A Comprehesnive Dynamic Modeling of Grid Connected Hybrid Renewable Power Generation and Storage System

Majid Nayeripour, Mohammad Hoseintabar

***Abstract*—In this paper, a comprehensive dynamic modeling and power management of hybrid power genaration including renewable power gearation and energy storage system in grid connected applications is presented. The studied system comprises Wind Turbine (WT), Fuel Cell (FC) as power generation systems and super capacitor as storage system. Due to unpredictable dynamic behyvior of Wind, the FC system is used to enhance the reliability of studied system. However, the FC system have slow dynamic. To solve this problem, super capacitor is used to supply load demand completely. The basic target of this system is that the hybrid system satisfies domestic load completely and the excessive power can be sent to grid system. The real datas of weather are used to be this research more applicable.**

***Index Terms*—grid connected power generation, hybrid power generation, renewable energy.**

I. Introduction

In recenet years, the consumtion of fuel and environmental pollution have been caused many important problems in the world. These important problems lead the goverments to change their policy. Due to these reasons, the governments try to replace convetional power generation system with the renewable energy power generation. The renewable energies are available easily and abundantly [1].

Among different renewable energies, WT and Photovoltaic (PV) systems are widely used in recent years. However, the unpredictable behavior of these energies makes the usage of these systems so hard especially in hybrid applications. To solve this problem, WT and PV systems are used as hybrid power generation beside the energy storage systems such as super capacitor and battery bank. In these cases, the storage system should supply and deliver demandeded power to improve power quality.

FCs power generation systems are the modern static devices that produce power from electrochemical process. The behavior of these systems is like a battery. Using FC system in hybrid power generation enhances the relaiability of hybrid power generation truly [2].

Different works have done to show the dynamic behavior and power management of hybrid power generation. Khan et. al in [3] proposed hybrid power generation of small wind and FC system in a stand alone application. In ref. [4], the ultra capacitor plays major role in the hybrid power generation. In ref. [5], dynamic modeling of a FC system with ultra-capacitor is presented. Power fluctuation suppression of stand-alone hybrid generation combining photovoltaic/ wind turbine and fuel cell systems is described in ref. [6]. M. nayeripour et. al proposed a new control strategy based on optimal usage of FC systems and also introduced a new structure of hybrid power generation in ref. [7] and ref. [8]. However in the pervious work, the authers don't investigate the effect of dynamic behvior of FC system in transiant event such as step load and vaiation of load demand in hybrid power generation in long duration of time.

In this paper, a new comperhensive dynamic modeling of hybrid power generation is proposed. The proposed system comprise of FC/WT and energy storage device. The real weather datas are used to investigate the whole system completely. The main goal of this paper is to show the dynamic behavior of FC system in transiant event. The propsed control strategy can easily protect FC system from internal damage due to lake of hydrogen in transient events such as step load.

This paper is organized as follow, after this section, system configuration is presented in Section 2. System components and their control strategy are explained in section 3 and section 4, respectively. Simulation result is presented in section 5. Finally, this paper is concluded in section 6.

II. System Configuration

Overall syetem configuration of proposed hybrid renewable power generation and storage system are shown in Fig.1. The studied system includes WT /FC as power generation part and also super capacitor is used as short term storage device. Each system is connected to the DC link with appropriate power electronics devices.The load demand data and the weather data (wind speed) are shown in Fig. 2 and Fig. 3 respectively. The datas are for whole day.

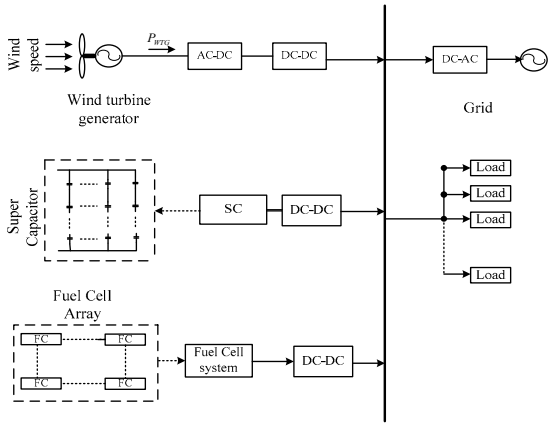

Fig. 1. System configuration of the proposed hybrid renewable energy/storage system

