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RESEARCH ARTICLE

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FUZZY LOGIC BASED PMSG WIND TURBINE SYSTEM WITH FAULT RIDE THROUGH TECHNIQUE

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ABSTRACT

This paper presents the PMSG-based wind turbine system configuration that includes not only an auxiliary converter to control ESS but also a coordinated control strategy that enhance the low voltage ride through capability to improve power quality. During normal operation, the line-side converter maintains the DC-link voltage constant. But during grid faults, a hierarchical coordinated control scheme works that includes line-side converter injecting reactive current into grid , energy storage system and braking chopper to control DC link voltage depending on the grid voltage sags. The feasibility and the effectiveness of the proposed system topology and hierarchical coordinated control strategy were verified using MATLAB/Simulink.

Key Words - braking chopper (BC) , energy storage system (ESS), fault ride through (FRT) , generator side converter (GSC), line side converter (LSC),permanent magnet synchronous generator (PMSG), point of common coupling (PCC) , low voltage ride through (LVRT) , wind turbine (WT), Wind energy conversion system (WECS).

INTRODUCTION

Among various renewable energy sources, the wind energy power generation has been concerned as one of the most rapidly growing energy source because of pollution free resource which has inexhaustible potential and also cost advantage over others. The main concern of wind is its irregularity in occurrence and so as to maximize the energy generated from wind turbine with better quality [1],[2].

When the wind power station is integrated to power grid, power quality issue arises like injection of harmonic, poor power factor and distortion from pure sine wave. One of the series issue for the operation is low voltage ride through capability to which the turbine are expected to comply with the requirement of grid code. Fig.1 [3]

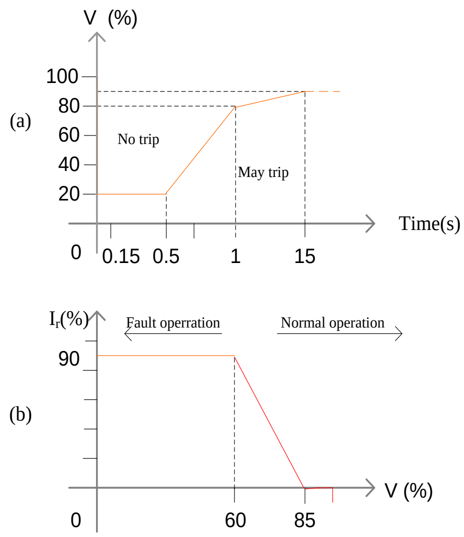

Fig . 1. Denmark grid code (a) Low voltage ride through requirement. (b) Reactive current requirement.

Wind energy conversion system (WECS) uses pitch angle control, drive train, generator and power converter to produce output power[4]. Variable speed wind turbine generator is used instead of fixed speed wind turbine which helps to increase the energy capture through maximum power point technique. Thereby, increasing efficiency and power quality of output power. The efficiency of variable speed wind turbine system improved significantly by using direct drive system [4].Direct drive wind energy conversion system use PMSG system which has lot of advantage over DFIG such as no gear box, high power density and simple control method except initial cost [4].

The threat to grid stability is controlled by pitch control and DC link voltage control, which results in low cost WECS and stable operation during fault [5] [6]. Wind turbine is protected from over speed and excess power through yaw scheme [7]. But, the energy captured is not optimum.

WECS supplemented with energy storage system [8]. The system is proposed by electrolytic capacitor[9] which is replaced with reduced stage of energy conversion [10].

An LVRT strategy is proposed for variable speed PMSG wind turbine system using the method of dc link voltage control and feedback linearization theory [11]. Generator side converter is used for analysis instead of gride side converter using the MPPT strategy [12].Reactive power compensation by STATCOM and SVC on the transient stability limit is analysed with LVRT capability of an induction generator that estimates the required rating of different compensation devices after a fault which produces a result that STATCOM is efficient then SVC [13].

