International Journal of Technical Research & Science A FUZZY LOGIC CONTROL OF MMC INTERFACED DFIG BASED WIND ENERGY CONVERSION SYSTEM

Shivani Johri, Vinod kumar, Shripati Vyas

E-Mail Id: sjohri07@gmail.com, vinodcte@yahoo.co.in, shripatiphd2018@gmail.com Department of Electrical Engineering, College of Technology and Engineering, Udaipur, India

Abstract- This paper presents the development of a fuzzy logic control for performance enhancement in DFIG based wind generation system in simulation environment to validate the performance of control. As in order to get satisfying output and to obtain efficient good amount of power quality, it is necessary to investigate and develop wind turbine generator systems (WTGS). An optimal control strategy for performance enhancement and efficiency optimization is developed and implemented with FLC.

Keywords: Multilevel matrix converter, wind turbine emulator, wind energy conversion system (WECS), doubly fed induction generator (DFIG).

1. INTRODUCTION

According to the wind statistics in a report published in WWEA on 12 February 2018, all installed wind turbines worldwide has capacity of 539,291 MW in which 52,552 MW were added in 2017 only. In year 2016,51,402 MW were added which was lesser than 2017. This is third largest recorded installed capacity after year 2014 and 2015. More than 5% of global electricity demand was covered by all wind turbines installed in 2017. Denmark won the credit with a latest world record as 43% of electrical energy which was derived from wind. Various countries as Germany, Ireland, Uruguay, Sweden, Portugal and Spain have reached a substantial wind power share.[1]World's wind power leader China with a total wind capacity of 188 GW installed 19 GW additional capacity which was lesser than that was in 2016. Leading wind markets of various countries have added splendid amount of installed capacity such as US added 6.8 GW making 89 GW total capacity, India added 4.6 GW making 32.9 GW in total ,UK added 3.3GW making 17.9 GW total capacity, Germany added 6.1 GW making 56 GW total capacity ,France added 1.7 GW making 13.8 GW in total and Brazil added 2GW making 12.8 GW in total. Figure 1.2 shows a forecast renewable source addition in 2019.[2]

For development in wind power market, technology would continue to improve various parameters, reduce emissions, clean air, cut down prices and generate new jobs in wind sector. According to enormous survey on wind energy worldwide, it is clear that with each passing year wind energy will become stronger. The performance of DFIG based WGS depends on power electronic converters implemented on both grid and rotor side. These power electronic converters can be back-to-back converters, PWM converters, multilevel converters, matrix converters (MC) or multilevel matrix (MMC) converters. MMC in wind energy systems is most promising one due to their modularity and capability to reach high nominal volume. to achieve objective of designing and implementing optimal control strategy based MMC converter for WPGS for performance enhancement and efficiency optimization. Objective is to design and implement optimal control strategy based MMC for WECS for performance enhancement and efficiency optimization.

Mathematical model and parameter estimation of generator and converter section. Modelling and analysis of DFIG are introduced to provide a comprehensive study of the generator. MMC is widely researched in wind generator applications, so a mathematical model and equation representation of the same is included. An optimal control strategy for performance enhancement and efficiency optimization is developed. A complete mathematical model of MMC based wind generation system (WGS) with DFIG generator is produced and discussed in the chapter. DFIG combines advantages of induction generator as well as those of synchronous generator. When limited range variable speed is required, primary choice is DFIG.

2. MATHEMATICAL MODELS OF DFIG

Generator dynamic model, turbine aerodynamic model and drive train dynamic model are physical model of DFIG. Simulation & modelling of SCIG and DFIG based WECS were presented in (Ernst,1985). Mathematical models of DFIG under disturbed grid voltage conditions in positive synchronous reference frame was investigated in (Hu, 2011). Two types of models are explained:

2.1 Full Transient Model

This is the type of model in which power electronic switches are modelled. For detailed modelling and practical purpose this type of model is utilized.

