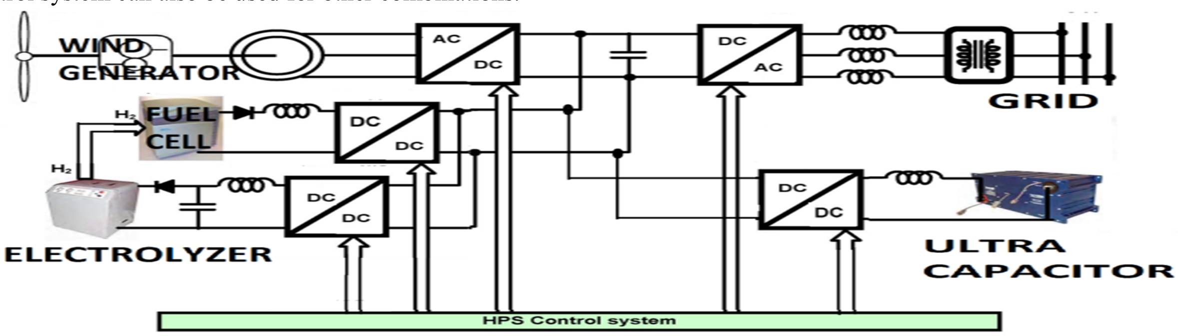

Fig.1. structure of the wind/hydrogen/UC HPS

A. Design and dynamic model of a wind turbine

In the literature, several studies have been reported regarding wind turbines and wind power driven generators. The model proposed in this paper is based on the wind speed versus wind turbine output power characteristics. The parameters used in the mathematical modeling of the wind turbine are as follows:

A turbine swept area [m2]

C_{p} performance coefficient of the turbine

$C_{\mathrm{p\_pu}}$ pu per unit (p.u.) value of the performance Coefficient C_{p}

k_{p} power gain for cp pu = 1 and !wind pu = 1 p.u., kp

p_{m} mechanical output power of the turbine [W]

$p_{\mathrm{m\_pu}}$ power in p.u. of nominal power for particular values of ρ and A

B blade pitch angle [deg]

λ tip speed ratio of the rotor blade tip speed to wind speed

ρ air density [kg (m3)−1]

v_{wind} wind wind speed [m s−1]

$v_{\mathrm{wind\_pu}}$ p.u. value of the base wind speed. The based wind speed is the mean value of the expected wind speed in (m s−1).

The output power of the wind turbine is given by

$$p_{\mathrm{m}} = C_{\mathrm{p}}(\lambda, \beta)\, \frac{\rho A}{2}\, v_{\mathrm{wind}}{}^{3} \qquad (1)$$

B. Design of fuel cell

Fuel cell use oxygen and hydrogen to convert chemical energy to electrical energy, among various types of FC systems, proton exchange membrane(PEM) FC plants have been found to be especially suitable to this HPS

1) *PEM FC Output Voltage Equation:* According to the Nernst's equation and Ohm's law, the cell voltage equation is given as

$$\mathrm{V} = \mathrm{N}\,(E^{o} + \frac{RT}{2F}\ln\{\frac{pH2(\ pO2/P_{std})^{1/2}}{pH2O}\} - L) \qquad (2)$$

Where,

V stack output voltage;

N number of cells in the stack;

E^0 cell open circuit voltage;

T operating temperature;

L voltage losses;

$pH2$, $pO2$ and $pHO2$ the partial pressures of each gas inside cell;

R gas constant (8.3144 J/mole*k)

F Faraday's constant (96439 C/mole)

$std\ P$ the standard pressure (101325 Pa)

The detailed model represents a particular fuel cell stack when the parameters such as pressures, temperature, compositions and flow rates of fuel and air vary. These variations affect the open circuit voltage (E_{oc}), the exchange current (i_0) and the tafel slope (A). E_{oc}, i_0 and A are modified as follows:

$$E_{oc} = k_c E_n \tag{3}$$

$$I_o = \frac{z\,Fk(P_{H2}+P_{O2})}{Rh}\,e^{\frac{-\Delta G}{RT}} \tag{4}$$

$$A = \frac{RT}{z\alpha F} \tag{5}$$

where

R 8.3145 J/(mol K)

