

# Participation of Energy Capacitor System in Hydrogen Production, Voltage and Frequency Control in Wind Generation.

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## ABSTRACT

This paper presents the use of an energy capacitor system (ECS) connected to a wind farm with an electrolyzer system to produce hydrogen gas, and also to achieve voltage and frequency control of the network. Simulations were run in PSCAD/EMTDC. The simulation results display the effect the energy capacitor system has in the smoothing of the output power of the wind farm, through the provision of active and reactive power from its electronic voltage source converter unit to the grid network.

(Keywords: ECS, wind energy, induction generator, hydrogen, electrolyzer)

## INTRODUCTION

As result of environmental concerns, the penetration of renewable power on power systems is increasing and thus the impact of conventional electrical generation on environment is being minimized. This development of electrical generation from renewable sources is due to the absence of harmful emissions on the environment and infinite availability of the energy used to be converted into electrical energy.

Wind energy is one way of electrical generation from renewable sources that uses wind turbines to convert the energy contained in flowing air into electrical energy. Wind power is the world's fastest growing energy source with a average growth over the past 5 years of 26% and foreseeable penetration 12% of global electricity demand by 2020 [1]. This important growth has been achieved by concentrating a large number of wind turbines in wind farms for a better exploitation of regions with good wind resources.

As a result of increasing wind farms penetration on power systems, the wind farms begin to

influence power system and the power system operators are concerned about the behavior of power systems with wind farms. This justifies the need for development of adequate wind farms models for representing the response of wind farm, evaluating their influence and thus improving the planning and exploitation of electrical network.

One of the most used wind farm concepts in power systems is based on fixed speed wind turbines (FSWT) with directly grid coupled squirrel cage induction generator connected to the wind turbine rotor through gearbox. This generator presents very small rotational speed variations because of the only speed variations that can occur are changes in the rotor slip, and therefore these wind turbines are considered to operate at fixed speed. A squirrel cage induction generator consumes reactive power, and therefore compensating capacitors are added to generate the induction generator magnetizing current, thus improving the power factor.

Wind farms with FSWT are composed of a large number of wind turbines with directly coupled induction generator and compensating capacitors, operating on an internal electrical network of lines and transformers to connect the wind farm to the grid. Energy capacitor system (ECS) composed of power electronic devices and electric double layer capacitor (EDLC) is used in power system applications [2]. This system has a feature of "clean energy" from an environmental viewpoint compared to batteries, as it does not contain heavy metals or toxic materials like Ni, Cd, Pb.

Over-charging and over-discharging in EDLC do not have a negative effect on its lifetime, though they have in the case of batteries. EDLC can be cycled millions of time, i.e., it has a virtually unlimited cycle life. Its standby loss is very low within the range of 0.2% of its power rating. As it has both real and reactive power control abilities,

ECS can be applied to load leveling, peak saving, sub-synchronous oscillations, transient and dynamic stability enhancement of power system. Moreover, it can also be applied for output power smoothing of and terminal voltage regulation of both fixed and variable speed wind generators. Hydrogen is widely seen as a possible fuel for transport, if certain technological barriers can be overcome economically. It may also be used in conventional internal combustion engines, or in fuel cells which convert chemical energy directly to electricity without the normal combustion process.

The commercial production of hydrogen requires either reforming natural gas (methane) with steam, or the electrolysis of water. The former process has carbon dioxide as a by-product, which exacerbates (or at least does not improve) green house gas emissions relative to present emission levels technology.

With intermittent renewable such as solar and wind, matching output to grid demand is very difficult, and beyond about 20% of the total supply, apparently impossible [3]. But if these sources are used for electricity to make hydrogen, then they can be utilized fully whenever they are available, opportunistically. Broadly speaking it does not matter when they are available, the hydrogen is simply stored and used as required.

