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Cutting off the oscilation peak of Power Output of SCIG Wind Turbine

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***Abstract*— This research is to suggest a scheme applying to a SCIG wind turbine such that the peak of output power variation of the wind turbine can be cut off. This scheme is developed by utilizing an energy storage system to produce hydrogen gas. Here, we must determine the reference active power which the hydrogen-based energy storage system should be withdrawn to smooth the actual output power of the SCIG wind turbine. To evaluate the proposed method, a 1.5MW-wind turbines is employed to simulate in MATLAB/Simulink environment. The simulation results indicated that with the recommended scheme, we can cut off significantly in the peak of output power variation of the wind turbine. Therefore, the proposed method is completely able to be applied in to the SCIG wind turbine to mitigate its negative impact on the grid connected.**

Keywords—ESS; fluctuation; hdrogen; SCIG; wind turbine

I. INTRODUCTION

The electricity demand in many countries in the world has been become higher and higher while fossil-based energy resources have been going to be exhausted [1]. Hence, the use of renewable energy resources such as wind, solar, geothermal, and so on to replace gradually fossil fuel-based resources like coal, oil, natural gas, etc. is necessary for the demand. Practically, wind energy has been exploited and meet an important part in electricity demand [1]. However, their main drawback comes from their negative impact on the connected power system especially in weak grids because their output power is always varied among the wind speed [2].

To reduce the variation of the output power of a wind turbine, many useful schemes were proposed to [2-19]. Generally, we can classify them into two groups including the use of energy storage system [2-3, 8-13], and the disuse of an energy storage system [2,4-7]. In the case of the controller usage like the use of inertia control [7], pitch control [14-17], DC link voltage control and so on [18], the wind turbine is not easy to operate completely at their optimal points [2, 4]; additionally, the output power is hard to smooth completely because it cannot charge/discharge amount of redundancy/ shortage power; the oscillation amplitude of the output power can be mitigated. By employing an energy storage system (ESS), thanks for adjusting amount of active power flowing from/to ESS, we can smooth the output power quite easily; and hence, wind turbines can completely operate on its optimal power points to withdraw a maximum available power. Therefore, by comparing to the case of ESS misutilization, with the use of ESS, the wind energy utilization and the wind turbine output is always better than that of without ESS.

The ESS employed to smooth the power output in the wind turbine are well-known as battery, super capacitor, and so on [2,3, 8-13]. Based on the kind of storage energy, ESS can divide into two groups. The first group is electrical energy and the second is not electrical energy. The electric based ESS consists of battery, supercapacitor, super magnetic energy system; Their storage ability is reliant on ESS's capacity; when its is full, we cannot charge any more. For the second group is used water pumping, hydrogen production, etc.; with this ESS types, we do not often cope with a difficulty as it becomes full because we can use this energy for other purposes; for example, when the reservoir of the pumping based ESS becomes full, we can release water for other purposes. The benefit of hydrogen production based ESS is that we can obtain both hydrogen and oxygen which can be used for many purposes.

For wind turbine, depending on the type of generators using in the wind turbine, the wind turbine is categorized in to fixed speed wind turbine and variable speed wind turbine [20]. For the fixed speed wind turbine, it cannot provide a control capability and hence, to smooth power output, we must use the pitch control or an ESS [3]. In the case of pitch control usage, the wind energy cannot be utilized wind energy with the highest efficiency. Likely, the employment of a battery system is limited by its capacity. Hence, in this research, we propose the installation of hydrogen based ESS to exploit the wind energy with a highest efficiency as possible.

This research is to propose a new scheme for cutting of the output power peak of a wind turbine by using an energy storage system. This energy storage system is based on an electrolysis system to produce hydrogen and oxygen gas. Here, we must calculate the reference active power of the electrolysis' controller to reduce the actual output power peak of the SCIG wind turbine. To evaluate this scheme, we simulate a 1.5MW-wind turbines in MATLAB/Simulink environment. The simulation results indicated that with the recommended scheme, we can cut off significantly the peak of output power variation of the wind turbine and we can withdraw a volume of hydrogen and oxygen gas which can be used for other purpose.