F 96485 A s/mol

z Number of moving electrons

E_n Nernst voltage, which is the thermodynamics voltage of the cells and depends on the temperatures and partial pressures of reactants and products inside the stack (V)

α Charge transfer coefficient, which depends on the type of electrodes and catalysts used

P_{H2} Partial pressure of hydrogen inside the stack (atm)

P_{O2} Partial pressure of oxygen inside the stack (atm)

k Boltzmann's constant = 1.38×10^{-23} J/K

h Planck's constant = 6.626×10^{-34} J s

ΔG Size of the activation barrier which depends on the type of electrode and catalyst used

T Temperature of operation (K)

K_c Voltage constant at nominal condition of operation

C. Ultra-Capacitor

It is an energy storage device that has a specific property that makes it an interesting component in some applications this property is its high power density that enables it to handle fast fluctuations in energy levels. The double layers formed on the activated carbon surfaces can be illustrated as a series of parallel RC circuits. In order to realize the storage systems of a certain size, several Super capacitors connected in series and parallel are needed to obtain the demanded power and the necessary stored energy. An equivalent theoretical circuit has been obtained, as in fig.3 is a complicated net of RC branches have not a linear behavior due to the dependence of the capacitances from the voltage.

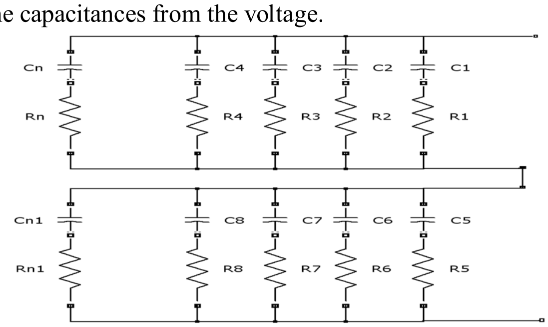

Fig.3. Theoretical method of a DLC

1) Mathematical modeling of super capacitor

The parameters used in the mathematical modeling of the SC bank are as follows:

C capacitance [F]

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C_{UC_total}	The total UC system capacitance [F]
EPR	Equivalent parallel resistance [Ω]
ESR, R	Equivalent series internal resistance [Ω]
N_s	The number of capacitors connected in series
N_p	The number of series strings in parallel
R_{UC_total}	The total UC system resistance [Ω]

Fig. 4 shows the classical equivalent circuit of the UC unit. The model consists of a capacitance (*C*), an equivalent series resistance (ESR, R) representing the charging and discharging resistance, and an equivalent parallel resistance (EPR) representing the self-discharging losses. The EPR models leakage effects and affects only the long-term energy storage performance of the UC. The amount of energy drawn from the UC bank is directly proportional to the capacitance and the change in the terminal voltage, given by

$$E_{UC} = \frac{1}{2}C(V_i^2 - V_f^2) \quad (6)$$

When the ultra-capacitor bank is subject to supply a prescribed amount of energy, the UC terminal voltage decreases. Eq. (6) represents the voltage variation versus energy released or captured by the ultra-capacitor bank. If the UC bank releases energy to the load side, E_{UC} is positive. If energy is captured by the UC bank E_{UC} is negative. The effective specific energy for a prescribed load can be supplied by various UC bank configurations. In practical applications, the required amount of terminal voltage and energy or the capacitance of UC storage system can be built using multiple UCs in series and parallel. The terminal voltage determines the number of capacitors which must be connected in series to form a bank and the total capacitance determines the number of capacitors which must be connected in parallel in the bank. The total resistance and the total capacitance of the UC bank may be calculated as

$$R_{UC\_total} = N_s \frac{\mathrm{ESR}}{N_p} \quad (7)$$

$$C_{UC\_total} = N_p \frac{C}{N_s} \quad (8)$$

The UC units can be arranged to build a UC bank, which is capable of providing the short-term peak load demand. The UC bank model has been implemented in MATLAB and SimPowerSystems for this study.