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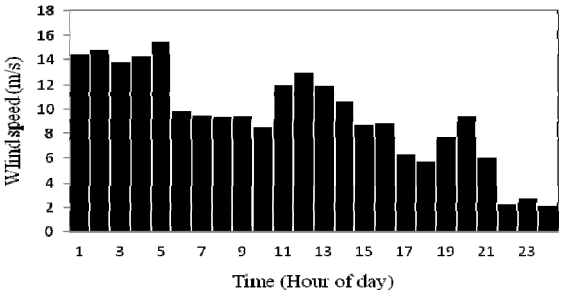

Fig.2. Real wind speed data used for proposed system simulation

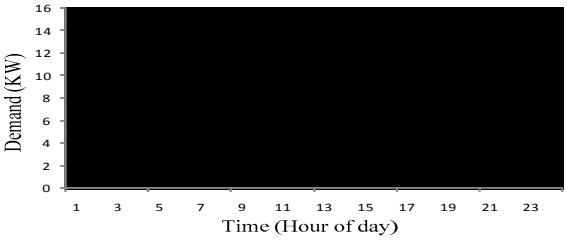

Fig.3. Load demand

III. System Componenet and Description

In this section, dynamic models and the charectristics of different systems that are used in this studied hybrid power generation systems are investigated. The models that are descibed in this section are wind energy conversion, super capacitor and FC power system.

A. Wind Energy Conversion System

The extracted power that is produced by WT is as follow:

$$P_{Wind} = \frac{1}{2}\rho A v^3 C_p(\lambda,\theta) \quad (1)$$

The produced power of WT is a function of the air density ρ in kilogram per cubic meter, swept area A of blades in squre meter, power coefficient or rotor efficiency C_p and wind speed v.

The maximum power coefficient of wind turbine (Cp) is obtained at a specific tip speed ratio of λ , which is a function of the aerodynamic design of the turbine.

The dynamic characteristic of Cp curves with pitch angle can be shown as a nonlinear function. The following function is used for definition of this nonlinear function. The value of this function parameters are listed in ref. [2]. Fig.4. demonstrates the *Cp* –λ characteristics of the Wind turbine generator at different pitch angles (θ).

$$C_P = C_1(C_2 - C_3\theta - C_4)\exp(-C_5) \quad (2)$$

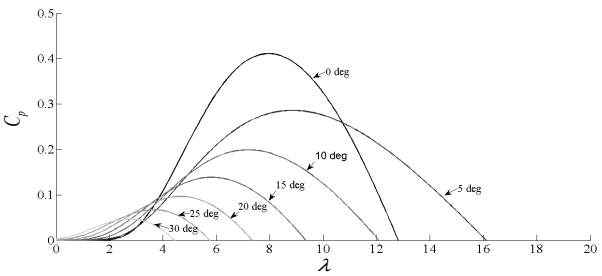

Fig.4. *Cp* –λ characteristics of the Wind turbine generator at different pitch angles (θ).

In this paper, WT system operates between cut-out speed and cut-in speed. When the speed of the wind is greater than cut-out speed (25 m/s), the system atumaticaly is taken out of operation for safety and the output power of WT will be constant at its maximum value in upper section of this rang by pitch angle control via reducing the Cp. Also, when wind speed is lower than the cut-in speed (4 m/s), the output power of the WTG will be zero. The wind system output power charectricstic is showen in Fig. 5.

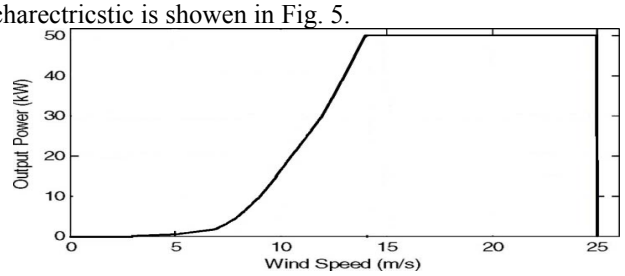

Fig.5. Wind turbine output power characteristic curve

B. FC Power Generation System

Fuel cell power generation system is used as relaible altrnative power generation. The power produced by wind power generation is unpredictable. To solve this problem differnet form of renewable power generation such as FC system are used as hybrid system to enhance the relaiabilty of whole system.

Among different types of FC systems, PEMFC has some advantages such as high power density, high efficiency and also have lower temperature. The PEMFC models have been preseneted in different based on relationship between output voltage and partial pressure of hydrogen, oxygen and water. Fig. 6 shows the chemical reaction of PEMFC system that occure inside the cell [9].

