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Enhancing Performance of IG Based Wind Power Application using Statcom by Comparing PI & FUZZY Controller

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Abstract: ***There has been a worldwide growth in exploitation of renewable sources of energy. Especially in the area of wind energy. Wind turbines are normally based on Squirrel cage Induction generator, since they have simple and maintenance free construction they are widely used as wind generator .They are connected directly with power grid. IG requires some amount of reactive power from the grid for the generation of active power and to maintain air gap flux respectively. In case if any fault occurs in the system IG's demand for reactive power compensation increases and that time if grid is unable to fulfill the respective requirement it leads to trip the wind turbine. This leads to disturbed the voltage profile of the bus to which wind power plant is connected and causes major instability in the grid. So to eliminate this problem it is important to maintain the stability of the grid whenever any disturbance occurs into the system. Nowadays FACTS devices have been widely used. Devices such as STATCOM, SVC,UPFC, DVR, etc plays an important role in such problems.SVC is reported to improve terminal voltage of IG by compensating the reactive power, but STATCOM has somewhat better performance then SVC. STATCOM is reported to recover terminal voltage of wound rotor IG after the fault clearance comparatively better than capacitor bank. In this work, we proposed the STATCOM based on voltage source converter (VSC) along with its control strategy. Moreover comparative analysis has been made for reactive power compensation provided to induction generator with PI and FUZZY based STATCOM. Simulation analysis with both the controllers PI and FUZZY based STATCOM have been done using MATLAB. Results indicate that FUZZY controller gives more stability and far better performance than PI controller.***

Keywords: Induction Generator (IG), Flexible AC Transmission Systems (FACTS), Static synchronous compensator (STATCOM) , Static Var compensator (SVC) , Unified power flow controller (UPFC) , Dynamic voltage restorer (DVR), Voltage source converter (VSC) , Insulated gate bipolar transistor (IGBT) ,Matrix laboratory (MATLAB).

1. Introduction

Renewable sources of energy such as wind, hydro, biomass solar, etc these are a good sources of energy that one can get. They are non polluting and moreover reasonable to get it.Wind power has many advantages that make it a lucrative source of power for both utility scale and small distributed power generation applications. Wind power doesn't produce any emissions and is not run down with time. Wind applications can take many forms, including large wind farms, distributed generation and single end use systems. Utilities can use wind resources tactically to help reduce load forecasting risk and trapped cost. Wind energy reduces dependence on conventional fuels that are subject to price and supply instability. Hence due to this consideration now in India wind power development has begun from last many years.[1]

In India, most of the wind plants are based on squirrel cage induction generator. Since it has simple construction and does not require much maintenance it has been widely used. Whenever any fault or disturbance occurs into the system, the wind plant use to get trip leaving the grid with fault due to unfulfilling the requirement of IG during the fault. Due to which grid enables to handle the fault hence leads to instability into the system. IG requires some amount of reactive power to generate active power, if grid enables to provide hence such problem occurs.

Nowadays FACTS devices have been used to secure the system from unwanted damping oscillation, loading. Devices such as STATCOM, static var compensator, and unified power flow controller provide solution to eliminate such problems into the system. STATCOM somewhat gives more stable performance then other facts devices due to its many advantages .[2] It is a regulating device used on alternating current electricity transmission network. STATCOM is based on power electronic voltage source converter and can act as either a source or sink of reactive ac power to an electricity network. Usually a STATCOM is installed to support a network that has a poor power factor often poor voltage regulation. The most common use of it is for voltage stability. They are also widely use to control power flow and improve the transient stability of the system.[5]

Many conventional controllers have been used in the STATCOM to improve the system behavior. From which Fuzzy is proven out to be the most preferable one. In this work, we proposed the comparative analysis between PI and Fuzzy controller based STATCOM, for the compensation of reactive power during disturbance, by considering different cases and their respective results of performance using MATLAB. [3]

2. Modeling of Wind Farm with STATCOM

Fig. 1 Shows the main model of the work. Modeling has been done using STATCOM connected with 33kv bus.120kv of grid is connected with frequency of 60HZ of the system. Transformer having rating of a120kv/33kv whose primary is star grounded.