2.2 Average Model

In this type of model, signal produced by the converter. Converter is basically replaced by controlled voltage source to assume that converter replaces the voltage from the control output. It was noted in [3] that rotor

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current should not be at fundamental value for average model. Model applicability and limitations were presented by Dig Silent in [4]. A multi mass representation of drive train was presented in [5] to observe the dynamic behavior of WT under varying wind speeds and balanced unbalanced conditions. Output power characteristics-based WT model was presented in [6].

2.3 Dynamic Model

State space model representation of fourth order using do frame i.e., synchronous reference frame was investigated in [7]. Reduced order machine model for WT was derived as illustrated in Fig. 2.1.



Fig. 2.1 Basic configuration of a DFIG wind turbine

Steady state & dynamic equivalent circuit of DFIG was presented in [8]. Fig 2.2 shows the required circuit. Following are various equations for DFIG: Stator voltage

$$\begin{aligned} \mathbf{v}_{ds} &= \mathbf{r}_{s} \mathbf{i}_{ds} + \boldsymbol{\omega}_{s} \boldsymbol{\psi}_{qs} \\ \mathbf{v}_{ds} &= \mathbf{r}_{s} \mathbf{i}_{qs} - \boldsymbol{\omega}_{s} \boldsymbol{\psi}_{ds} \end{aligned} \tag{1}$$

Rotor voltage

$$\begin{aligned} \mathbf{v}_{d\mathbf{r}} &= \mathbf{r}_{\mathbf{r}} \mathbf{i}_{d\mathbf{r}} - \mathbf{s} \boldsymbol{\omega}_{\mathbf{s}} \boldsymbol{\psi}_{\mathbf{q}\mathbf{r}} + \frac{d \boldsymbol{\psi} \mathbf{d}_{\mathbf{r}}}{dt} \\ \mathbf{v}_{d\mathbf{r}} &= \mathbf{r}_{\mathbf{r}} \mathbf{i}_{\mathbf{q}\mathbf{r}} + \mathbf{s} \boldsymbol{\omega}_{\mathbf{s}} \boldsymbol{\psi}_{\mathbf{q}\mathbf{r}} + \frac{d \boldsymbol{\psi} \mathbf{q}_{\mathbf{r}}}{dt} \end{aligned} \tag{2}$$

Flux linkage

$$\psi_{ds} = -L_{SS} i_{ds} + L_m i_{dr} \tag{3}$$

$$\Psi_{qs} = -L_{SS}i_{qs} + L_{m}i_{qr} \tag{4}$$

$$\psi_{dr} = -L_m i_{ds} + L_{rr} i_{dr} \tag{5}$$

$$\psi_{qr} = -L_m i_{qs} + L_{rr} i_{qr} \tag{6}$$

Electromagnetic torque

$$\mathbf{T}_{\rm em} = \psi_{\rm qr} \, \mathbf{i}_{\rm dr} - \psi_{\rm dr} \, \mathbf{i}_{\rm qr} \tag{7}$$

For assurance of safe, efficient power extraction from wind with proper damping and robustness. Loads of control techniques were investigated and implemented with various control loops to maintain accurate operations. These techniques are used for-

- Limiting the extracted power in case of higher speeds.
- Adjusting the power drawn in order to trace the optimum operating point.
- > Regulating the reactive and active power exchange between wind turbine and grid.

Many controls such as space vector control phase locked loop control (PLL), stator and grid flux orientation control, internal mode control was discussed in [9]. Inner fast field oriented current (FOC) control loop was described in [10] whereas rotor current control approach was introduced for SCIG in [11].

2.4 Multilevel Matrix Converter and its Configuration

Following types of power converters are ruling the wind industry:

- Back-to-back PWM converters
- PWM converters
- Multilevel converters
- Matrix converters

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Fig. 2.2 Wind power conversion along demands to Power Electronics

MMC is also considered as new family of matrix converters. For reducing switching loses and harmonic content of output AC waveforms multi-level conversion is required. The very first investigation about MMC was done which was based on simple switch cells. A novel MMC was presented which involved flying capacitors to provide middle voltage levels along with simple control strategy. When matrix converter replaces the conventional converter, it creates various topologies for MMC. [12] proposed DC multi-level topology.