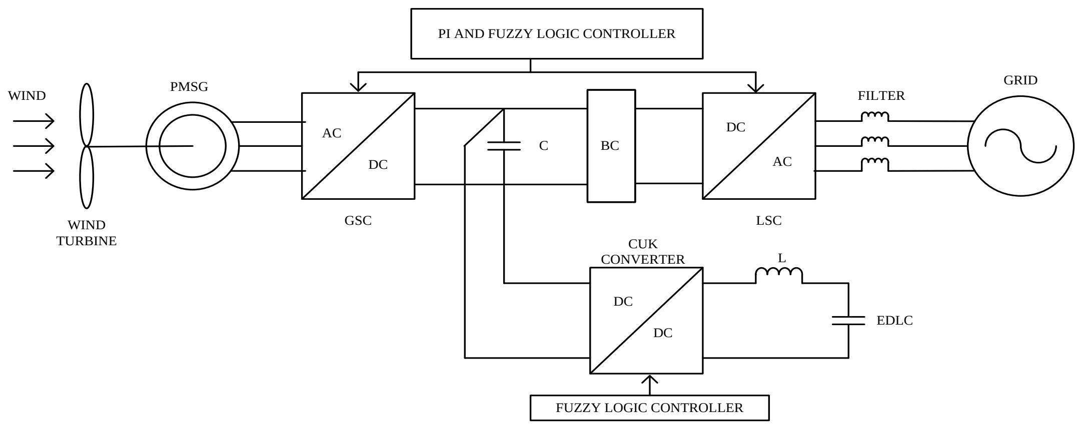

Fig.2. Configuration of PMSG wind turbine system consisting of ESS and BC

SYSTEM CONFIGUGRATION

In this paper, the variable speed wind turbine with full scale frequency converter is used for research on distributed power generation systems as shown in Fig 2. LSC controls the DC-link voltage constant. GSC controls the torque and the speed of WT.

The two converters are connected by a DC link capacitor in order to have a separate control for each converter. This aspect requires additional infrastructure to convey the generated power with better power quality to the demand centres. Therefore fault ride through (FRT) technique is proposed for the system. By using the control mode during fault period, the ESS control the DC link, BC is used to smoothen the output voltage by dissipating the extra power and the LSC act as STATCOM by feeding reactive power into the grid. To have an efficient and a reliable control, the system is used with CUK converter, fuzzy logic controller and PI controller.

MODELLING OF WIND TURBINE

Wind turbine is a device that converts kinetic energy into electrical energy. The kinetic energy is obtained by the blade from the wind which is transformed into mechanical energy.

The wind turbine cannot extract full energy from wind. The wind turbine's output power is given by,

$$P_w = 0.5\ \rho \pi R^3\, VW^3\, C_p(\lambda,\beta) \qquad (1)$$

P_w = Extracted power from the wind, ρ = Air density, (approximately 1.2 kg/m^3 at $20\,^{\circ}C$ at sea level), R = Blade radius (in m), (it varies between 40-60 m) ,V_w = Wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s),C_p =The power coefficient which is a function of both tip speed ratio (λ), and blade pitch angle (ßº)

$$\lambda = \frac{\omega R}{\vartheta} \qquad (2)$$

The common AC generator used for wind turbine are field excitation induction generator (FEIG), squirrel cage induction generator (SCIG), doubly fed induction generator (DFIG), permanent magnet synchronous generator (PMSG). The use of PMSG in WT shown in Fig 3, increased due to no field excitation loss, smaller physical size, low maintenance and use of power electronics converter with full rating. Therefore PMSG for WT is efficient then other generator [12].

CONTROL OF BACK-BACK CONVERTER

A. *GSC Control:* GSC act as rectifier. Rectifiers are electronic devices which convert AC into DC through PI and fuzzy logic controller. IGBT switch bridge circuit works as a six pulse rectifier.

Converting the variable frequency/variable amplitude AC output voltage of the generator to a DC voltage of a variable level, the WT generator can be operated at different speeds and frequencies other than its fixed synchronous speed.