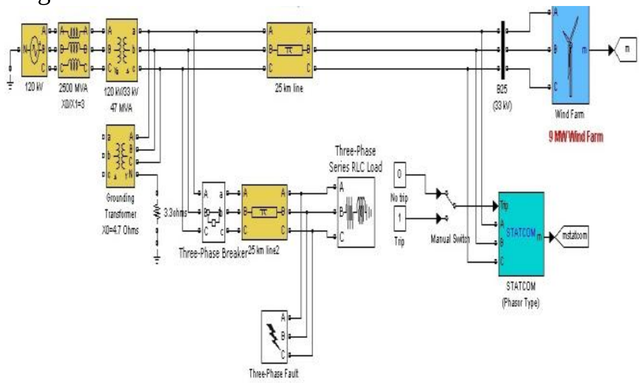

Figure 1: Modeling of wind farm with STATCOM

Grounding transformer is parallel connected to transmission line which is use to neutralize surges. Three phase RLC series load is connected with the 25km transmission line. Wind farm comprises of three set of wind turbine each having two turbine of 1.5mw. in total wind farm has 9MW of capacity.

3. Wind Turbine

Wind turbines are normally based on IG as already discussed. to the grid. Kinetic energy available in the wind is converted into electrical energy by means of rotor gearbox and generator. The wind turns the blades of wind mill like machine. The pitch angle needs to be controlled to maintain the generator output power to its nominal value in case if wind speed is high. Induction generators speed must always be slightly above then synchronous speed for the generation of power . But due to the variation of the speed since it is so small that wind turbine induction generator has to be considered as fixed speed wind generator.[9] The mechanical power that wind extracts can be given as

$$P_m = 0.5\, C_p\, (\lambda, \beta)\rho A V^3 \quad (1)$$

Where, P_m is the mechanical output power
C_p is the turbine's performance coefficient
$\lambda\beta$ is the pitch angle of the blade
ρ is density of air
A is the swept area of the turbine
V is the speed of the wind

$$\lambda = \frac{V_W}{\omega_\beta} \quad (2)$$

$$C_P\,(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_2} - C_3\beta - C_4\right) e^{\frac{-c_5}{\lambda_i}} + C_6\lambda \quad (3)$$

Equation (3) is another equation to model the performance coefficient of turbine with blade pitch angles.

4. Modeling of STATCOM

STATCOM is the most advantageous FACTS device. Such as it is flexible in nature and compact in size. It basically helps to improve the transient stability of the system the function is similar to that of synchronous condenser. In general it provides reactive power compensation to solve a variety of power system and industrial system problems. A STATCOM consist of three phase inverter using SCR, MOSFET, or IGBT. Fig 2 shows STATCOM based on VSC with IGBT to produce the voltage V_2, it is having a dc capacitor V_{dc} which provides the dc voltage.

As shown in fig V_1 is the voltage of the system which is to be controlled whereas V_2 is the voltage which is generated by VSC. STATCOM acts as capacitive and it generates reactive power if the system voltage is low. Whereas it act as inductive and absorb reactive power when the voltage of the system is higher. Voltage source converter (VSC) is responsible for such behavior of reactive power. VSC is connected at the secondary side of transformer.
The block of control system shown consist of an important block of phase locked loop (PLL), this block helps to compute the components of direct and quadrature axis of three phase voltage and current respectively. The output of AC voltage regulator gives I_{qref} which is responsible for reactive power compensation and DC voltage regulator gives I_{dref} responsible for controlling active power flow. The phase of the voltage and magnitude generated by PWM converter is been controlled by current regulator block. Now from PWM modulator pulses are given back to VSC. [4]

