Dynamic Modeling and control of a Wind-Fuel Cell through Hybrid Energy System

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Abstract *–The main focus in present days is towards renewable energy sources due to the depletion of fossil fuels. Nuclear energy seems toehold the long term solution to this energy problem. However we know that nuclear energy has its own downfall in the production and the disposal of the radioactive waste produced. Wind energy and solar energy have gained considerable importance. The main problem associated with wind energy is that, due to unpredictable and varying wind speed, the system cannot be used to supply a constant load demand. This also leads to problems in attaching the wind generation system to a common bus. The same problem exists with solar power generation as well. To overcome this problem in this paper we have proposed a method by adding a fuel cell, ultra capacitor stack as an auxiliary energy source. This energy source is used to supply the power demand during lack of wind. Furthermore the system is designed in such a way that these fluctuations are tolerated and the system is relatively free of harmonics in by using a new topology.*

Keywords – fossil fuels, nuclear energy, wind energy, solar energy.

I. INTRODUCTION

The economy on depleting fossil fuels and the adverse environmental effects of conventional power generation systems created renewed interest in renewable energy sources toward building a sustainable energy economy in the next decade. Wind as a type of renewable energy has received considerable attention for producing electricity because of its cost competitiveness in comparison with other types of energy which are conventionally used for power generation and it is a free and abundant source of energy and hence, is attractive in terms of the cost and energy security. However, wind is in nature intermittent and its energy has a large range of variations. This causes significant technical challenges for a wind energy conversion system, particularly when compared with the conventional energy Sources which have a controllable output power.

The main drawback of identified in wind turbines is that naturally variable wind speed causes voltage and power fluctuation problems at the load side. This problem can be solved by using appropriate power converters and control strategies. Another significant problem is to store the energy generated by wind turbines for future use when no wind is available but the user demand exists [1]. This is achieved by storing the energy generated by the wind by passing it through an electrolyzer. This electrolyzer splits water into hydrogen and oxygen. The hydrogen produced is then stored inside hydrogen storage tanks which can be later used. The generated hydrogen is then used as input to the fuel cell. Fuel cells produce a DC voltage corresponding to the input hydrogen. Thus the fuel cell is used as an auxiliary energy source. The concept of storing the excess wind energy as hydrogen is new and it is significant because hydrogen storage has higher energy density when compared to the use of a conventional battery. By using an electrolyzer, hydrogen conversion allows both storage and transportation of large amounts of power at much higher energy densities [2]. FC power plants use oxygen and hydrogen to convert chemical energy into electrical energy. Among the various types of FC systems, proton exchange membrane (PEM) FC power plants have been found to be especially suitable for hybrid energy systems with higher power density and lower operating temperature. However, assisting an FC power plant with a parallel ultra-capacitor

(UC) bank makes economic sense when satisfying the peak power demands or transient events. Ultra-capacitors are electrical energy storage devices with extremely high capacitance values (a few Farads to several thousand Farads per cell) offering high energy densities when compared to conventional capacitors [3]. Without the UC bank, the FC system must supply all power demand thus increasing the size and cost of the FC power plant. This paper introduces a wind conversion system with integrated energy storage. The energy storage serves as an auxiliary source for the wind conversion system during dynamics resulted from the wind power fluctuations and/or load changes. A control strategy is developed that manages the flow of power among the wind-turbine generator, energy storage and the grid, so as the overall wind conversion system is turned into a dispatch able power source.

II. POWER CONDITIONING OF THE SYSTEM

Power conditioning forms a major aspect of this hybrid power generation system. Firstly the output power from the wind generator is rectified by using a double bridge thyristor controlled rectifier system [4]. The main advantage of using the double bridge rectification is that it reduces harmonics. This DC voltage is then fed to the electrolyzer and the hydrogen storage tank. The fuel cell utilizes hydrogen from this system and the amount of hydrogen used can be seen in the storage tank. The fuel cell outputs a DC voltage which is then fed to an IGBT controlled inverter [4]. This inverter inverts the DC voltage into an AC voltage which is then fed to the load.