Frequency control is essential for a secure and stable operation of any power system. Nowadays, power systems are facing wind penetration increase that may lead to difficulties in frequency control. It is recognized that the presence of a large wind power penetration (either as embedded generation or in large wind farms) may lead to a reduction of power system frequency regulation capabilities, namely, when wind generation replaces conventional synchronous units that supply the major portion of the active power consumed by the grid and are responsible for reestablishing the overall system frequency [4].

In this study, ECS is proposed for the control of the system frequency and terminal voltage. Hydrogen gas could also be produced with the help of an electrolyzer connected to the system. Simulations were run in PSCAD/EMTDC (Power System Computer Aided Design/Electromagnetic Transient including DC).

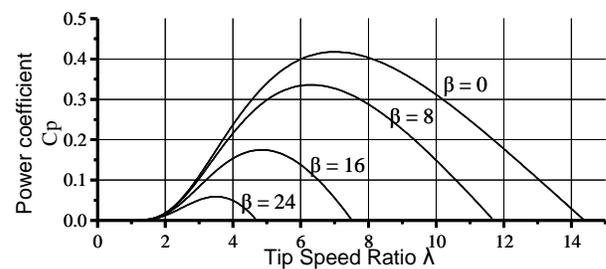
## TURBINE MODELING AND MODEL SYSTEM

The mathematical relation for the mechanical power extracted from the wind can be expressed as follows [5, 6, and 7]:

$$P_w = 0.5 \rho \pi R^2 V_w^3 C_p(\lambda, \beta) \quad (1)$$

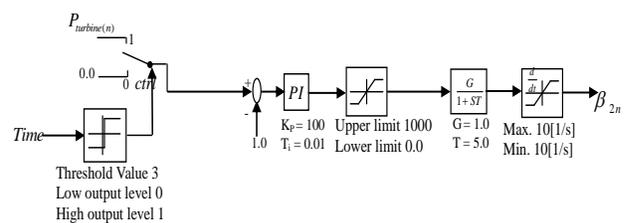
where,  $P_w$  is the extracted power from the wind,  $\rho$  is the air density [ $\text{kg/m}^3$ ],  $R$  is the blade radius [m],  $V_w$  is the wind speed [m/s] and  $C_p$  is the power coefficient which is a function of both tip speed ratio,  $\lambda$ , and the blade pitch angle,  $\beta$  [deg].

The wind turbine characteristic for this study is shown in Figure 1.



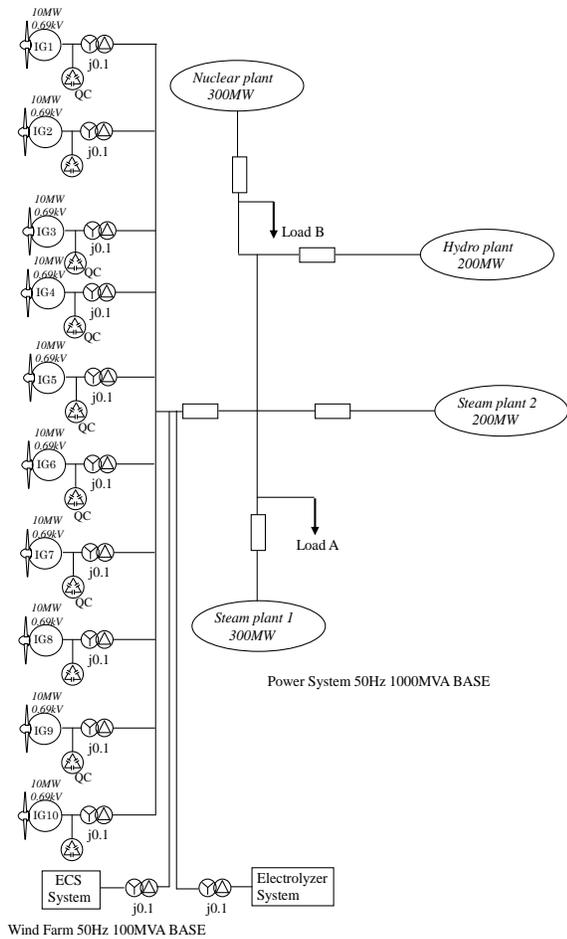
**Figure 1:**  $C_p$ -  $\lambda$  Curves for Different Pitch Angles (for FSWT).