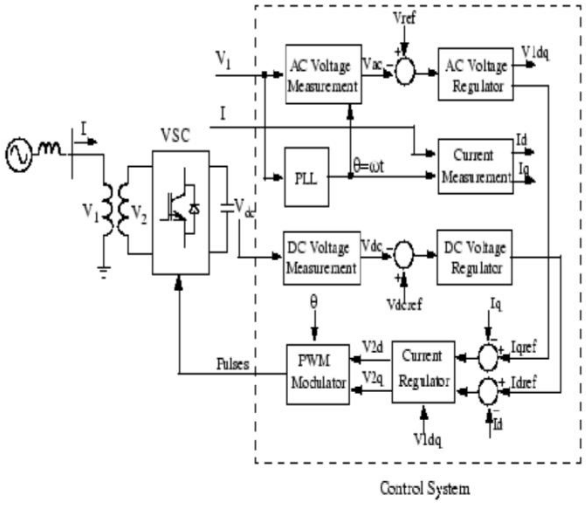

Figure 2: modeling of STATCOM

5. PI Controller Design

The classical PI controller finds extensive application industrial control. The structure of continuous time PI controller used in Fig. , where E_{rr} signal of terminal voltage of IG is the input. K_P and K_i represents constant proportional and integration gain.

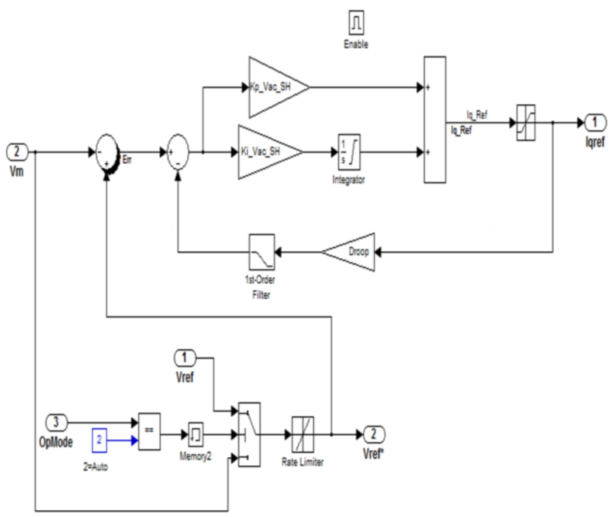

Figure 3: PI controller connected in STATCOM

6. Fuzzy logic Controller inside STATCOM

The PI controller of AC voltage controller is chosen for the replacement with fuzzy controller. Fuzzy logic is a branch of artificial intelligence that deals with reasoning algorithm use to emulate human thinking and decision making in machines. These algorithms are used in applications where process data cannot be represented in binary form.

The input to the fuzzy system is the output of the process, which is entered into the system via input interfaces. Information would then go through the fuzzy logic process where the processor would analyze a database to obtain an output. It involves the execution of IF….THEN rules which are based on input conditions. Then it specifies how well it fits into a particular graphic set

The output of a fuzzy controller is also defined by grades. The three main actions performed by fuzzy logic controller are : Fuzzification , Fuzzy processing , Defuzzification.
When the fuzzy controller receives the input data it translates into a fuzzy form. This process is called Fuzzification. It consist of two main component: membership functions and lables. [6]

1) Membership Functions
During fuzzification a fuzzy logic controller receives input data , also known as fuzzy variable and analyses it according to user define charts called membership function, it can be of any shape like triangular, Gaussian, S or Π shape .

