ENERGY MANAGEMENT AND POWER CONTROL OF A HYBRID SOLAR GENERATOR FOR DISTRIBUTED POWER GENERATION AND GRID INTEGRATION

Ms. K. Moulika, Mr. K. V. Kishore,
PG Scholar, Department of Electrical and Electronics Engineering, Narayana Engineering College, Nellore, Andhra Pradesh, India. Assistant Professor, Department of Electrical and Electronics Engineering, Narayana Engineering College, Nellore, Andhra Pradesh, India

ABSTRACT
The main goals of smart grids are to provide an interface for fair transaction of electricity and to optimize the power flow in electric power networks with less required extra energy storages, particularly in case of integration of renewable energy sources (e.g., photovoltaic and wind) and the plug-in Hybrid Electric Vehicles. Currently, the control principles in smart grids are mainly market-oriented. Wind energy is the world’s fastest growing energy source. 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. 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. The amount of power generated by wind energy depends on the speed of the wind. Because of the intermittent and fluctuating wind speed they are not suitable to micro grid applications unless proper power and energy management strategies are available. Hence a suitable method of giving stable active, reactive power is required. Hybrid power systems are proposed to overcome the problems with energy storage and power management strategies. Fuel cells (FCs) and electrolyzers (ELs) have high energy storage density. This makes them suitable for long term energy storage systems.

Index Terms—smart grids, renewable energy sources, photovoltaic and wind, hydrogen/super capacitor hybrid power system.

I. INTRODUCTION
The use of renewable energy sources either as distributed generators in public AC networks or as isolated generating units supplying is one of the new trends in power-electronic technology. Renewable energy generators equipped with electronic converters can be attractive for several reasons, such as environmental benefits, economic convenience, social development. The main environmental benefit obtained by using renewable sources instead of traditional sources, is the reduction in carbon emission. Many countries have adopted policies to promote renewable sources in order to respect the limits on carbon emissions imposed by international agreements. Moreover, renewable energies can be economically convenient in comparison with traditional sources, if the economic incentives for grid connected renewable sources are taken into account or in other particular situations to supply stand alone loads. In some cases, it can be more convenient to supply an isolated load with renewable local source instead of extending the public grid to the load or to supply it with diesel electric generators. In this case, in order to evaluate the economic benefits of renewable energy solution, it is necessary to take in account either the cost of the fuel and the cost of its transport to the load, that can be located in remote and hardly reachable areas.

The wind energy systems work like passive generators. Because of the discontinuous and fluctuant wind speed, they will not offer any ancillary services to the electrical system in a micro grid application. The 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, Fuel cells run on hydrogen, the simplest element and most plentiful gas in the universe. Hydrogen is a diatomic element, meaning that in its liquid and solid states, hydrogen naturally forms into pairs of atoms, which is why hydrogen is often referred to as “H2”. Hydrogen is the lightest element, yet it has the highest energy content per unit weight of all fuels. Hydrogen’s energy density is 52,000 Btu/lb., which is three times greater than that of gasoline. In nature, hydrogen is never found on its own; it is always combined into molecules with other elements, typically oxygen and carbon. Hydrogen can be extracted from virtually any hydrogen-containing compound, including both renewable and non-renewable resources. Regardless of the fuel source, fuel cells utilize hydrogen with little to no polluting emissions, making hydrogen the ultimate clean energy carrier. 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. Super capacitors store charge in a similar way to conventional capacitors, but the charge does not accumulate in two conductors, but in the interface between the surface of a conductor and an electrolytic solution. Super capacitor devices consist of two electrodes which allow a potential to be applied across the cell, therefore they present two double-layers, one at each electrode/electrolyte interface. An ion-permeable separator is placed between the electrodes in order to prevent electrical contact, but still allows ions from the electrolyte to pass through. The electrodes are made with high effective surface materials, such as porous carbon or carbon aero gel. Two principal technologies are used: aqueous (maximum voltage of
1.2 V and work voltage of 0.9 V) and organic (voltage near 3V but with a much higher series resistance). The principal super capacitor characteristic that makes it suitable for using in ESS, is the possibility of fast charge and discharge without lost of efficiency, for thousands of cycles. This is because they store electrical energy directly. Super capacitors can recharge in a very short time having a great facility to supply high and frequent power demand peaks.