The pitch controller of the induction generator helps in reducing the speed of the wind turbine, during high wind speed to the rated speed of the turbine. Figure 2 shows the control block of the pitch controller used.

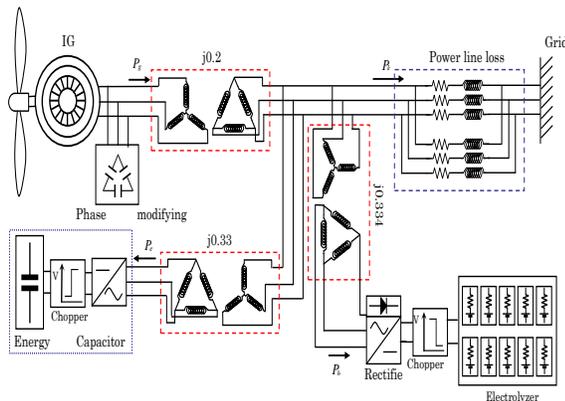


**Figure 2:** Induction Generator Pitch Angle Controller.

The model system used for this study is shown in Figure 3, where the wind farm is integrated to an existing power system. The aggregated simulation model of the wind farm with detailed connection of the ECS and the electrolyzer is shown in Figure 4.



**Figure 3: Model System of Wind Farm Connected to the Power System.**



**Figure 4: Aggregated Simulation Model of Wind Turbine, ECS and Electrolyzer.**

## PRODUCTION OF HYDROGEN

Improvements to the efficiency of hydrogen production on a small scale using electrolysis would allow the cost-competitive production of hydrogen at retail sites, greatly facilitating the introduction of hydrogen powered vehicles. In addition, the currently available commercial methods for storing hydrogen (compressed gas or cryogenic liquid) do not provide sufficient on-board capacity to provide vehicles with the range demanded by consumers, therefore research and development on solid-state hydrogen storage materials is required.

Fuel cells remain too costly, except for niche application, and improvement to stack lifetimes are required in order for fuel cells to compete with the well developed incumbent technologies for power generation and automobile propulsion.

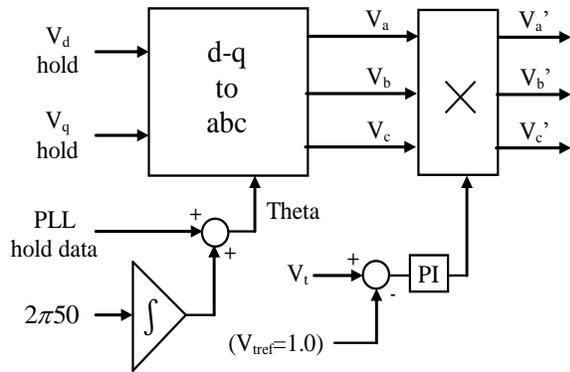
Figure 4 displays the simulation set-up for hydrogen production using a fixed speed wind turbine (Induction Generator) and Energy Capacitor System (ECS), which is used for the smoothening of the output power fluctuation of the fixed-speed wind turbine output due to wind fluctuations.

The control scheme of the ECS is based on a sinusoidal pulse width modulation (PWM) voltage source converter and dc-dc buck/boost converter using insulated gate bipolar transistor (IGBT) [8,13]. The energy capacitor system consists of power electronic devices and electric double layer capacitor (EDLC) as shown in Figure 4.

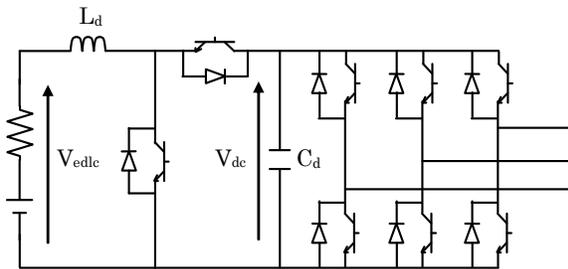
Also, a capacitor bank is connected at the terminal of the induction generator for phase modifying and reactive power compensation. But a more constant terminal voltage is maintained with the help of the energy capacitor system during wind speed variation, since it can provide reactive power through its converter to the grid system. The control structure of the energy capacitor system is shown in Figure 5.