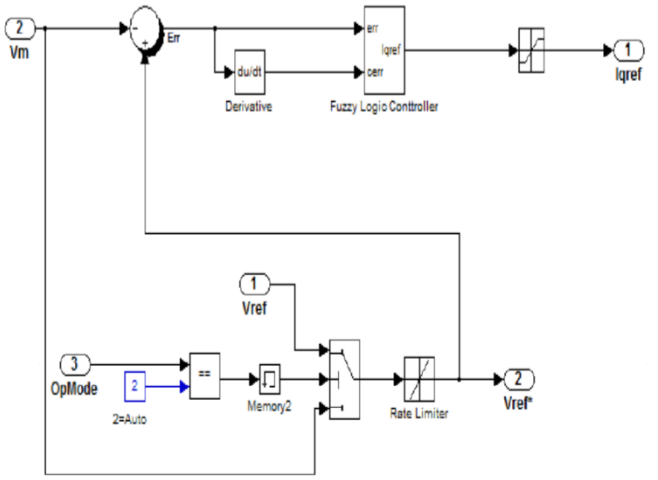

Figure 4: Design of Fuzzy controller in STATCOM

2) Labels
Each fuzzy controller can have several membership functions. Each membership function is defined by a name called as label.
During fuzzy processing the controller analyzes the input data, as define by membership functions, to arrive at a control output. Once the fuzzy controller finishes the rule processing stage and arrives at an outcome conclusion it begins the de-fuzzification process. Fig 4 shown is the design of fuzzy controller connected inside the STATCOM by replacing PI controller. Fuzzy controller requires two input signal error and complimentary error signal. Derivative block is nothing but the complimentary error block, both the signals is then given to fuzzy logic controller. The inside view of fuzzy logic controller is shown in fig 5, with a gain of 2 & 10 respectively.

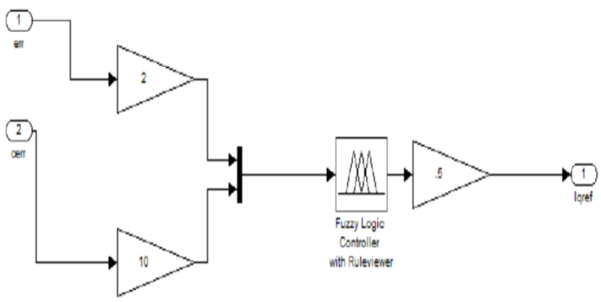

Figure 5: view of Fuzzy Logic Controller

The triangular membership functions for the input & output fuzzy sets are shown in Fig 6. The linguistic variables are represented by R (Red), Y (yellow), and G (green) for input. The proposed fuzzy controller is based on Mamdani's concept with centre of area method (COA). Fig 6 shows the input membership function. Whereas fig 7 shows the output set of fuzzy with nine rules implemented. [7][8]