The purpose of this paper is to present the proposed power strategies of Hybrid power system (HPS) in order to control the dc-bus voltage and to respect the grid according to the micro grid power requirements. These requirements are formulated as real- and reactive-power references, which are calculated by a centralized secondary control centre in order to coordinate power dispatch of several plants in a control area. This area corresponds to a micro grid and is limited due to the high level of reliability and speed required for communications and data transfer.

II. HPS AND CONTROL SYSTEM

A) Structure of HPS:
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.

![Fig.1 Wind Energy and Wind Power](image1)

![Fig.2. Structure of the studied wind/hydrogen/SC HPS](image2)

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 (Fig.3) The switching control unit (SCU) is designed for each power converter. In an SCU, the drivers with opt couplers generate the transistor’s ON/OFF signals from the ideal states of the switching function [0, 1], and the modulation technique (e.g., pulse width modulation) determines the switching functions from the modulation functions (m).

![Fig.3. Hierarchical control structure of the HPS.](image3)

The 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

The control schemes in the ACUs are shown in Fig. 4 with block diagrams.

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 N05. 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 N04. 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 N03. 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 N02.

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 \( i_{l\_ref} \) by the three-phase inverter N01, because the grid transformer is considered as an equivalent voltage source \( u_{grid} \).

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.

B) Power Control Level

The power exchanges with various sources are controlled only via the related five references 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. The sources’ powers are calculated by dividing the power reference with the measured current or the measured voltages the wind energy conversion system, a maximal-power-point-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. It receives the measured.

IV. POWER-BALANCING STRATEGIES

A. Grid-Following Strategy

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 the dc-bus voltage control is shown by a closed loop \( (p_{dc\_ref} \rightarrow p_{g\_ref} \rightarrow p_{g} \rightarrow p_{dc}) \). Thus, the required power for the dc-bus voltage regulation \( (p_{dc\_ref}) \) is used to estimate the grid power reference \( (p_{g\_ref}) \).

\[
P_{pow1e} : \quad p_{g\_ref} = p_{sour} - p_{dc\_ref}
\]

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

\[
P_{pow2e} : \quad \tilde{p}_{sour} = \tilde{p}_{wg} + \tilde{p}_{sto}
\]

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

\[
P_{pow3e} : \quad \tilde{p}_{sto} = \tilde{p}_{sc} + \tilde{p}_{h2}
\]

\[
P_{pow4e} : \quad \tilde{p}_{h2} = \tilde{p}_{fc} - \tilde{p}_{el}
\]

In steady state, the dc-bus voltage is regulated, and the averaged power exchange with the dc-bus capacitor can be considered as zero in.
V. PHOTOVOLTAIC SYSTEM WITH GRID

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices.

This photovoltaic system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The Block diagram of the PV system is shown in Fig.5. A. Photovoltaic cell A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

The equivalent circuit of PV cell is shown in the fig.6. In the above figure the PV cell is represented by a current source in parallel with diode. \( R_s \) and \( R_p \) represent series and parallel resistance respectively. The output current and voltage form PV cell are represented by \( I \) and \( V \).
VI. MATLAB MODELING AND SIMULATION RESULTS

Fig 7: Structure of the studied wind/Fuel cell/Electrolyser

Fig 8: Simulated output wave forms under Power of Wind generation, Power of Super capacitor, Power of Fuel Cell, Power of Electrolyser.

Fig 9: Active and reactive powers of grid Power of Super capacitor, Power of Fuel Cell, Power of Electrolyser.
Fig 10: Simulated output wave forms of Dc voltage and Power of the Grid

Fig 11: Simulated output wave forms Wind generation active and reactive powers

Fig 12: Matlab/simulink model of wind/Fuel cell/Electrolyser/Pv cell

Fig 14: Simulated output wave form of Power of PV cell

VII. Conclusion

In this paper, a dc-coupled HPS has been studied with the four 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 long term energy storage system 4) Photo Voltaic . 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 source following 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.

VIII. References