Demand Side Management of Variable Speed Wind Turbine Power Generation Systems

Mirza Abrar Baig, *Member IAENG*, Razali Jidin, Zaheeruddin

***Abstract*—Due to high cost of fossil fuel, increase in demand, and environmental issues, Renewable energy is becoming integral part of power generation systems. Among many renewable energy sources, Wind is easily available anywhere in the world. However, due to fluctuating nature of wind, electric power, acquired by wind, has variations in frequency and well as voltage. This paper presents Smart Building Power Control System (SBPCS) to control the variations in voltage and frequency and to manage the load when there is change in supply.**

***Index Terms*—Wind Turbine, demand side, power, smart building**

I. INTRODUCTION

THE utilization of wind energy has a very long tradition. Some historians suggest that wind turbines (windmills) were known over 3000 years ago [1]. Due to the ever-increasing economic viability of the technology and the relatively ubiquitous nature of the resource, wind turbines are also finding an increasingly broader application in the global energy production market [2]. Wind power has become one of the most attractive energy resources for electricity production as it is virtually pollution-free (if noise is not considered as pollution) [3].Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine [4].Today the wind powerplants of up to 5 MW unit capacities are operating simultaneously with electric power network [5]. This paper contains six sections. Section one is introduction. In section two types of wind turbines are discussed. In section three wind energy and types of generators used in wind turbines are discussed. In section four we discuss proposed SBPCS. In section five we have discussed conclusion and future work. In section six we presented simulated results of proposed controller. In section seven we discussed conclusion and future work.

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Section eight is Appendix A. We have analyzed historical data of Yanbu by using Homer Software. Results from the analysis are included in Appendix A. Section eight is references.

II. TYPES OF WIND TURBINES

There are two major design classes for wind turbines: Horizontal Wind Axis (HWAT) Turbines and Vertical Wind Axis Turbines (VWTA). HWAT design is the typical windmill or propeller design; VAWT is less familiar. The HWAT design can further be broken into upwind or downwind designs. In upwind designs, the propeller is on the windward side of the turbine. Most wind turbines are horizontal axis and upwind design.

For horizontal upwind turbine, the wind hits the turbine blade before it hits the tower. For horizontal downwind turbine, the wind hits the tower first. Most commonly used Wind Turbine Power System.

A. Fixed Speed Wind Turbines
B. Variable Speed Wind Turbine Power Systems

A. Fixed Speed Wind Turbine Systems (FSWTS)

A Fixed-speed wind turbine system uses an induction machine almost exclusively for converting the mechanic power extracted from wind into electric power. These types of systems have quality problems which are the influence on static voltage level and ondynamic voltage variations. The Magnetization of generator and connection of the capacitor also influence the voltage transients of the turbine [6].

B. Variable Speed Wind Turbine Systems (VSWTS)

The generator torque in a variable-speed system remains almost constant that in turn changes the turbine speed. The change in rotor speed absorbs the variations in incoming power. This results in fairly constant electric power, i.e. without any significant variations [7].

The variable-speed system requires power electronic controller (PEC) to operate with variable speed. The generator control system that can operate with variable speed, use induction and synchronous machines [8]. Examples of VSWTS are Induction machine and rotor resistance control, induction machine with rotor converter, Induction machine with squirrel cage rotor, systems with asynchronous machine. PEC controlled synchronous machine serves to damp mechanical oscillations. Reactive power controllability is a natural property of this system. A principal configuration of a variable-speed system with a synchronous machine is given in Fig 1.

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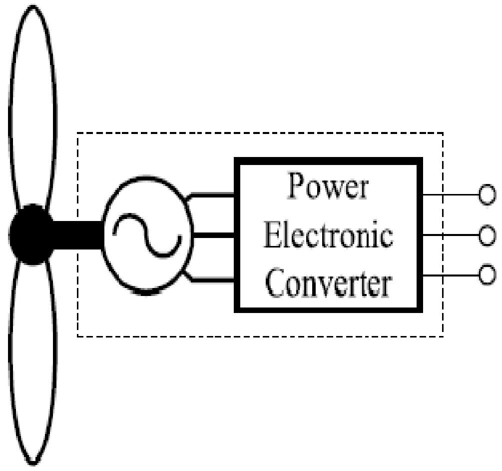

Fig. 1. Variable-speed system with synchronous machine [7]

A fixed-speed system incorporates a gearbox due to the rotational speed of the turbine which is always lower than the generator speed [9]. The advantage of the use of a synchronous machine is to avoid the gear box. In this way one will not to worry about the breakage of gear box which is normal routine with any turbine system. Use of a permanentmagnet synchronous machine has become more common and further simplifications to the system have been achieved [7].