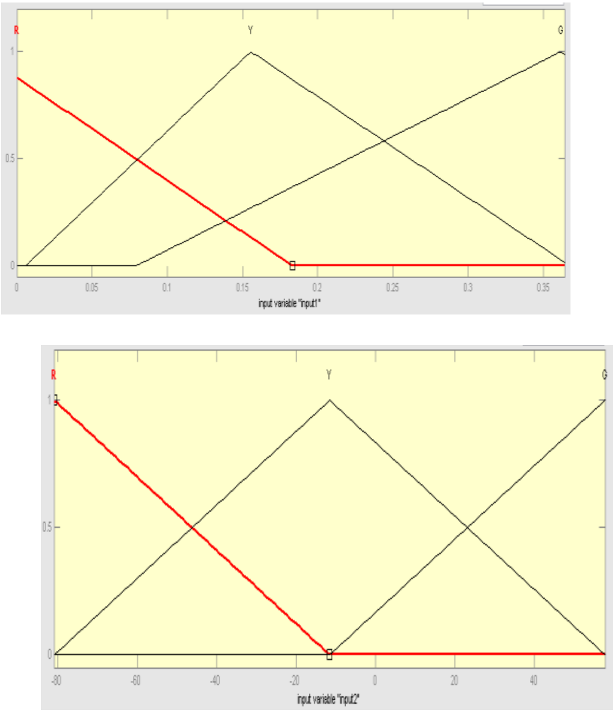

Figure 6: input membership function

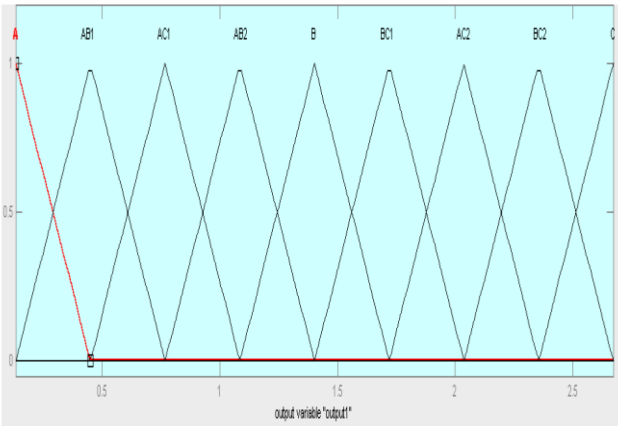

Figure 7: Output membership functions

IF-THEN rules are implemented as :
IF (input 1 =R) and (input 2 = R)THEN (Iqref = A)
IF (input 1 = R) and (input 2 = Y)THEN (Iqref = AB1)
IF (input 1 = R) and (input 2 = G) THEN (I_{qref} = AC1)

Table 1: Rule chart

OUTPUT		INPUT 2		
		R	Y	G
INPUT 1	R	A	AB1	AC1
	Y	AB2	B	BC1
		AC2	BC2	C

7. Simulation Analysis

CASE I: Considering initial condition

In this case the System behavior is seen when there is no fault in the system. The simulations are carried out and comparison is made between both the controllers. The dotted line shows the result of fuzzy and normal line indicates about PI. Fig shows the terminal voltage of IG. Results clearly indicate that fuzzy gives more stable result than PI. The terminal voltage gets stable faster with fuzzy controller than PI controller as shown in figure. Looking at figure 9, there is a wide difference in the result of both the controllers, even when the fault did not occurred the reactive power generated by STATCOM with fuzzy controller fives better performance than PI .

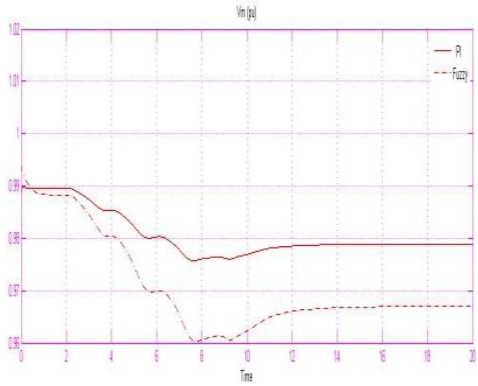

Figure 8: Terminal voltage of IG under initial state

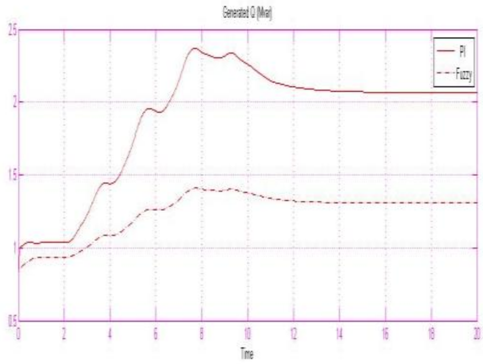

Figure 9: Reactive power generated by STATCOM

CASE II: When fault occurs in the system

Now considering when LLLG fault occurs into the system. Fault time is set at 15sec, for reactive power compensation STATCOM is connected in the system. When fault occurs into the system, need of reactive power compensation increases. Looking at the voltage profile of figure 10, when fault occurs it gets completely dip at 15 sec with PI controller and recovers after sometime, but with fuzzy controller it recovers almost in 15.1 sec. Similarly reactive power compensation with PI controller takes more time to make the system stable but with fuzzy it immediately improves the transient stability of the system by compensating reactive power and recovers the system making it stable within less time.