From Faraday law of electrolysis, it is possible to generate hydrogen gas by using electrolyzer, thus the amount of produced hydrogen gas depends on only the electrolyzer current, by simulating the hydrogen generator with the electrolyzer and the power electronic devices that will provide constant current to the electrolyzer [9].

Figure 6 below shows the schematic diagram of the hydrogen generator.



**Figure 5:** Control Structure of the Energy Capacitor System.



**Figure 6:** Hydrogen Generator Model.

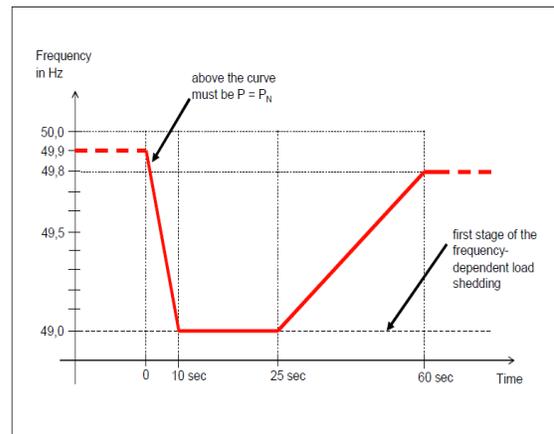
## FREQUENCY CONTROL

In accordance with the Electricity Supply Regulations 1989 and hence the National Grid Company's (NGC) Transmission License, the frequency delivered to the consumer must not vary from the declared values by more than  $\pm 1\%$  [10]. The system frequency is controlled by balancing the generation of power against the load demand on a second-by-second basis. Under the Grid Code, all larger generators connected to the network must have the technical capacity to contribute to frequency control. These requirements are summarized in Figures 7-9, based on the Germany E.ON Netz [11].

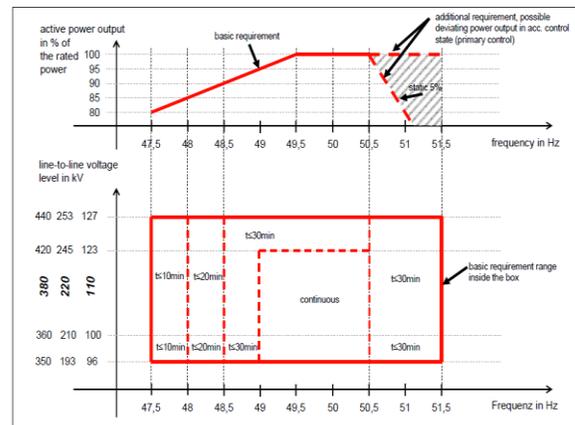
In order to meet these statutory requirements, the system frequency of the network under normal conditions is maintained at 50Hz within operational limits of  $\pm 0.2$  Hz. This is achieved by

the use of the energy capacitor system in smoothing the output of the wind turbine generators while operating the synchronous generators on a governor droop, normally around 4%. However, if there is a sudden change in generation or load, the system frequency is allowed to deviate by up to  $\pm 0.5$  Hz.

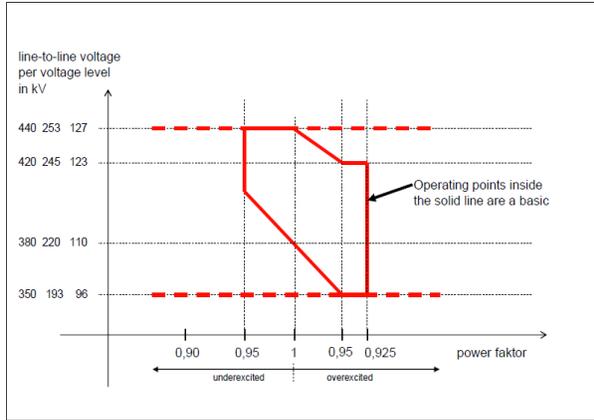
In the event of frequency drops above the thick line in Figure 7, the active power output must not be reduced even if the generating plant is being operated at rated power.