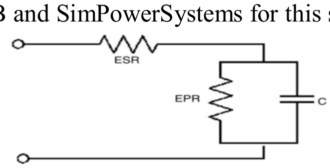

Fig.4. Classical equivalent model for the Ultra-capacitor unit

Table 1 Maxwell Boostcap® PC2500 UC characteristics

UC Parameters	Value
Capacitance	2700±20% [F]
Internal resistance (dc)	0.001±25% [)]
Leakage current	0.006 [A], 72 h, 25 #C
Operating temperature	−40 #C to 65 #C
Rated current	100 [A]
Voltage	2.5 [V]
Volume	0.6 [l]
Weight	0.725 [kg]

Each UC unit has a nominal voltage of 2.5V corresponding 2700 F.

Assuming a 400V dc output from the FC system, string of **160** UCs in series (16.875 F / string) is used to represent 400V and the initial voltage of the UC bank is set to be 363.5V. The energy is stored in a 16.875 F capacitance at 400V. This size of the UC can be changed to suit various power capacities for different applications.

2) *Simulink modeling of super capacitor:* The RC branch forms the equivalent Super-capacitor by substituting the values of R_{UC_total} and C_{UC_total}, which is connected to dc-dc chopper across the dc-bus.

III. POWER-BALANCING STRATEGIES

A. Grid-Following Strategy

The **grid-following strategy** uses the line-current loop to regulate the dc-bus voltage. With the grid-following strategy, the dc-bus voltage is regulated by adjusting the exchanged power with the grid, while the WG works in MPPT strategies. In Fig.5 Thus, the required power for the dc-bus voltage regulation (pdc_ref) is used to estimate the grid power reference

$$\textbf{Pow1e}: P_{g\_ref}\_\text{ref} = P_{sour} - P_{dc\_ref}. \qquad (9)$$

The source total power (*p*sour) is a disturbance and should
also be taken into account with the estimated wind power and the sensed total storage power

$$\textbf{Pow2e}: P_{sour} = P_{wg} + P_{sto} \qquad (10)$$

The energy storage systems help the wind energy conversion system satisfy the power references, which are asked by the microgrid operator

$$\textbf{Pow3e}: P_{sto} = P_{uc} + P_{H2} \qquad (11)$$

$$\textbf{Pow4e}: P_{H2} = \_P_{fc} - P_{el} \qquad (12)$$

If the microgrid system operator sets a power requirement (P_{gc_ref}), it must be equal to the sources power reference (P_{sour_ref}), as shown in Fig. 6

$$\textbf{Pow1c}: P_{sour\_ref} = P_{g\_ref} = P_{gc\_ref} \qquad (13)$$

In order to help the wind energy conversion system respect the active-power requirement, the energy storage systems should be coordinated to supply or absorb the difference between this power requirement (P_{gc_ref}) and the fluctuant wind power (P_{wg}), as shown in Fig.

$$\textbf{Pow2c}: P_{sto\_ref} = P_{sour\_ref} = P_{wg} \qquad (14)$$

Among the energy storage systems, the FCs and the ELs
are the main energy exchangers because a large quantity of hydrogen can be stored for enough energy availability. For efficiency reasons, the FC and the EL should not work at the same time. The activation of the FC or the activation of the EL depends on the sign of the reference (P_{H2_ref}). Thus, a selector assigns the power reference (P_{H2_ref}).) to the FC (P_{fc_ref}) or to the EL (P_{el_ref}) according to the sign of P_{H2_ref}).