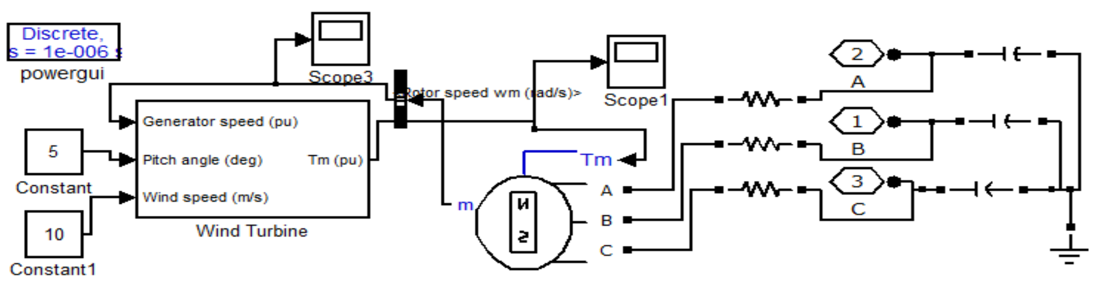

Fig.3. PMSG in wind turbine.

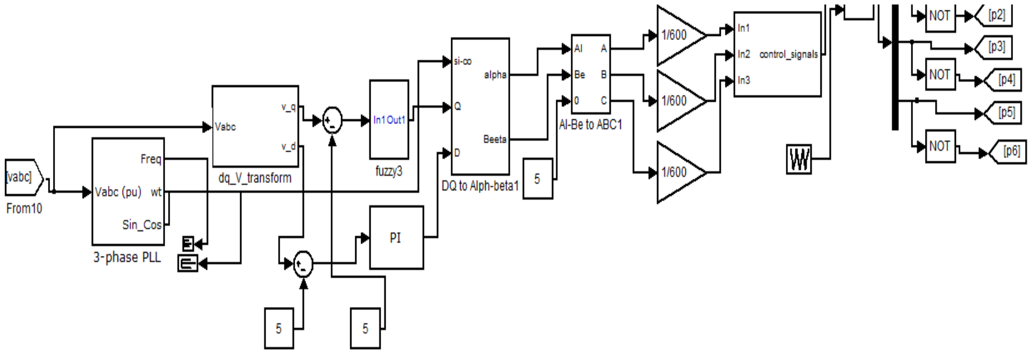

Fig .4. Switch connection for generator side converter

GSC is used to control the torque or speed of the wind turbine. The GSC performs vector control in which the fuzzy logic and PI controller combine to control the inner current control loop and outer speed control loop shown in Fig 4.

The reference speed is commutated by multiplying the previous value by a constant k, in which the constant k depends on the system inertia constant (H_s) and the sampling period of the speed controller (T). The new speed reference ω^*_{new} can be expressed as

$$\omega^*_{new}(i) = k \cdot \omega^*_{new}(i), \quad i=1, 2,\ldots,n$$

$$(\omega^*_{new}(0) = \omega_{init\_ft}) \qquad (3)$$

where ω_{init_ft} is the initial value of the generator speed after the fault occurrence, i is i^{th} sampling time, and n is the number of sample speeds during the fault duration ΔT, which is calculated by

$$n = \left(\frac{\Delta T}{T_{s-speed}}\right) \qquad (4)$$

B. *LSC Control*

LSC act as inverter. An *Inverter* is a device that converts DC to three phase AC electricity, which can be fed directly into the mains grid because LSC operate in sync with the utility grid and produce electricity that is identical to utility grid power.

The inverter used here is IGBT-diode based bridge configuration inverter. The IGBT switch of the bridge are controlled by the PWM pulses through both the PI and fuzzy logic controller. The line side converter controls the DC link voltage at normal condition. Under fault condition the LSC act as STATCOM by injecting the required reactive power into grid according to the grid code. Fuzzy logic controller and PI controller combine to control the current in the inner loop and voltage in the outer loop.

The voltage at the point of common coupling (PCC) is given by

$$E_{PCC} = E_g + Z_g I_{LSC} \qquad (5)$$

where I_{LSC} is the LSC compensated current. During unbalanced grid sags, the positive- and negative-sequence components are adopted for the LSC [19]. The negative and positive sequence is calculated from DC link output voltage [20].Fuzzy logic controller is used to control the DC link voltage by controlling the cuk converter. During the grid sag, ESS controls the dc-link voltage . Hence, an initial error, ΔVdc_I_int, of the integral regulator is set to zero.

$$\Delta Vdc\_I\_int=0. \qquad (6)$$

V.CONTROL OF ESS AND BC

The ESS and the BC are used to suppress the output power fluctuation in normal conditions. But during fault condition, the ESS and BC controls DC link voltage instead of LSC.