II. WIND TURBINE CONFIGURATION

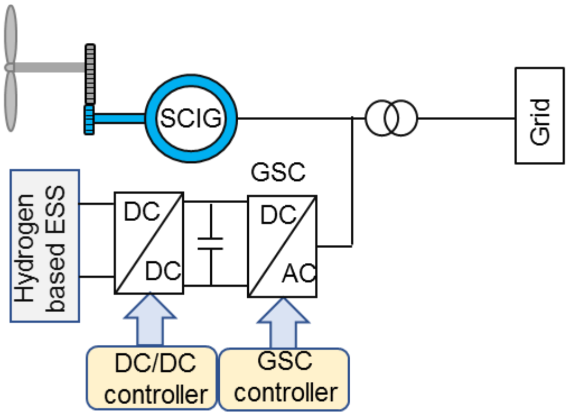


Fig. 1. *Wind turbine configuration in this research*

In this research, we consider a fixed speed wind turbine in which a Squirrel cage induction generator (SCIG) is used. To cutting off the peak of power output of the wind turbine, a hydrogen based ESS is installed at the wind turbine's terminal as Fig.1. The hydrogen based ESS in this research is a Polymer electrolyte membrane (PEM) electrolysis.

A. *SCIG wind turbine*

Generally, a wind turbine system is constructed from three main components. They are a three-blade system, a generator, and a shaft system to link the blade system and the generator together [20]. In SCIG, the stator winding is always connected directly to the grid [20, 21]. Therefore, during operation period, the grid must supply reactive power to the generator to produce flux in the generator. Therefore, a SCIG wind turbine must accompany to a reactive power source like capacitor bank, SVC, STATCOM and so on [20].

The duty of the blade system is to produce a mechanical energy on its shaft from the kinetic energy of the wind. This converting efficiency is expressed via $C_p(\lambda, \beta)$, which is normally named power coefficient [8, 22]. This coefficient has a strong relationship with both pitch angle β and tip speed ratio λ. The tip speed ratio is expressed by [8, 22]

$$\lambda = \mathrm{R}\frac{\omega_r}{V_w} \tag{1}$$

where,

R: blade's length,

ω_r: the speed of shaft,

V_w: wind speed attacking to the wind turbine blade.

The relationship of the coefficient $C_p(\lambda, \beta)$ versus the tip speed ratio λ at different values of pitch angle β of a wind turbine can be described in Figure 2a [8]. As can be seen from this figure, at a constant value of the pitch angle, the power coefficient $C_p(\lambda)$ owns a maximum point corresponding to an optimal tip speed ratio. As the pitch angle is kept at zero, β=0, the optimal point of power coefficient, $C_p(\lambda)$, versus the tip speed ratio is $(C_{pmax}, \lambda_{opt})$.

The mechanical power on the wind turbine shaft is depended on three variables including the power coefficient $C_p(\lambda, \beta)$, wind speed V_w, and rotor speed ω_r, [8, 22]

$$P_m = \frac{1}{2}\rho\pi R^2 C_p(\lambda, \beta) V_w^3 \tag{2}$$

where,

ρ: the density of air at the wind turbine location.

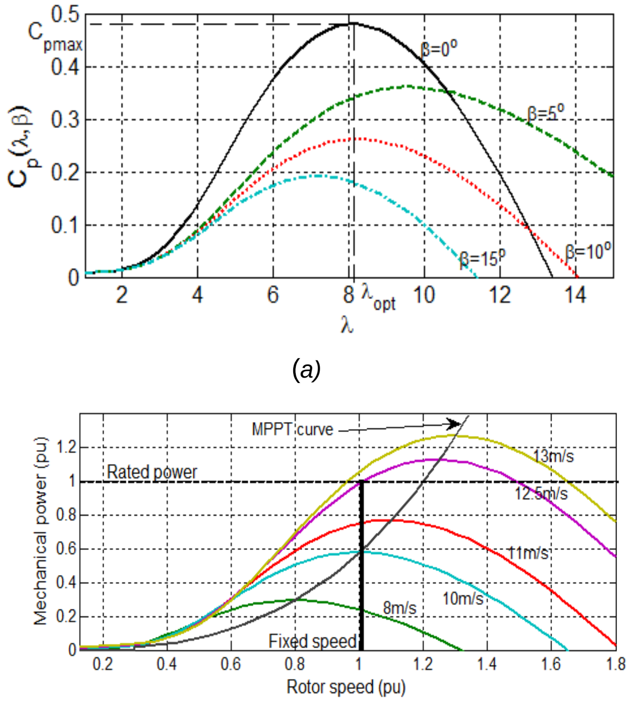
From (2), we can see that the mechanical power is proportional to the cubic of the wind velocity V_w. When the wind speed is higher than the rated speed, the power output of wind turbine is often controlled at its rated value by controlling the pitch angle β of the blade system. Otherwise, we should keep the pitch angle at a minimum value, normal value is zero, while we control the rotor speed to the optimal value (3). If this control objective is obtained the wind turbine will operate at the optimal point $(\lambda_{opt}, C_{pmax})$ and the power output of the wind turbine will be maximum as (4)