However, the power reference (P_{sto_ref}) is a fast-varying quantity due to the fluctuant wind power (P_{wg}) and the varying grid power (P_g). In order to avoid the fast-chattering problem when it is close to zero, it should be slowed down. Moreover, the FCs and the ELs have relatively slow power dynamics, and fast-varying power references are not welcome for their operating lifetime. Therefore, a low-pass filter (LPF) with a slope limiter should be added

$$\textbf{Pow3c}: P_{H2\_ref} = \frac{1}{1+\tau s} P_{sto\_ref} \qquad (15)$$

where τ is the time constant of the LPF and should be set large enough by taking into account the power dynamics of the FCs and the ELs, as well as the size of the UCs. The UCs are not made for a long-term energy backup unit because they have limited energy storage capacities due to their low energy density. However, they have very fast power dynamics and can supply fast-varying powers and power peaks. They can be used as an auxiliary power system of the FCs and ELs to fill the power gaps during their transients

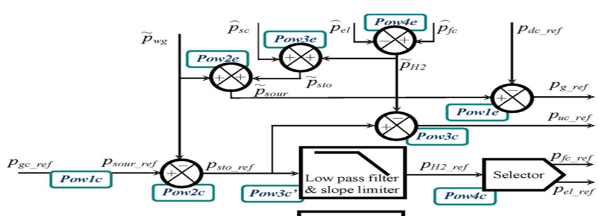

Fig.5. The block diagram of the grid-following strategy

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B. Source-Following Strategy

The total power (P_{sour}) from the energy storage and the WG can also be used to provide the necessary dc power (P_{dc}) for the dc-bus voltage regulation Fig. . In this case, the necessary total power reference (P_{sour_ref}) must be calculated by taking into account the required power for the dc-bus voltage regulation (P_{dc_ref}) and the measured grid power (P_g) as disturbance input by using the inverse equation of ***Pow*1**

$$\boldsymbol{Pow1c} : P_{sour\_ref}=P_{dc\_ref}+ P_g. \qquad (16)$$

Then, the total power reference of the storage systems is
deduced by taking into account the fluctuant wind power with the inverse equation of ***Pow*2** (Fig. 8)

$$\boldsymbol{Pow2c} : P_{sto\_ref} = P_{sour\_ref} - P_{wg}. \qquad (17)$$

This power reference is shared among the FCs, the ELs,
and the UCs in the same way as explained earlier (***Pow*2*c***,***Pow*3*c***, ***Pow*4*c***, and ***Pow*_3*c***).
In addition, now, the grid power reference (P_{g_ref}) is free to be used for the grid power control. The microgrid system operator can directly set the power requirements (P_{gc_ref} and q_{gc_ref}) for the grid connection system ($P_{g\_ref}= P_{gc\_ref}$). 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.

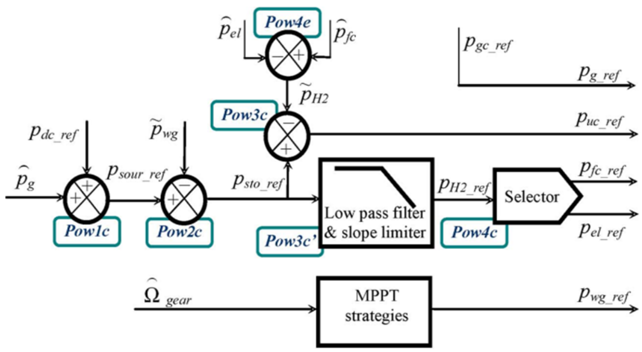

Fig.6. The block diagram of the source-following strategy

IV. SIMULATION RESULTS AND DISUSSIONS

A. Grid Following Strategy

In the grid-following strategy, the dc-bus voltage is well regulated around 400 V by the grid power conversion system Fig. The energy storage systems help the WG supply the microgrid power requirement ($P_{sour\_ref} = P_{gc\_ref}$= 600 W). Because of the different power losses in the filters and power converters, the grid active power is slightly less than the microgrid's requirement ($P_g < P_{gc\_ref}$= 600 W).