A. *DC- link voltage control.*

During grid sags, the dc-link voltage of the back-to-back converter is controlled by the ESS through FLC as shown in Fig 6. The outer fuzzy logic voltage controller produces a current reference for an inner current controller. Dynamic equation of DC link voltage is expressed as

$$P_{gen} - P_{BC} - P_{ESS} = \frac{1}{2} C \frac{dV_{dc}^2}{dt} \quad (7)$$

where C is the dc-link capacitance, P_{gen} is the generator power, P_{BC} is the power dissipated by the BC, and P_{ESS} is the power of the ESS,ESS voltage is V_{ESS}, and the EDLC current I_{ESS}, as

$$P_{ESS} = V_{ESS} \cdot I_{ESS} \quad (8)$$

The I^*_{ESS} is given as,

$$I^*_{ESS} = K_{P2} (V^*_{dc} - V_{dc}) + \frac{K_{I2}}{s} (V^*_{dc} - V_{dc}) + \frac{P_{gen} - P_{BC}}{V_{ESS}} \quad (9)$$

where K_{p2} and $K_{I2}$are controller gains of the dc-link voltage control.

The voltage controller's transfer function is given as

$$\frac{V_{dc}(s)}{V^*_{dc}} = \frac{V_{ESS} K_{p2} \left(s + \frac{K_{I2}}{K_{p2}}\right)}{s^2 + \frac{V_{ESS} K_{p2}}{CV_{dco}} s + \frac{V_{ESS} K_{I2}}{CV_{dco}}} \quad (10)$$

B. *CUK converter control*

The CUK converter shown in Fig 5 used to control the EDLC through controller action. Since the CUK converter made of boost-buck principle, it consists of inductor both in the input and output side. This in turn helps to reduce the ripple loss.

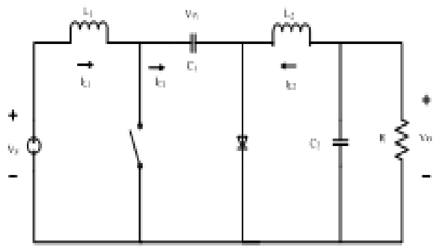

Fig.5. cuk converter

C. *EDLC current control*

The wind turbine produce fluctuating power. So, to produce steady, smooth and continuous power, energy storage system – EDLC shown in Fig 7 is used in between generator and grid.

Current control for converter involves the estimation of voltage across inductance

$$V_{Lf} = L_f \frac{dI_{ESS}}{dt} = D_{ESS} V_{dc} - V_{ESS} \quad (11)$$

where L_f is the boost inductance, and D_{ESS} is the duty cycle.

The output of the current controller,

$$V^*_{Lf} = K_{pc} (I^*_{ESS} - I^*_{ESS}) + \frac{K_{Ic}}{s} (I^*_{ESS} - I_{ESS}) \quad (12)$$

where K_{pc} and K_{Ic} are gains of the current control.

The duty cycle is

$$D_{ESS} = \frac{V_{ESS} + V^*_{Lf}}{V_{dc}} \quad (13)$$

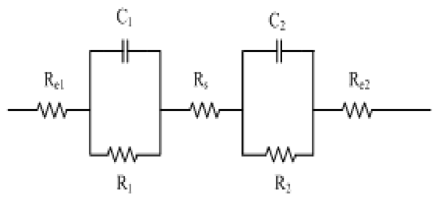

Fig.6. structure of EDLC

D. *BC control*

During fault period, the rest of power is dissipate through BC.

$$P_{BC} = P_{gen} - P_{ESS} \quad (14)$$

The duty ratio

$$D_{s3} = \frac{R_{bc}}{V_{dc}^2} P_{BC} \quad (15)$$

where R_{bc} is the braking resistance.

VI. CONTROLLER

A.*PI controller*

PI controller shown in Fig 8 is used to control the IGBT switches of line side converter and grid side converter.