$$\omega_{ropt} = \frac{\lambda_{opt} V_w}{\mathrm{R}}. \tag{3}$$

$$P_m = \frac{1}{2}\rho\pi R^2 C_{pmax} V_w^3 = K_{opt}\omega_{ropt}^3 \tag{4}$$

where

$$K_{opt} = \frac{1}{2}\rho\pi R^5 C_{pmax}/\lambda_{opt}^3, \tag{5}$$



(a)

(b)

Fig. 2. *Power coefficient curve versus tip speed ratio at different pitch angle (a) and mechanical power versus rotor speed at different wind speed*

However, with the SCIG wind turbine, we fail to adjust the rotor speed, and hence, the rotor speed is almost kept at a constant, normally is over 1% comparing to synchronous speed. We have the characteristic of the SCIG wind turbine as Fig. 2b.

As can be seen from the Fig 2b, we can see that the power output of this SCIG wind turbine is always varied among the wind speed. Hence, it is important to reduce the power variation of the wind turbine.

A Squirrel Cage induction generator is an induction generator. This generator is modelled detail in [23].

B. Hydrogen based ESS

To integrate a hydrogen based ESS into the SCIG wind turbine, it must be connected at the stator winding through a DC/DC converter and a DC/AC converter. The maim of the DC/DC converter to step up/down the PEM system's terminal voltage to another DC voltage level and the AC/DC converter, namely grid side converter (GSC), to interface to the SCIG wind turbine. The DC/DC converter and GSC are mentioned in detail in [9].

A PEM electrolysis cell is generally consisted of an anode and a cathode chamber as Fig.3a. When we supply a current to the electrolysis system which makes potential applied across two electrodes of the cell. This voltage is at least 1.23V, the electrochemical reactions occurs at both the anode and cathode electrodes. Water at the anode is dissociated into oxygen as [24- 26]

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-, \tag{6}$$

and the hydrogen ions are moved to the cathode under an electric field and then they are received with the electrons supplying from the external circuit to form hydrogen gas

$$4H^+ + 4e^- \rightarrow H_2 \tag{7}$$

Hence, from (6) and (7) we have global reaction

$$H_2O + electrical\ energy \rightarrow \frac{1}{2}O_2 + H_2 \tag{8}$$

The modelling of a PEM electrolysis cell is described in [25, 26]. In here, we use an empirical equation to determine the electrolysis cell voltage as [25]

$$\mathrm{V}_{1cell} = \mathrm{V}_{o1cell} + \mathrm{R}i_e = 0.326 i_e + 1.476, \tag{9}$$

where i_e and V_{o1cell} are the current and is the open voltage of one cell, respectively; R is the resistance of a cell. It means $\mathrm{V}_{o1cell} = 1.476V$ and $\mathrm{R} = 0.326\Omega$. Hence, the equivalent circuit of the PEM electrolysis is shown as Fig. 3b where V_o and R are the open voltage and the resistance of a cell.

In the case of $N_s$cell in series and N_p in parallel, the voltage at terminal and current input are calculated as

$$V = \mathrm{N}_s \mathrm{V}_{1cell} = \mathrm{N}_s(0.326 i_e + 1.476) \tag{10}$$

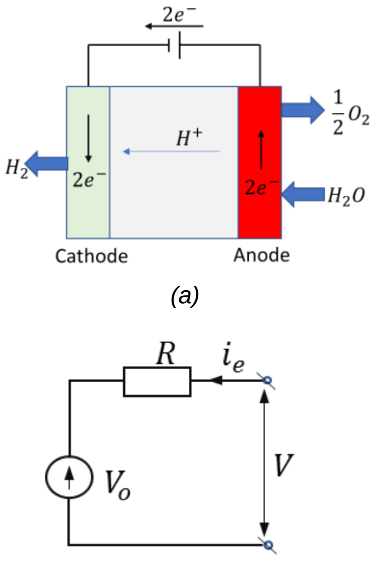
$$I = \mathrm{N}_p i_e \tag{11}$$

From Faraday's law, amount of hydrogen emitted in an electrolysis cell is directly proportional to the electrical current passing between two electrodes [26].