A power control strategy is used here in such a way that for load demands greater than 32KW the fuel cell ultra capacitor stack is used to supply the demand along with the wind turbine and for values less than 32KW the wind supply alone supplies the system charging the Ultra capacitor and the fuel cell. This mechanism is implemented in MATLAB by using a compare to constant function to which the value of 32KW is given as input. A combination of switches and this block enables the implementation of the above logic.

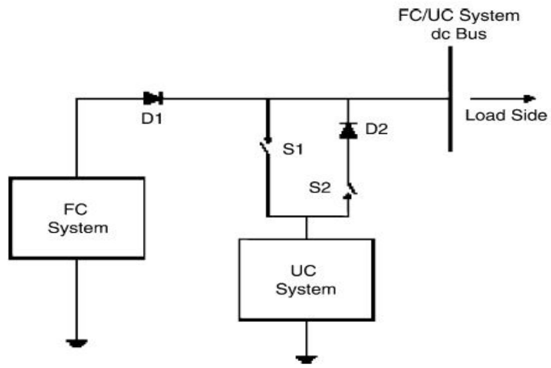


Fig.1 FC/UC hybrid system

III. ASYNCHRONOUS INDUCTION GENERATOR

The built-in SimPowerSystems block model of an asynchronous induction machine is used as a power generator driven by the wind turbine. The asynchronous induction generator model parameters used in this model are as follows:

*f*n nominal frequency
H combined rotor and load inertia constant
*I*s stator current
*n*s synchronous rotations per minute
p number of pole pairs
*P*e electrical power output
*P*m mechanical input power
R's combined rotor and stator resistance and inductance
L's referred to stator
*S*n apparent power output
*T*e electromagnetic torque
*T*m shaft mechanical torque
*V*s stator terminal voltage per phase
δ power angle
θm rotor angular position
ωm angular velocity of the rotor

We know that for an asynchronous machine the synchronous speed and the angular velocity of the rotor can be expressed as

$$n_s = \frac{60}{p} f_n.$$

$$\omega_m = \frac{2\pi}{60} n_s.$$

The mechanical torque which drives the rotor shaft of the generator yields the mechanical power output which is given by

$$P_{\rm m} = T_{\rm m}\omega_{\rm m}.$$

The electrical power output of the machine is given by

$$P_{\rm e} = 3\frac{E_{\rm s}V_{\rm s}}{\sqrt{R'^2_{\rm s} + (2\pi f L'_{\rm s})^2}}\sin\delta.$$

In this study, the rotor windings of the generator are short circuited and the rotor shaft is driven by the wind turbine which produces the mechanical torque according to the wind and generator speed values. The loads are connected to the electrical power output of the generator.

3. SYSTEM MODEL

The main components of the system are wind turbine, fuel cell stack, electrolyzer and controller. A standard classical method of representing the system by a set of differential equations and PID controller by a transfer function is used [5]. **Wind turbine** rotor diameter is 1.14 m. This self-regulating permanent magnet alternator based variable speed wind turbine produces 400 W at a wind speed of 12.5 m/s. Self-regulation (stall controlled) is achieved by the twisting of the blades. A wind

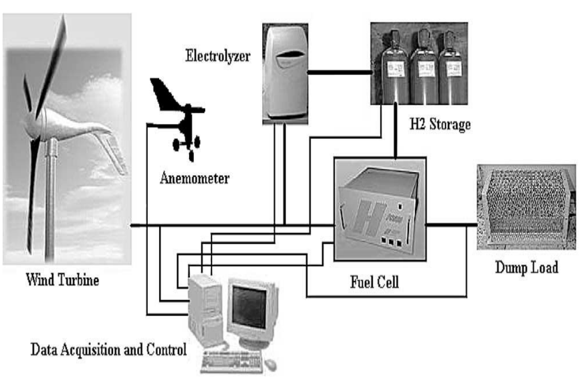


Fig. 2. Proposed wind fuel cell hybrid energy system.