**Figure 7:** Frequency Envelope for Frequency Drops in which there may be No Limitation of the Active Power Output as set by E.ON Netz.



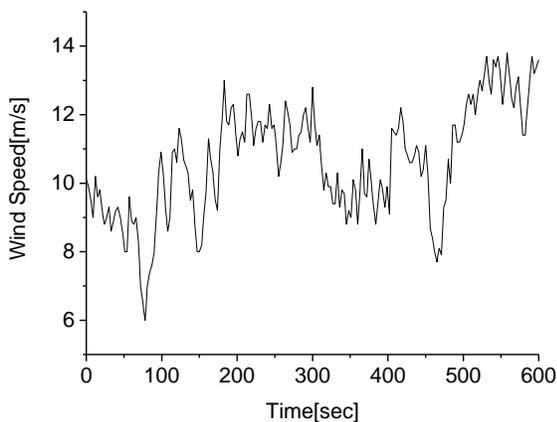
**Figure 8:** Requirements Placed on the Output Power of a Generating Plant to the Grid for Certain Periods as Function of Grid Frequency and Grid Voltage as set by E.ON Netz.



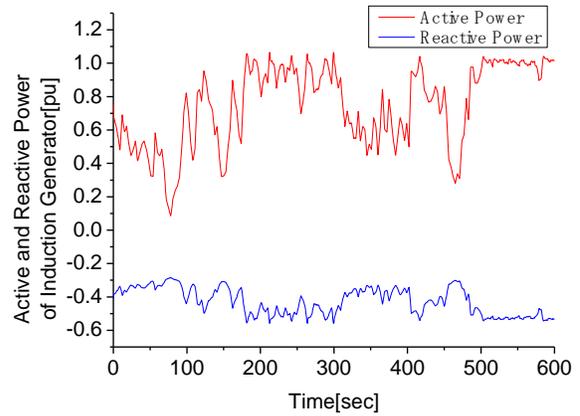
**Figure 9:** Requirements Placed on the Reactive Power Provision of a Generating Plant at Frequencies between 49.5 and 50.5 Hz and without limiting the Active Power as set by E.ON Netz.

**SIMULATION RESULTS**

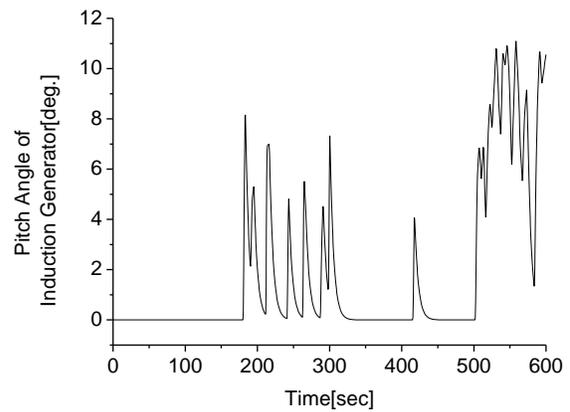
Simulations were run in power systems computer aided design/electromagnetic transient including DC (PSCAD/EMTDC) [12], for 600sec with natural wind speed data obtained from Hokkaido Island, Japan. The capacities of the energy capacitor system and hydrogen generator are 60MW and 10MW, respectively. Some of the responses of the model system are shown as follows:



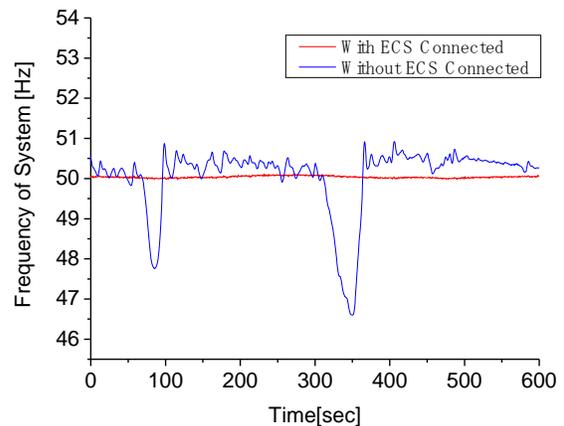
**Figure 10:** Natural Wind Speed Data.