Fig 2.3 Diode clamped DC MC topology

explained a direct control algorithm for cascaded H bridge (CHB) for development of switching states. In this, bi-directional switches are replaced by cascaded H bridge modules.



Fig. 2.4 Cascaded H Bridge Topology

2.5 Development of Control Strategy using Fuzzy Logic Controller

Fuzzy logic has an old relation with DFIG and vector control. [14] observed fuzzy gain tuner for vector control of DFIG. TS fuzzy controller and neuro fuzzy vector control were investigated in [15]. Decoupling control based on fuzzy PI controller was explained in [16]. For controlling active and reactive power by three level DC

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multilevel using vector control was observed. Fuzzy control for rotor current with IMC. A comparative analysis of PI and fuzzy controllers i.e., single fuzzy with and without the cascaded current controller for RSC. Investigation was proposed for two back-to-back five level NPC converters in rotor circuit along with vector control.



Fig. 2.5 Developed System for DFIG based WECS Interfaced Multilevel Matrix Converter

Fuzzy means unclear which indicates control of the systems whose parameter are unknown unclear & vague. This control consists of input stage, output stage and processing stage. This process uses linguistic variables which describes input and output values which get fuzzified and developed in the form of membership function. Advantages of FLC are insensitivity, acceptance of noisy and inaccurate signals and fast convergence parameter.



Fig. 2.6 Fuzzy Control Block Diagram

The main objectives of the fuzzy controllers are to achieve more accurate active and reactive power control of the wind turbine driving the DFIG. For the proposed FLC, d- and q-axis rotor current errors are the inputs to the direct and quadrate axis. Developed Controller has following 7-segments membership functions:

- Very Negative Big (VNB)
- Very Negative Medium (VNM)
- Very Negative Small (VNS)
- \blacktriangleright Zero (ZR)
- Very Positive Big (VPB)
- Very Positive Medium (VPM)
- Very Positive Small (VPS)

These are the fuzzy rule set for proposed controller which provides required outputs in the form of various membership functions as well as error membership functions. Table 2.1 explains the procedure to extract desired results by fuzzy rule set of proposed developed fuzzy controller.

K _p , K _i		dE						
		VNB	VNM	VNS	VZR	VPB	VPM	VPS
Е	VNB	В	В	В	В	В	В	В
	VNM	S	В	В	В	В	В	S
	VNS	S	S	В	В	В	S	S
	ZR	S	S	S	В	S	S	S
	VPB	S	S	В	В	В	S	S
	VPM	S	В	В	В	В	В	S
	VPS	В	В	В	В	В	В	В

Table-2.1 Fuzzy Rules Set of Proposed Control

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Fuzzification, Fuzzy rules and defuzzification are the three steps which are being designed in FIS editor of MATLAB software and then the fuzzy controller is integrated in a simulation file to apply the created rules. Figure shows Proposed fuzzy controller to control reactive power of DFIG.



Fig. 2.7 Proposed Fuzzy Controller to Control Reactive Power of DFIG

This Fuzzy logic controller with two inputs and one output. Error signal is calculated from difference between the actual and reference d- component voltage. The error signal e (k) and change in error ed (k) is given as input to the q-components of fuzzy logic controller, error signal is calculated from difference between the actual and reference q- component voltage.

$$\Delta e_{d}(K) = \frac{1}{T} [e_{d}(K) + e_{d}(K-1)]$$
(8)

$$\Delta e_{q}(K) = \frac{1}{T} [e_{q}(K) + e_{q}(k-1)]$$
(9)

Where 'T' represents the sampling time

3. RESULTS AND DISCUSSIONS

There are various fault conditions, phase to ground fault conditions always cause voltage sags and voltage dips in the system. These are for vary short duration of approximately .02 sec near the grid.



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The proposed controller observes that distortion levels and the unbalance during the fault are smaller. Ripples during transient conditions are not bigger than 4.1 sec. All the parameters are in limit with the developed control strategies.