turbine power curve and small wind turbine is capable of extracting maximum power until a wind speed of 40 mph. Above a wind speed of 40 mph (17.9 m/s) the wind turbine quickly enters stall mode by blades twisting avoiding any over speed. This small wind turbine is well suited for roof top installation. Power curve of this wind turbine is nonlinear. It is digitized and the resulting table is used for simulation. Dynamics of the wind turbine are added by considering the wind turbine response as a second order slightly under damped system [5]. This is true when we take a first order moment of inertia (*J*) and friction based dynamic model for the wind turbine rotor and a first order model for the permanent magnet generator. Using this simple approach wind turbine dynamics are modelled as [5].

Y(*s*) /*X*(*s*) _ 1/(*s*2 _ *s* _ 1) (1)

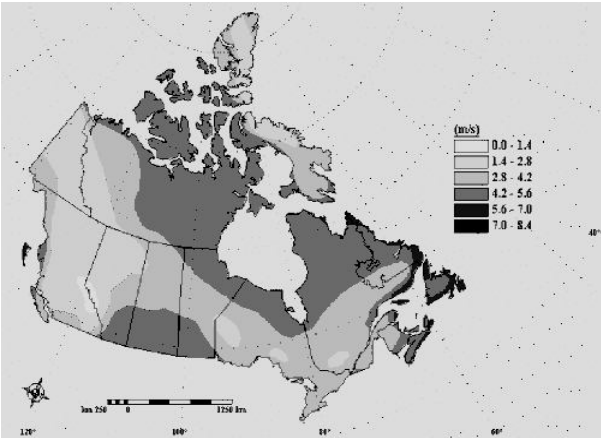
Where input is power obtained from the power curve for a known wind speed and output is actual power of the wind turbine. Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. The basic building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. A schematic representation of a fuel cell with the reactant/product gases and the ion conduction flow directions through the cell is a typical fuel cell, gaseous fuels are fed continuously to the anode (negative electrode) compartment and an oxidant (i.e. oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electric current. Fuel cells are classified by the type of electrolyte used in the cells and includes: (1) proton exchange membrane (polymer) electrolyte fuel cell (PEMPC); (2) alkaline fuel cell (AFC); (3) phosphoric acid fuel cell (PAFC); (4) molten carbonate fuel cell (MCPC); and (5) solid oxide fuel cell (SOFC). These fuel cells are listed in the order of approximate operating temperature, ranging from _80°C for PEMFC to 1000°C for SOFC. Fuel cells can operate on natural gas/propane using a reformer. PEMFC running on hydrogen for stationary and portable applications are commercially available from a number of sources [6]. A number Wind-fuel cell system analysis

Need for wind-fuel cell system:

- Canada has excellent wind energy potential
- Energy from the wind is dependant on wind
- Hybridization would minimize fluctuations
- Wind-fuel cell system is a suitable, clean and reliable solution

Simulation of a wind-fuel cell system:

- Modeling is essential for design, optimization and performance analysis
- Proposed scheme is modeled based on physical & empirical equations



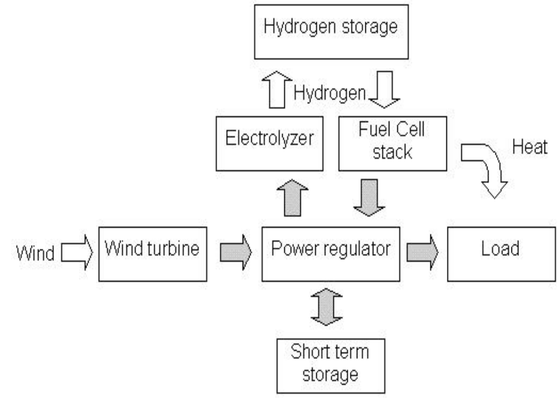


Fig. 1. Wind fuel cell hybrid energy system.