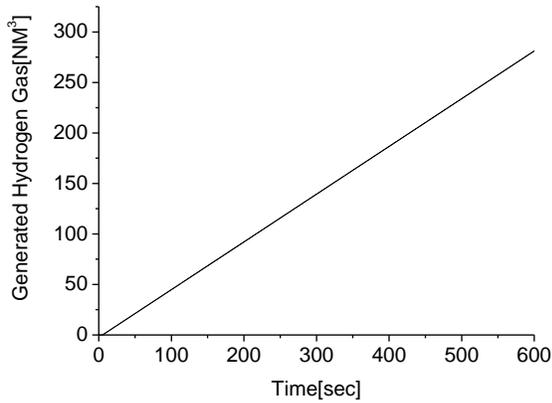
**Figure 11:** Active and Reactive Power of Induction Generator.



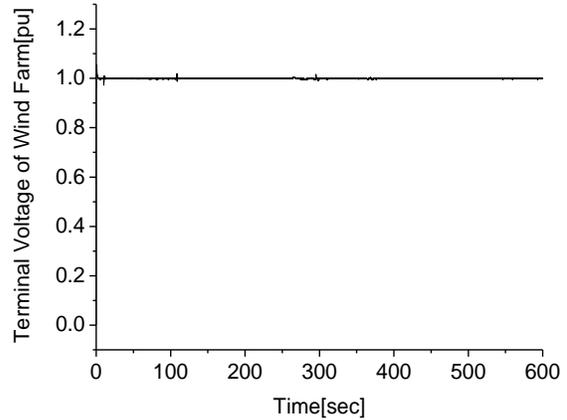
**Figure 12:** Pitch Angle of Induction Generator.



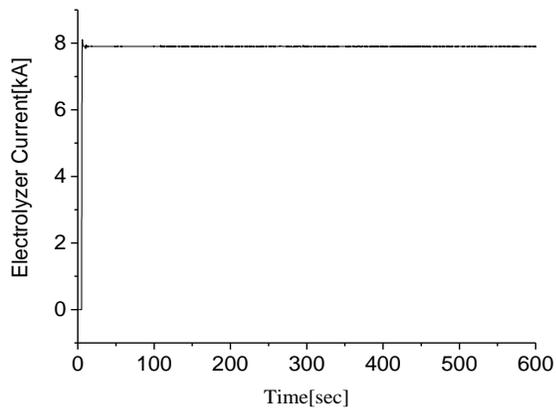
**Figure 13:** System Frequency.



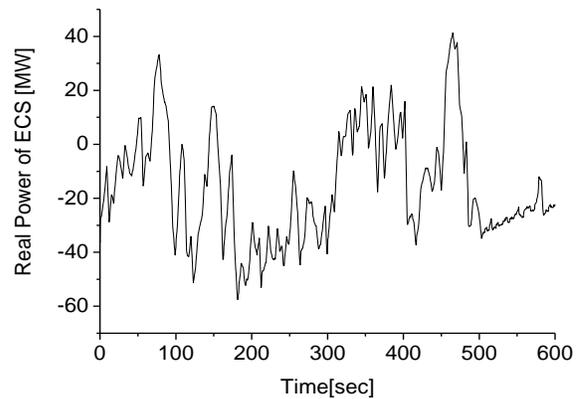
**Figure 14:** Hydrogen Gas Produced.