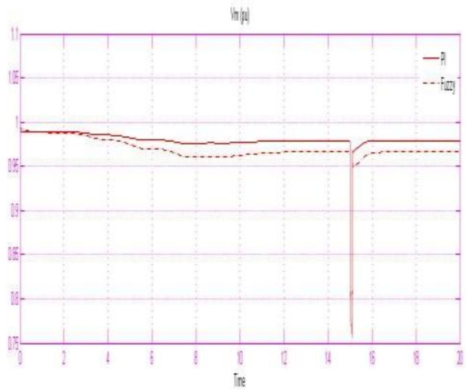

Figure 10: Terminal voltage during LLLG fault

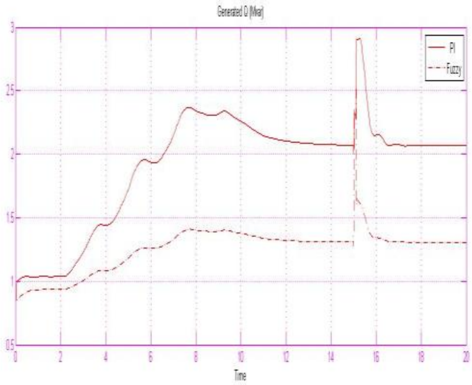

Figure11: Reactive power generated during LLLG

CASE III : When fault occurs at the Grid

Another case is considered, when fault occurs at the grid itself. Simulation results is been carried out when the amplitude of the grid is changed i.e when fault occurs into the grid respectively. Results are compared with PI & fuzzy controller connected in STATCOM gives the following results regarding the affect on terminal voltage of STATCOM when amplitude gets changes into the grid. Seeing the results it can be concluded that STATCOM with fuzzy gives much stable performance than PI controller.

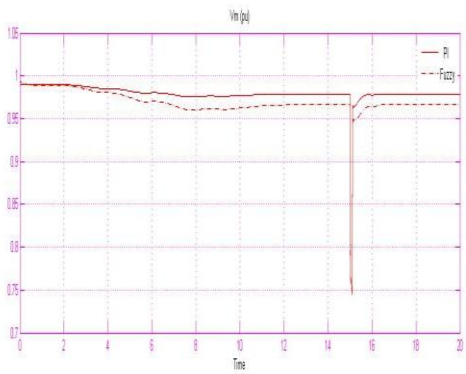

Figure12: Behavior of voltage during fault at grid

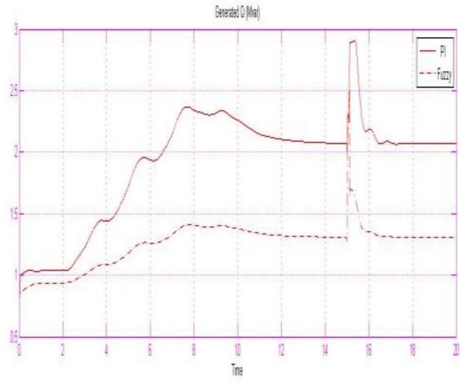

Figure 13: Reactive power generated during fault at grid

8. Conclusion

In this work, importance of renewable source of energy especially wind energy is focused onto which the importance of FACTS device STATCOM is projected. Here in this work STATCOM based on voltage source converter is been used with two different controllers PI and FUZZY. STATCOM is a FACTS device that not only enhances steady state stability but also improves transient stability of the system when any disturbance or any severe fault occurs into the system. Comparative analysis between PI and FUZZY controllers has been made to detect which controller gives better performance with STATCOM. Simulation is done using MATLAB. Results clearly prove that fuzzy controller based STATCOM gives much better result than PI controller. In our future we would like to study wind turbine based on doubly fed induction generator and its effect on the system

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