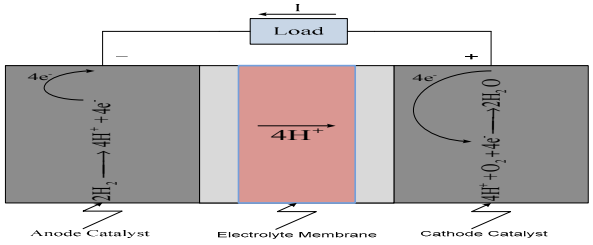

Fig.6. Schematic diagram of a PEMFC

However, FC system have different and effective problem such as slow dynamic and need hydrogen as fuel continuously.

In the prviouse works, the dynamic behavior of FC system is neglected and FC system is simulated without its slow dynamic. In this paper a new control startegy based on FC system protection is proposed. The proposed control strategy has two important advanteges. First, It can simulate the actual dynamic behavior of FC system. Second, this control strategy is simple and economical way for protection of FC system. This control startegy is based on coordination of FC system and the dynamic behvior of utilization factor. This control strategy can keep the utilization factor in its optimal value by synchronizing of between FC system and power electronic interfacing. The proposed control strategy is implemented in hybrid power management.

The dynamic behavior of fuel valve is simulated as first order lead-lag transfer function and is applied to the power electronic interfacing through reference power of FC system. With this control strategy, the hydrogen consumed by FC

stack is equel to the hydrogen that is injected by hydrogen fuel valve.

The overall control strategy that is used for FC system is shown in Fig.7.

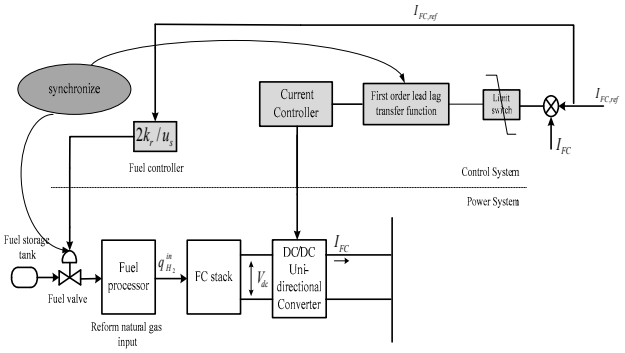

Fig.7. Overall control strategy used for FC system

IV. Power Management

Power mangement is an important issue in hybrid power generation system. In the power mangement of renewable hybrid power generation system, the power produced by WT system has priority to produce power. However, the power produced by WT systems and some of other renewable energy resources such as PV systems are not reliable. To solve this problem, these systems are combined with FC and super capacitor systems to satisfy the load demand completely and to enhance hybrid system reliability.

The FC system have slow dynamic. To solve this problem, the storage device such as battery and super capacitor is used. Among different storage devices, super capacitor has better and rapid dynamic respond against battery. The SC system captures and recaptures power in transiant events such as step load and help FC system to solve the dynamic of FC system truly. If the power of wind system is more than the load demand, the exessive power will be sent to the grid.

The overall control strategy and power management of the hybrid power generation system is shown in Fig. 8.

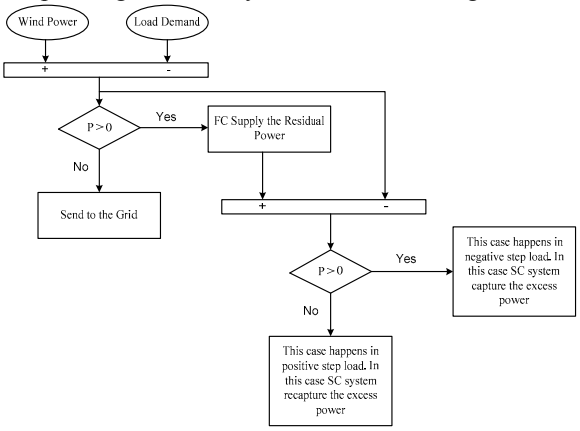

Fig.8. Overall control strategy and power management of the hybrid power generation system

V. Simulation Results

The proposed system is simulated with matlab simulink. The real weather datas for a day are used to show the behavior of the whole system exactly. The power of load demand that is used in this paper is shown in Fig.3.

The produced power of wind system based on wind speed that is expressed in Fig.2 is shown in Fig.9 (Zb=100Kw).