Basics:

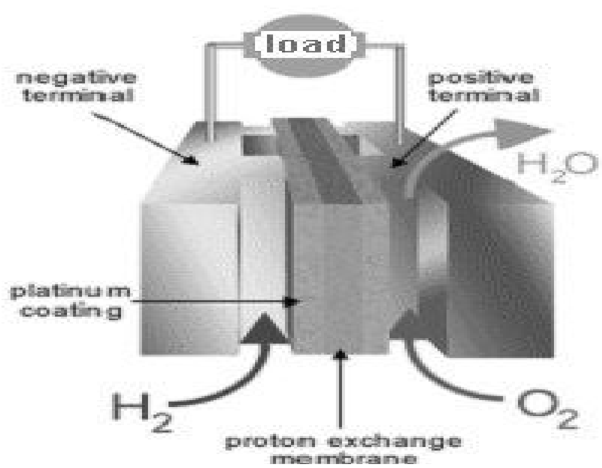
- A Fuel cell generates electricity by electrochemically reacting hydrogen (H2) and oxygen (O2) and producing water (H2O).

H2+O2 => H2O + Heat

- A cell contains an anode, cathode and electrolyte.
- Several cells are connected to form a stack to deliver sufficient power

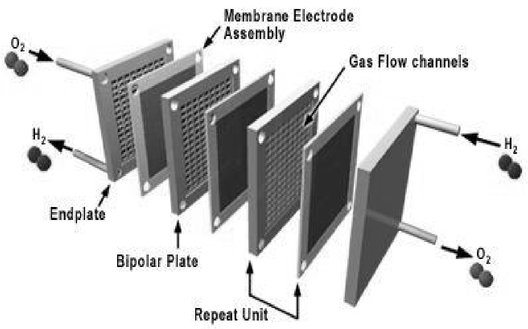
Fuel cells are characterized as:

- Very low emitting, Quiet, Highly scalable and Efficient
- Could be used in Transportation, Distributed & Utility generation and Portable systems



Layout of the scheme

- Main system specifications : 500watt, 120V, 60Hz
- Wind turbine produces electricity depending on availability of wind
- Excess power is used for hydrogen production by the electrolyzer
- Hydrogen is kept in the storage tank
- Any deficit in power demand is met by the fuel cell stack Sudden changes in the load demand is offset by the ultra-capacitor units
- The inverter converter 48V dc into 120V, 60Hz ac
- A controller controls power flow to and from the components



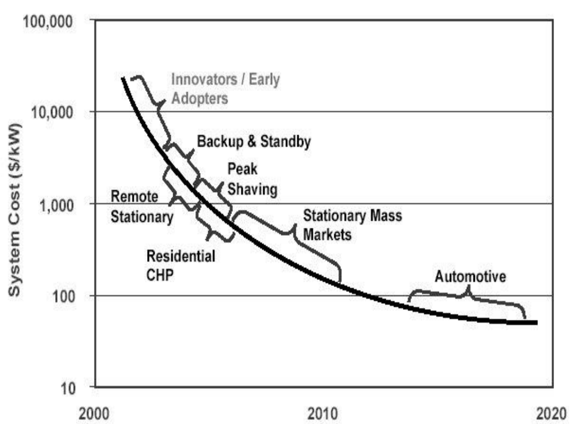
Fuel cell technology challenges and prospects

Challenges for Fuel cell technology:

- Fuel processor development
- Hydrogen storage development
- High performance material development
- Increasing Energy density
- Cost reduction

Prospects:

- Fuel cell technology is expected to revolutionize power generation scenario
- Worldwide R&D schemes would reduce its cost and increase performance, drastically



VI. CONCLUSION

In this paper a new method of combating the fluctuations of the wind speed from affecting the system is developed by using a combined hybrid system comprising of an electrolyzer, hydrogen storage model and a fuel cell ultra capacitor stack. second. Hybrid energy systems are best suited for isolated communities. It can be noted that as designed by the power controller the wind turbine supplied power to the system for values upto 32KW and for power over that value the combined system was used. This hybrid topology exhibits excellent performance under variable wind speed and load power requirements. The proposed system can be used for non-interconnected remote areas or isolated cogeneration power systems with nonideal wind speed characteristics.

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