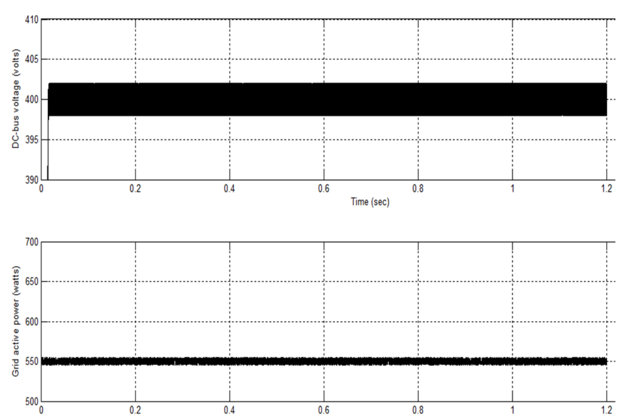

Fig.7. DC-bus voltage and Grid active power in Grid- following strategy

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B. Source-Following Strategy

In the grid-following strategy, the energy storage systems are controlled to supply or absorb the necessary powers in order to maintain the dc-bus voltage (around 400 V) against the fluctuant wind power Fig.7 The grid active power is also regulated and is equal to the microgrid's requirement, because the line-current control loop regulates directly the grid powers ($P_g = P_{gc\_ref}$= 600W). Therefore, the source-following strategy has better performances on the grid power regulation than the grid-following strategy, and it can provide ancillary services according to the microgrid's requirements.

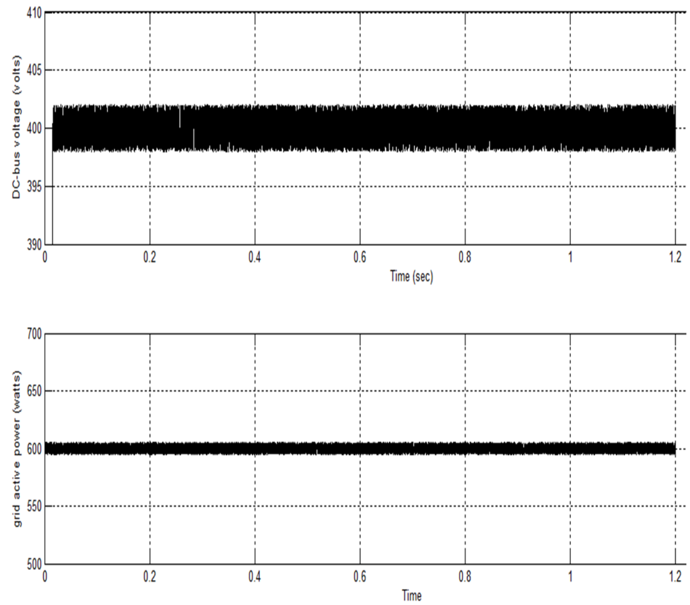

Fig.7. DC-bus voltage and Grid active power in source following strateg

V. 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) UCs as a fast-dynamic energy storage system; and 3) FCs with ELs and hydrogen tank as a long term energy storage system. Two power-balancing strategies have been presented and compared the grid-following strategy and the source following strategy. For both of them, the dc-bus voltage and the grid power can be well regulated. The simulation results have shown that the source-following strategy has better performance on the grid power regulation than the grid-following strategy.

REFERENCES

[1] Tao Zhou and Bruno François," Energy Management and Power Control of a Hybrid Active Wind Generator for Distributed Power Generation and Grid Integration" *IEEE Transactions On Industrial Electronics, Vol. 58, No. 1, January 2011*

[2] W. Li, G. Joos, and J. Belanger, "Real-time simulation of a wind turbine generator coupled with a battery super capacitor energy storage system," *IEEE Trans. Ind. Electron.*, vol. 57, no. 4, pp. 1137–1145, Apr. 2010.

[3] G. Delille and B. Francois, "A review of some technical and economic features of energy storage technologies for distribution systems integration," *Ecol. Eng. Environ. Prot.*, vol. 1, pp. 40–49, 2009.

[4] C. Abbey and G. Joos, "Super capacitor energy storage for wind energy applications," *IEEE Trans. Ind. Electron.*, vol. 43, no. 3, pp. 769–776, May 2007.

[5] O. C. Onar, M. Uzunoglu, and M. S. Alam, "Dynamic modeling design and simulation of a wind/fuel cell/ultra-capacitor-based hybrid power generation system," *Power Sources*, vol. 161, no. 1, pp. 707–722,Oct. 2006.