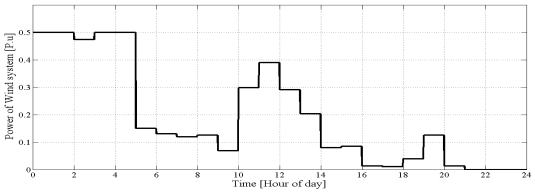

Fig.9. Wind turbine output power (Zb=100Kw)

The wind power has priority to satisfy load demand completely. In the proposed hybrid system, the FC system is used as back up system. FC system supplies the residual power completely. Fig.10. illustrates the FC system output power in pu.

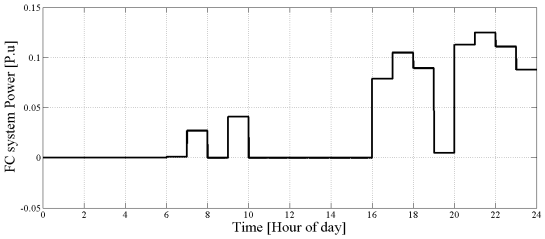

Fig.10. FC system output power (Zb=100Kw)

Due to slow dynamic in FC system actuator, the FC system can not change its power to desired value as fast as the load variation. In the proposed system, the dynamic respond of fuel valve is simulated as first lead-lag transfer function and this delay time is applied to the power reference to keep the utilization factor of FC system at its optimal value to improve FC system liftime. The behavior of the FC system in transiant events such as step load demand is shown in Fig.11 for a specified zoom.

To enhance the power quality of load demand, the SC system compensates the slow dynamic of the FC system. The produced power of SC system is expressed in Fig.12.

The behavior of the FC system in transient events such as step load demand is shown in Fig.13 for a specified zoom.

Fig 11 and Fig. 13 show that The FC and SC system complete each other. Finally, the delivered power to the grid is shown in Fig. 14.

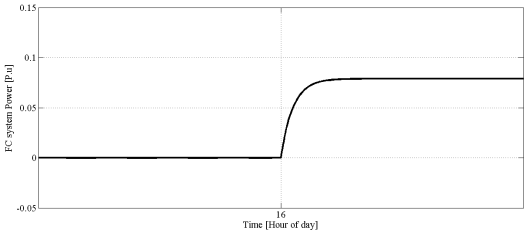

Fig.11.The FC system output power (at hour of 16)

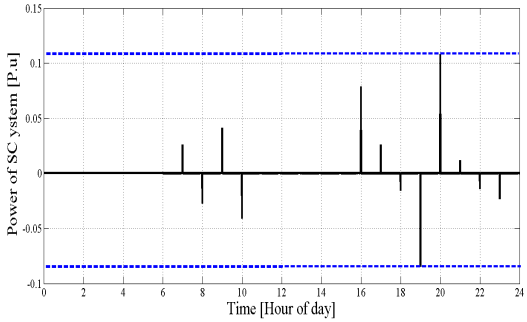

Fig.12. The produced power of SC system

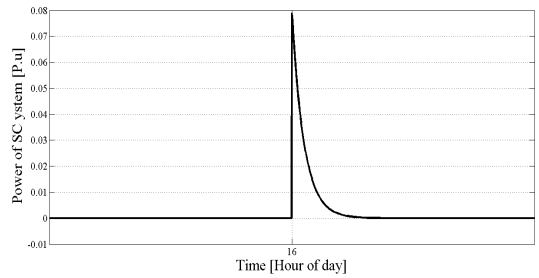

Fig.13. The SC system output power (at hour of 16)

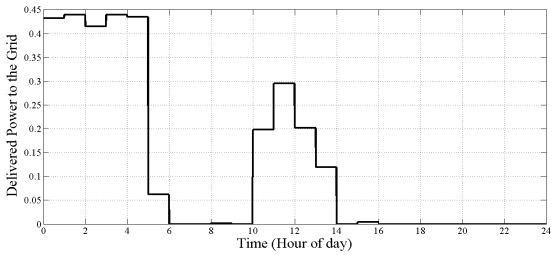

Fig.14. Delivered Power to the Grid

VI. Conclusion

In this paper a comperhesive analysis of hybrid power generation in grid connected system is investigated. In the proposed system a new control startegy base on optimal usage of FC system is proposed and is implemanted. This control startegy can prolong FC system liftime and can imropve its performance. Proposed system is simulated for a day and real weather datas. The simulation results show the validity of proposed power management and control startegy.

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