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영구자석형 동기발전기를 갖는 풍력발전시스템을 위한 EDLC의 새로운 응용 방법

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A novel EDLC application scheme for PMSG type wind power generation system

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Abstract - Electric double layer capacitor (EDLC) is used to overcome power quality problem caused by output power oscillation of wind turbines. A novel EDLC application for permanent magnet synchronous generator type wind power generation system is proposed in this paper. The structure of the proposed system is cost-effective and efficient. The proposed system including an EDLC is modeled and analyzed by PSCAD/EMTDC. The simulation results show the effectiveness and major features of the proposed system.

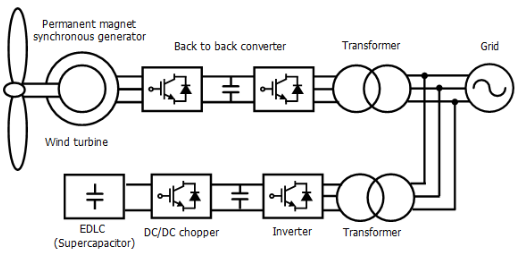
1. Introduction

Wind power generation system (WPGS) is the fastest increasing renewable energy source technology nowadays. However, output power fluctuation of the WPGS due to variation of wind speed causes a problem of low or some high frequency oscillation in power system.

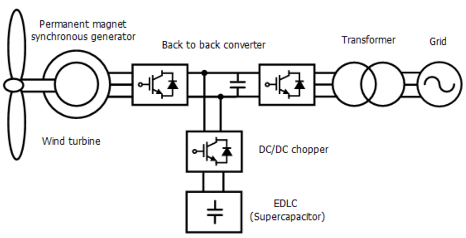
An energy storage system (ESS) is connected to WPGS through a power converter for overcoming this problem. The conventional ESS with an EDLC consists of a bidirectional DC/DC converter using insulated gate bipolar transistor (IGBT) and a six-pulse width modulation inverter using IGBT as in Fig. 1 [1]. The ESS without the inverter as shown in Fig. 2 is reported for reducing the power converter losses [2].

In this paper, a new connection scheme of electric double layer capacitor (EDLC) to WPGS is proposed in which the EDLC is directly connected to DC-link of WPGS with permanent magnet synchronous generator (PMSG).

The proposed system is modelled and analyzed by PSCAD/EMTDC. The simulation results show the effective operation of the proposed system to smooth output power fluctuation of WPGS. Finally, the major features of the proposed system is discussed.



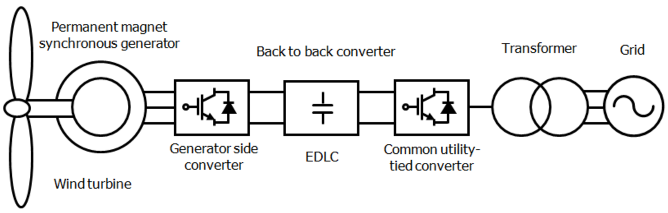
<Fig. 1> Conventional energy storage system with an electric double layer capacitor



<Fig. 2> Energy storage system without an inverter

2. Modeling of the proposed system

The configuration of the proposed system is shown in Fig. 3, in which an EDLC is connected to DC link of WPGS with PMSG. Because no additional power converter for the EDLC is needed, both the system cost and power losses are minimized.



<Fig. 3> The configuration of the proposed system

2.1 Wind turbine model

The MOD-2 based wind turbine [3] is modeled in the PSCAD/EMTDC. The MOD-2 model is characterized by the following equations.

$$C_p = \frac{1}{2}(\lambda - 0.022\beta^2 - 5.6)e^{-0.17\lambda} \quad (1)$$

$$T_w = \frac{1}{2}\frac{\rho\pi R^3 v_{wind}^2 C_p}{\omega} \quad (2)$$

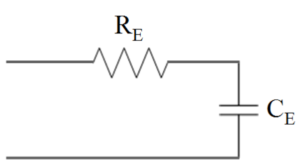
where, Power coefficient (C_p) is calculated by tip speed ratio (λ) and the blade pitch angle (β). The torque of wind turbine is calculated by (2), where ρ is the air density. Table 1 shows the specifications of the modelled 3 MW wind turbine.

<Table 1> MOD-2 wind turbine parameters

Propeller type	Horizontal propeller
Rated power	3 MW
Cut-in wind speed	5.8 m/s
Rated wind speed	11.8 m/s
Cut-out wind speed	16 m/s
Blade diameter	91.43 m

2.2 Electric double layer capacitor model

An EDLC has many advantages including high efficiency, high response speed and millions of times of electrical charge and discharge. As shown in Fig. 4, the simplified equivalent model for EDLC is used [4].



<Fig. 4> The simplified equivalent model for EDLC

The EDLC bank is composed of the EDLC module which is connected in series-parallel. The parameters of bank are shown in Table 2.