Fig. 3.2 Simulated responses during three-phase (L-L-L) fault. Grid voltage (pu), grid current (pu), grid active power (kW) and grid reactive power (kvar), fictitious dc link voltage (V), generator speed (pu)

It is seen that load voltage is well maintained despite the variation of loads. But the load current is changing with load variation as expected. It tends to be seen from the Result Responses of load voltage that multilevel matrix converter is very proficient to make the load voltages balanced even during the unequal load situation. Experimental results also validation that at low harmonic distortion, keeping the power factor constant, controller also performs at satisfactory mode under steady state as well as dynamic condition. From the given responses of unbalanced voltage situations which has been created by unbalancing one phase, it can be observed that good voltage regulation can be attained by MMC.

Variation in voltage using both balanced and unbalanced situations give satisfactory results and also observed the disturbed rejection capability. All the responses check the adequacy of system and as far as harmonics are concerned, THD is reduced to 2.1%. Inrush current also reduces as it generally generated for 1 to 6 ms but here it gets steady state value after applying developed strategy. Ill effects of Inrush current can be harmonic resonance and insulation deteriorates. Proposed converter enhance power quality and close loop control maintain the DC link voltage stable and grid voltages steady irrespective of current as current decreases with FLC.

3.1 Comparable Response Analysis during Transient Conditions

Simulated waveform for the transient behaviour of both converters based WECS with DFIG, active and reactive power, rotor speed, torque to validate the better performance of MMC based control strategy. DOI Number: https://doi.org/10.30780/IJTRS.V06.I02.002 pg. 17

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Fig. 3.3 Simulated response of the proposed MC interfaced WECS under three-phase fault with (a) Proposed control, and (b) conventional/traditional control. (Where waveform are of matrix converter voltage, grid current, grid frequency, grid voltage, grid active power, and fictitious dc link voltage)

The developed fuzzy control system observes the optimum blocking period for the serious fault such as 0.2ms for single phase and 15 sec for three phase faults. In this case the system is simulated with wind speed of 10 m/s that after a fault grid voltage recovers completely in 0.5 sec and wind turbine do not trip .Transient stability is slightly increased by using proposed system. The grid frequency in the wind turbine is negligibly affected by fault along with the constant grid voltage. Grid code requirements are met by using proposed strategy and small voltage dips recovers in 0.35 sec. So, it can be determined by the given results that overall response of the system is more acceptable and less fluctuating with better performance parameters by using Fuzzy logic control and MMC as control strategy to avoid extra fluctuations and enhance stability.

CONCLUSION

It is seen that load voltage is well maintained despite the variation of loads. But the load current is changing with load variation as expected. It tends to be seen from the Result Responses of load voltage that multilevel matrix converter is very proficient to make the load voltages balanced even during the unequal load situation. Experimental results also validation that at low harmonic distortion, keeping the power factor constant, controller also performs at satisfactory mode under steady state as well as dynamic condition. The modelling implemented investigates the dynamic steady state analysis of MMC based DFIG for wind turbine . The modelled DFIG with MMC is further tested for real time performance evaluation for active and reactive power for a various range of wind and generator speeds for balanced as well as unbalanced conditions at different values of voltages and currents are compared with the results obtained from laboratory setup. Implementation of complete setup in MATLAB®/Simulink® provides flexibility of changing the operational as well as system parameters during on run environment.Fuzzy Logic Controller approach for MMC based DFIG is derived and fulfills the need of better performance than conventional PI controllers. Following observations have been recorded: -

Proposed approach also maintains higher power factor at input resulting wider control range of FLC based multilevel matrix converter. Simulation and experimental results verify the robustness of proposed controller for varying loads and rotor speeds. This presents a balanced set of output voltages with desired magnitude and frequency.

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- This control strategy improves efficiency reduces balanced power harmonics, voltage harmonics and current harmonics, improves the output power, minimize ripple in output power. At higher speed of rotor, reactive power generation capacity is limited by rotor currents and at low rotor speed reactive power generation capacity is limited by rotor voltage. So, here the reactive power capability of DFIG gets improved by proposed control strategy.
- From experimental and simulation results, it can be verified that DFIG has an equilibrium in output voltage and current, reduced power losses.

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