$$n_{H_2} = \eta_F \frac{N_P N_S i_e}{2F} = \eta_F \frac{N_S I}{2F}, \tag{12}$$

where $i_e$is DC current flowing between two electrodes or in electrolyser. F is Faraday constant. η_F is efficiency of cell [26].

$$\eta_F = 96.5(e^{\frac{0.09}{i_e}} - e^{\frac{0.09}{i_e^2}}) \tag{13}$$



(a)

(b)

Fig. 3. *Structurer of a PEM cell (a) and equivalent circuit (b) of a PEM system.*

III. CONTROLLER SYSTEM

A. DC/DC controller

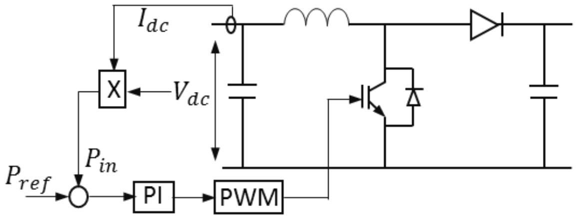


Fig. 4. *Controller of DC/DC converter*

The objective of the DC/DC controller is to control the power input of the PEM electrolysis to the reference value. The reference value is defined by

$$P_{ref} = \begin{cases} P_{wout} - P_{wout}^{av} & if\ P_{wout} \geq P_{wout}^{av} \\ 0 & if\ P_{wout} < P_{wout}^{av} \end{cases} \tag{14}$$

where P_{wout} and $P_{wout}^{av}$are the actual power output of the SCIG wind turbine and its average value, respectively. The average actual power output is defined by using Exponential Moving Average method [4] as (15)

$$P_{wout}^{av}(t) = P_{wout}^{av}(t-T) + \alpha\left(P_{wout}(t) - P_{wout}^{av}(t-T)\right) \ . \tag{15}$$

Here, we use PI controller as Fig.4 where $P_{in}$is actual power received by PEM electrolysis. This power is the production of DC current I_{dc} and the DC voltage at GSC side V_{dc}. The output of the PI controller, which converts the error of P_{ref} and P_{in} to duty ratio, is used to generate pulse via a Pulse-width modulation (PWM). This pulse is supplied to valve of the DC/DC converter.

B. GSC controller

The main objective of the AC/DC controller is to remain a constant DC voltage on the DC link and a constant reactive power to the wind turbine. The controller for GSC is used in [27].

IV. SIMULATION RESULTS

In this research, we use Matlab/Simulink to simulate the wind turbine system in Figure 1. In here, we simulate only one 1.5MW wind turbine. The power coefficient of this wind turbine is shown as (16)-(17) [8]. This wind turbine owns characteristics as shown in Fig. 2. To test the proposed scheme, we use a wind speed data as in Fig. 5.

$$C_p(\lambda,\beta)=0.5176\left(\frac{116}{\lambda_i}-0.4\beta-5\right)e^{-\frac{21}{\lambda_i}}+0.0068\lambda \qquad (16)$$

$$\frac{1}{\lambda_i}=\frac{1}{\lambda+0.008\beta}-\frac{0.035}{\beta^3+1}. \qquad (17)$$