A *PI Controller* (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used.

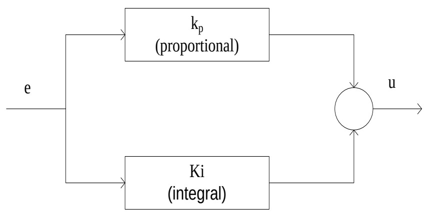

Fig.7. General diagram of PI controller

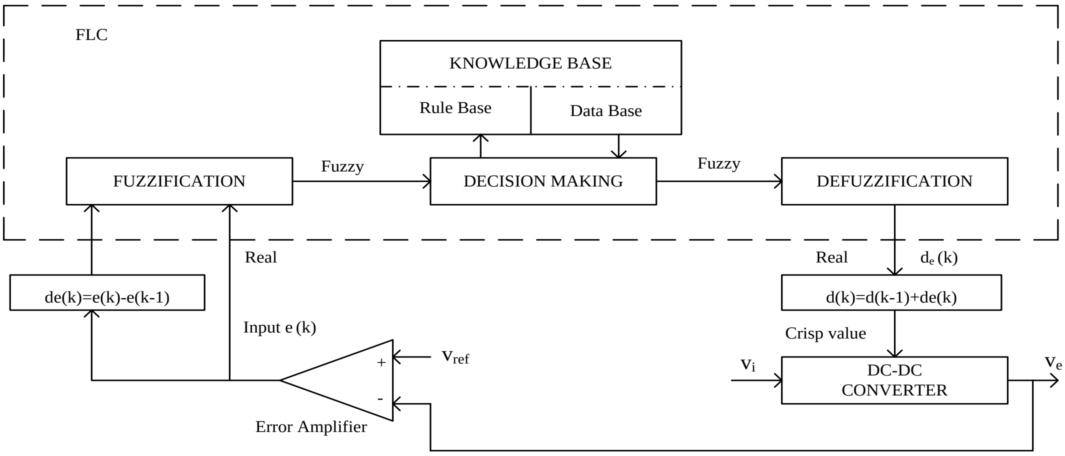

Fig. 8. Fuzzy logic controller.

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. The PID controller block is reduced to P and I blocks as shown in figure.

B. *Fuzzy logic controller*

Fuzzy control system shown in fig 9 is used to control the cuk converter , generator side converter and line side converter.

A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyses analogy input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively).

The objective of this dissertation is to control the output voltage of the Cuk converter. It also controls the switching pulse of the GSC and LSC converter combined with PT controller.

Fuzzy control system design is based on empirical methods, basically a methodical approach to trial-and-error.

The general process is as follows:

-Document the system's operational specifications and inputs and outputs.

-Document the fuzzy sets for the inputs.

-Document the rule set.

-Determine the defuzzification method.

-Run through test suite to validate system, adjust details as required.

-Complete document and release to production.

SIMULATION OUTPUT

In order to check the performance of the proposed system, the PMSG wind energy conversion system is constructed via MATLAB/SIMULINK .

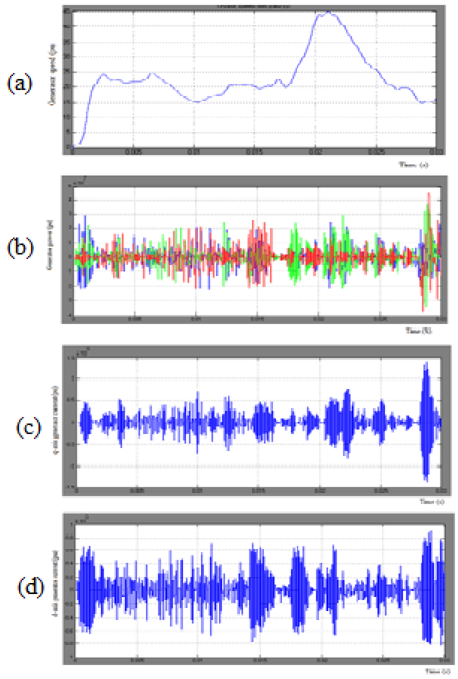

Fig.9. Performance of generator under unbalance sag simulation. (a) Generator speed. (b) Generator power. (c) q-axis generator current. (d) d-axis generators current.