<Table 2> EDLC bank parameters

Rated voltage	4000 V
Storage Energy	5 MJ
Capacitance	0.625 F
Internal resistance	13.5 ohm
Module numbers	1500

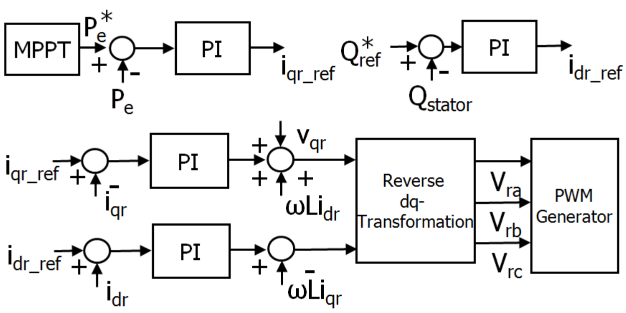
2.3 Control design of generator side converter

The maximum power from wind turbine is extracted by a generator side converter (GSC). The maximum power of wind turbine is given by (3) [5].

$$P_{\max} = \frac{1}{2}\frac{\rho\pi R^5 C_{p\max}}{\lambda_{opt}^3}\omega_{opt}^3 \qquad (3)$$

where, P_{max} is the power reference of GSC.

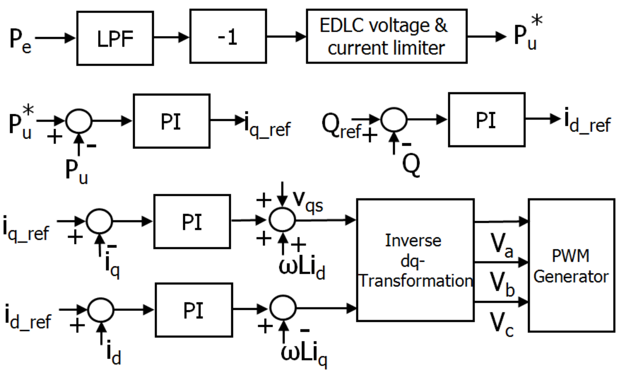
Fig.5 shows the control block diagram of GSC. The active power of the generator is controlled by the q-axis current of generator (i_{qr}). And the d-axis current is linked to the reactive power. Reference currents of dq-axis are controlled by the PI controller, which generates the voltage reference and PWM for GSC.



<Fig. 5> The control block diagram of generator side converter

2.4 Control design of common utility-tied converter

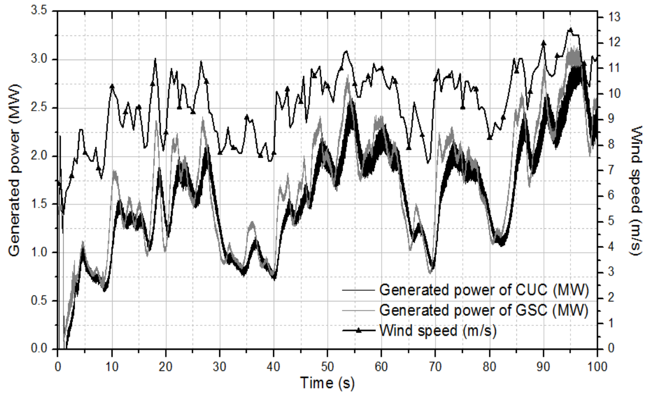
A common utility-tied converter (CUC) smoothen the power fluctuation of generator side converter. Fig. 6 shows the control block diagram of CUC. Power reference of CUC is limited by the state of EDLC as indicated in Fig. 6. The structure of power and current controller is the same as GSC.



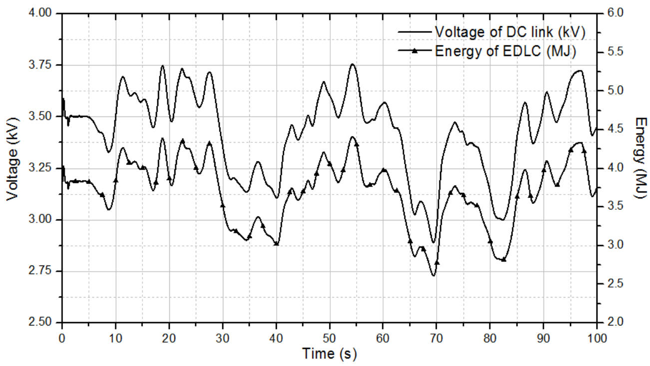
<Fig. 6> The control block diagram of common utility-tied converter

3. Simulation results and discussion

As shown in Fig. 7, the generated power of CUC is much less fluctuated compared with generated power of GSC. The voltage of DC link is fluctuated for smoothing the generated power of CUC as shown in Fig. 8. The operation voltage range varies from 2.75 kV to 4 kV.



<Fig. 7> Wind speed and generated power of the system



<Fig. 8> Voltage and stored energy of EDLC

4. Conclusion

This paper presents a novel EDLC application scheme for PMSG type WPGS. The proposed system mitigates the fluctuation of generated power without an additional inverter or converter. Hence, the system cost and power losses can be reduced. In this system, EDLC operation voltage is limited. However, energy density of the EDLC at low voltage is low. The 5 MJ EDLC and 3 MW wind turbine are modeled and analyzed by PSCAD/EMTDC for demonstrating the effectiveness of the proposed system.

Acknowledgements

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