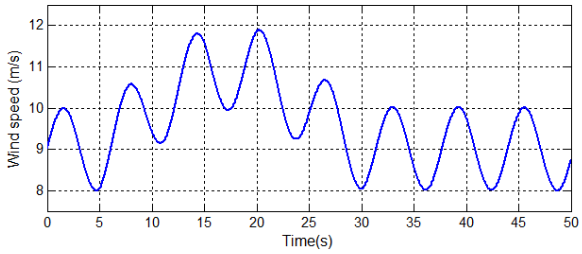
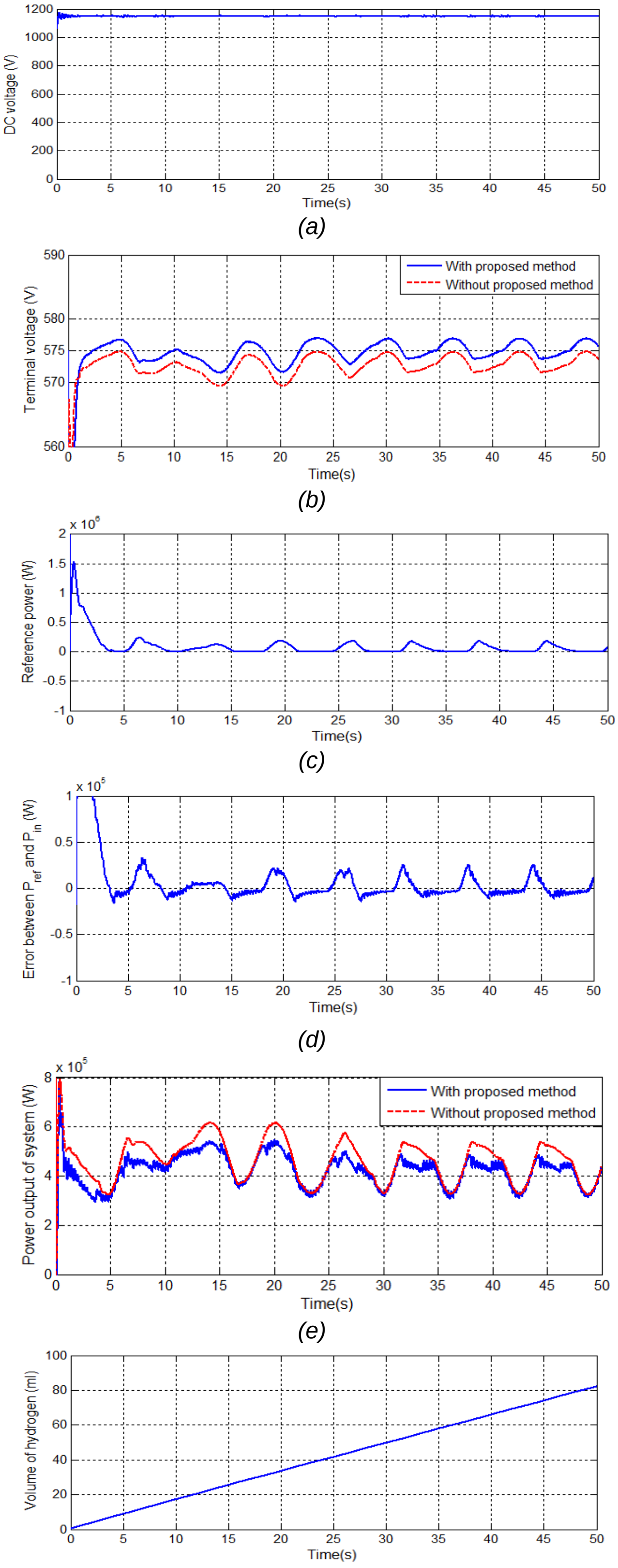


Fig. 5. *Wind speed data*

With the wind speed data in Fig.5, simulation results are indicated in Fig.6.

As can be seen from Fig.6a, the DC voltage on the DC side of GSC is remain at constant 1150V as the reference value. Moreover, the voltage at the terminal of SCIG is improved thanks for the objective of the GSC controller which remains the voltage at the SCIG terminal at rated value; however, due to the limited capacity of GSC, it is hard to remain at constant; by comparing to the case of without proposed method, the SCIG terminal voltage is improved because without the proposed method, the SCIG terminal voltage is below the rated value.

Concerning to the DC/DC converter's controller, its aim is to adjust the active power supplying to the PEM electrolysis approach to its reference value. The reference power is calculated from (15) is shown as Fig.6c. We can see from this figure, the reference power is higher zero as the SCIG power is around the peak value. The error of the DC/DC controller is indicated in Fig. 6d. Thanks for adjusting power absorbing from the PEM electrolysis, the peak of the power output of the SCIG wind turbine system whole is cut off significantly as Fig. 6e. Obviously, the oscillation peak of power output is always lower than the SCIG power output.



(a)

(b)

(c)

(d)

(e)

(f)

Fig.6 Simulation results: (a) Dc voltage, (b) SCIG terminal voltage, (c) reference power, (d) error of DC/DC controller, (e) actual power of whole wind turbine system, and (f) volume of hydrogen

With the proposed idea, we utilized electric power from the oscillation peak of SCIG power output to produce hydrogen gas and this production is indicated in Fig. 6f. From this figure, we can see that we can withdraw around 80ml of hydrogen gas at the end of simulation.

From the analysis of the simulation results, we can conclude that the proposed method can be completely used to reduce the oscillation range of a SCIG wind turbine.

V. CONCLUSION

This research proposed a scheme to cut off the oscillation peak of the actual power output of a SCIG wind turbine. The proposed method is developed from a hydrogen-based energy storage system. We design the controller of DC/DC converter and thanks for this controller it can withdraw amount of active power such that it can cut off the oscillation peak of the actual power output of a SCIG wind turbine. Simulation results indicated that we can reduce the variation range of the output power of wind turbine.

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