III. WIND ENERGY AND TYPES OF GENERATORS

Wind energy is the kinetic energy of air that can be transformed into mechanical or electrical energy. Like solar energy, wind energy is also renewable energy but it has some advantages over solar energy, (i) The wind does not stop at night, (ii) Wind energy is efficiently converted into mechanical and electrical energies, and (iii) Ideal windy sites are plains, hilltops, wind gaps and offshore in close proximity to people.
The powerP_w of a wind-stream, crossing an area A with velocity v is given by

$$P_w = \frac{1}{2}\rho A v^3 \qquad (1)$$

Where ρ is the air density

The amount of aerodynamic torque $\tau_w$in Nrn is given by the ratio between the power extracted from the wind (P_w), in Watt, and the turbine rotor speed in rad/s, as follows

$$\tau_w = \frac{P_w}{\omega_w} \qquad (2)$$

The power coefficient C_p is defined as the ratio of mechanical power extracted from turbine (P_m) to the wind power (P_w), since $P_m < P_w$, so the power coefficient is always less than one.
The power coefficient also depends on tip speed ratio of the wind turbine and angle of blades [1].

$$C_p = \frac{P_m}{P_w}\ ; \quad C_p < 1 \qquad (3)$$

$$P_m = \frac{1}{2}\rho R^2 v^3 C_p \qquad (4)$$

In case of variable-speed turbine system the mechanical torque transmitted to the generator is the same as the aerodynamic torque because of absence of gearbox. It means in such a system the gearbox ratio is *1*. The power coefficient *Cp*reaches a maximum value equal to *Cp*= 0.593, which is Betz's limit. [10].

Permanent Magnet Synchronous Generator (PMSG) is one of the systems which efficiently convert wind energy into electrical and mechanical energies. The PMSG are stable and secure during normal operation and they do not need an additional DC supply for the excitation circuit (winding) [11].

IV. SMART BUILDING POWER CONTROL SYSTEM(SBPCS)

The proposed SBPCS block diagram is shown in fig 2. It is assumed thatthe regulated power, generated by VSWGS, is fed to power control system. When there are fluctuations in generated power, either due to wind condition, or by variable load, the power controller is activated and brings this power variation to the acceptable range. The proposed power controller is shown in fig 2.

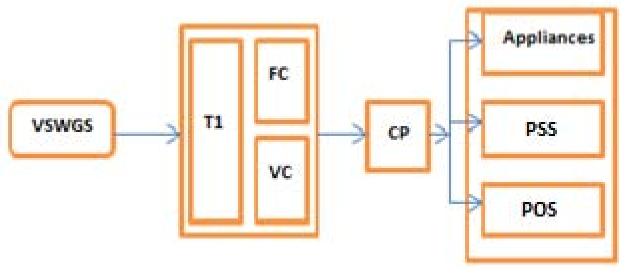

Fig. 2. Smart Building Power Control System Block Diagram

The SBPCS consists of following sections:

A. Step-Down Transformer (T_1)
B. Frequency Controller (FC)
C. Voltage Controller (VC)
D. Control Panel (CP)
E. The Power Storage System (PSS)
F. Power Overflow (POS)

A. Step-Down Transformer (T_1)

It steps down the voltage to 22 volts. Now this low voltage is used to sense the signal frequency and voltage by FC and VC.

B. Frequency Controller (FC)

It consists of frequency counter and a PID controller. The output of frequency counter is subtracted by a reference frequency signal. The resultant signal is fed to PID controller. If the signal frequency deviates from the acceptable range (60Hz +- 5%),the controller generates the control signal which is fed to the Control Panel (CP). The block diagram of PID controller is shown in fig 3.

C. Voltage Controller (VC)

It consists of a PID controller. If the supplied voltage is not within the acceptable range (220V +- 5%), it sends the control signal to CP.

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D. The Control Panel (CP)

Based on the output of power controller (VC and FC), manages the appliances/PSS. If available power is less than the rated power, it has two options. If PSS is fully charged, it uses the required power from it and fed it to main power panel so all appliances run smoothly. If PSS is not charged, it turns certain appliance(s) off to achieve the balance between supply and load. If it is above than rated power, it switches has two options as well. If all appliances are switchedON, and supplied power is above the rated range, it stores the power by using Power Storage System (PSS). If PSS is fully charged, and not all appliances are switched ON, it switches them ON.

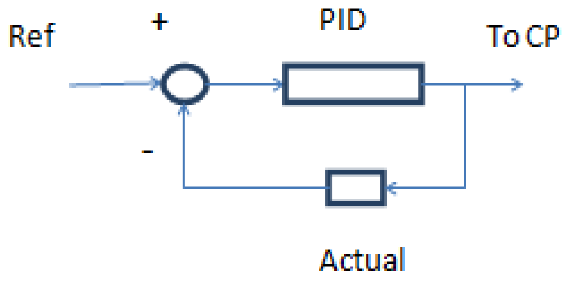

Fig. 3. Block diagram of PID controller

E. The Power Storage System (PSS)

It consists of charger and bank of batteries. It activates by CP. If all appliances switched ON, and there is excess power, it switches ON and power is stored in bank of batteries. If there is deficiency of power, the stored power is utilized by CP whenever and wherever is needed.