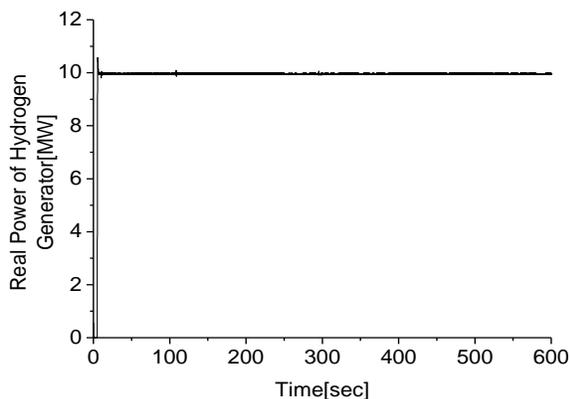
**Figure 17:** Terminal Voltage of Wind Farm.



**Figure 15:** Electrolyzer Current.



**Figure 18:** Real Power of ECS.



**Figure 16:** Real Power of Hydrogen Generator.

Figure 10 shows the natural wind speed data that is used for the study while Figure 11 shows the active and reactive powers of induction generator. The negative sign of the reactive power indicates reactive power is being absorbed as the wind speed varies. Figure 12 shows the response of the pitch angle of the induction generator, where the pitch angle controller in Figure 2, does not work until the active power of the induction generator exceeds 1.0pu in Figure 11.

From the results, it is seen that the frequency of the system could be maintained within the acceptable limit required by the grid code by the use of the ECS unit in Figure 13. Figures 14 to 16 show the generated hydrogen gas, electrolyzer current and real power of hydrogen generator. Also, the terminal voltage of the wind farm is maintained at 1.0pu Figure 17, despite the wind generation fluctuations, because of the reactive

power provided by the energy capacitor system to the grid. The real power of the ECS as shown in Figure 18 indicates that it varies as the wind speed data varies.

## CONCLUSION

The use of an energy capacitor system for application of hydrogen production, frequency and terminal voltage control has been carried out by simulations in PSCAD/EMTDC. The configuration of the hydrogen simulation model system above provide prospects for addition of hydrogen to conventional renewable power generation, which offers numerous advantages over the stand-alone systems. Elimination of redundant systems, enhanced efficiency, improved performance capability, and opportunities to provide optimized application specific design are just a few of the possibilities. Future in-depth analyses and systems integration studies will prove invaluable in determining the specific configuration and applications providing the lowest cost of energy.

Also, wind energy system that includes an integrated hydrogen system provides grid integration benefits. By including components whose energy consumption or production can be controlled, dispatch ability is added to the wind energy power plant system. This dispatch ability can be used to provide power at peak times of the day or year or to provide other ancillary services to the grid. In addition, it is to reduce transmission line capacity from the wind plant by using the hydrogen system to “clip the power peaks” of wind output. In this way, the grid capacity factor would be increased. With regeneration or batteries added, capacity factor would be increased even more.

The model system above provides prospects for adding hydrogen components to wind energy plant and thus increase the number of available options for site-specific optimization. For example, one might choose to provide more electricity and less hydrogen if the winds are steady and grid needs are high. One might also choose to produce more hydrogen and less electricity in locations with strong winds but small electrical loads. Even the type of grid available could influence the system optimization. Weak grids might need more hydrogen-base regeneration or more battery power when compared to stronger grids so that the wind plant

could be dispatched when necessary to support the weaker grid.

Under high penetration of wind power it will be required to model large power systems with many wind farms to investigate the effect of inertia and frequency response of wind farms over the power system frequency variations. This requires a simplified model of wind turbines where a wind farm can be modeled by a number of coherent machines. This paper presents the provision of frequency control using a single wind turbine generating unit. The frequency control in the large power systems that involves the co-coordinated actions of multiple generating units was achieved by the use of ECS control strategy.

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## SUGGESTED CITATION

Okedu, K.E. 2011. "Participation of Energy Capacitor System in Hydrogen Production, Voltage, and Frequency Control in Wind Generation". *Pacific Journal of Science and Technology*. 12(1): 605-612.