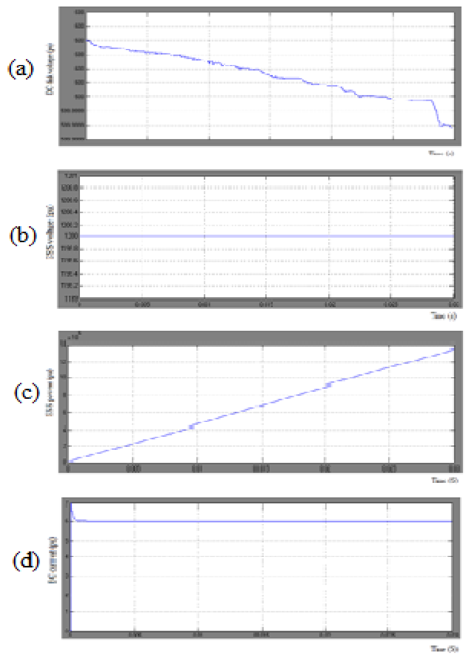

Fig.10. Performance of ESS and BC under unbalanced sag. (a) DC- link voltage. (b)ESS voltage.(c)ESS power.(d)BC current.

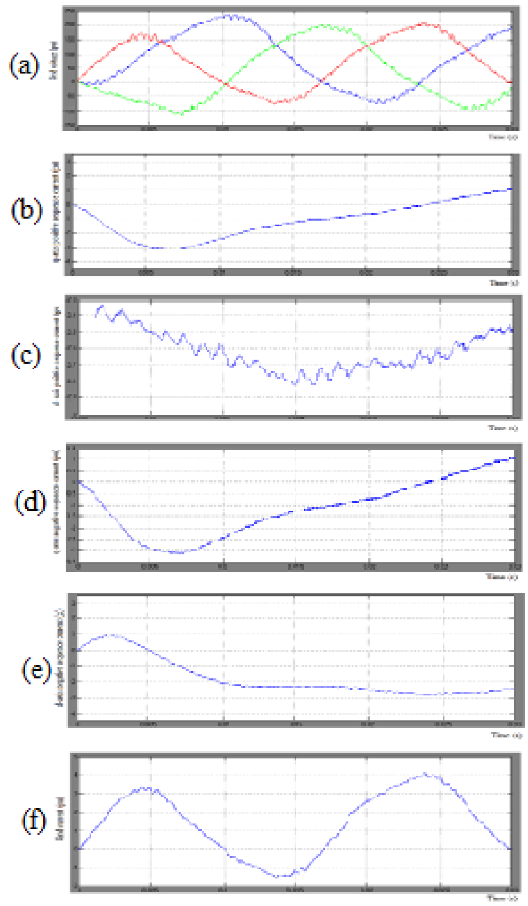

Figure.11.Performance of LSC under unbalanced sag. (a)Grid voltage.(b)q-axis positive sequence current. (c)d-axis positive sequence current. (d)q-axis negative sequence current. (e)d-axis negative sequence current. (f)Grid current.

CONCLUSION

This paper use combination of both the PI and fuzzy logic controller to control the GSC and LSC. The fuzzy logic control system alone to control the ESS. The BC is used to dissipate the excess power. The LVRT is achieved by using ESS and BC to control the DC-link voltage and LSC to inject the required reactive power to the grid according to grid code. This technique which is used in PMSG wind turbine system to produce power with less fluctuation is verified using MATLAB/SIMULINK. This simulation result shows that even though both PI and fuzzy logic controller are able to produce the same output power, the fuzzy logic controller helps to simplify the process as far as possible by eliminating the complexity involved in using the PI controller alone in the system.

TABLE: PARAMETER OF PMSG

PARAMETERS	VALUES
Rated power	1.5MW
Generator current	0.9 A
Stator resistance	0.18 Ω
Stator inductance	8.5Mh
Number of poles	4
Moment of inertia	0.00062 kg m^2
ESS voltage	1200 V
BC resistance	100 Ω

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