F. The Power Overflow System (POS)

If there is excess power in the system, it can be fed to power grid for commercial purpose.

V. SIMMULATED RESULTS

The PID controller's simulation procedure is adopted, using CSharp. Results are show in fig 4. It shows the VC controls the grid voltage and brings it to the desired level. The data is recorded for each minute for 1600 minutes. If the voltage at any moment is less than a desire value the voltage controller compensate it. The horizontal line shows the uniform voltage supplied to the appliances.

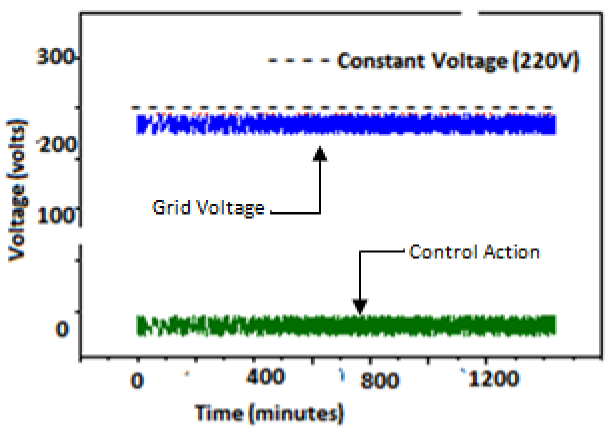

Fig. 4. The simulated results of the Voltage controller (For 1600 minutes)

The fig 5 shows the simulated results of FC. The data is recorded for each minute for 1600 minutes. If the frequency at any moment is less than a desire value the frequency controller (FC) compensate it. The horizontal line shows the uniform frequency fed to the appliances.

VI. CONCLUSION AND FUTURE WORK

In this paper we have successfully demonstrated the proposed SBPCS by simulated results. FC controller kept the signal frequency within the required range. Also VC kept the voltage within the required range. We have analyzed data of Yanbu Saudi Arabia, where two of the authors reside. For the analysis, Homer software is used. Wind and solar energy data of Yanbu were analyzed. Results are shown in Appendix A. From results shown in Table 1, we can conclude that average wind of Yanbu has average wind speed 3.7 m/s which lie in moderate range and enough to setup an isolated hybrid wind farm. Also from Table 2, we can conclude that the average daily radiation of Yanbu is 5.978 KWh/m^2 /day, with the average cleanness index 0.653.Hence in future we would study the feasibility to setup an isolated hybrid wind turbine power generation system with PV/diesel/battery system at Yanbu, Saudi Arabia.

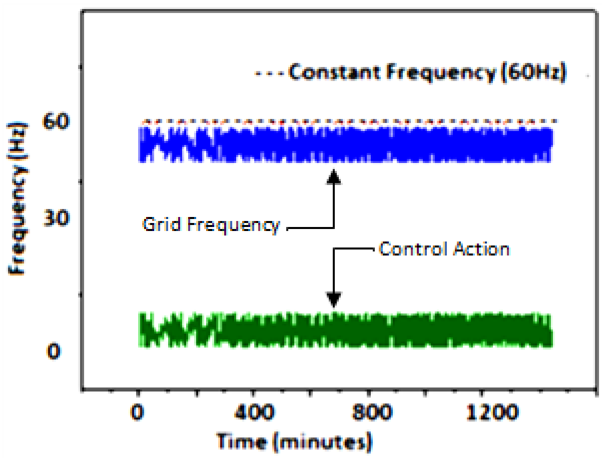

Fig. 5. The simulated results of frequency controller (For 1600 minutes)

APPENDIX A

Table 1: Local monthly wind data of year 2011 of Yanbu Saudi Arabia

Month	Wind Speed (m/s)
Jan	3.2
Feb	3.5
Mar	3.0
Apr	3.7
May	4.1
Jun	4.5
Jul	4.0
Aug	4.1
Sep	3.7
Oct	3.2
Nov	3.0
Dec	3.2
Average	3.7

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Table 2: Daily Radiation (KWh/m^2/day), year 2011 of Yanbu, Saudi Arabia

Month	**Clearance Index**	**Daily Radiation (KWh/m^2/d)**
Jan	0.652	4.451
Feb	0.645	5.116
Mar	0.623	6.256
Apr	0.662	6.899
May	0.649	7.164
Jun	0.665	7.495
Jul	0.647	7.169
Aug	0.629	6.666
Sep	0.649	6.265
Oct	0.660	5.479
Nov	0.649	4.578
Dec	0.649	4.156
Average	0.653	5.978

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