I J C T A, 9(5), 2016, pp. 2315-2322

ANFIS Based Soft Computing Approach of STATCOM for Multi Machine System Stability Analysis

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ABSTRACT

In this paper, the static synchronous compensator (STATCOM) is used to improve the damping effect of an off-shore wind farm (OWF) connected to 9-bus 3-machine system. The operation of OWF analyzed with doubly-fed induction generator (DFIG). The operating behavior of the studied OWF is designed by an equivalent doubly-fed induction generator (DFIG) fed by an equivalent model of wind turbine (WT) through a gearbox. A fuzzy logic controller (FLC) and a hybrid PID plus adaptive neuro-fuzzy inference system (ANFIS) of the proposed STATCOM are designed to grant adequate damping characteristics to the effective modes of the system considered under different operating conditions. It can be concluded from the provisional simulated results that the proposed STATCOM with PID plus ANFIS controller improves the stability of system compare to STATCOM with FLC controller.

Keywords: Doubly-fed induction generator, fuzzy logic controller, multi-machine system, offshore wind farm, stability, static synchronous compensator, PID, ANFIS.

1. INTRODUCTION

When the wide range of renewable energy sources are taken in to consideration the wind energy has been more competent in harnessing and judicious in utilization. There are some small scale OWF are under evaluation and some large scale OWF have been under operation commercially. But the impact of power quality has been a concern when an extensive quantity of electric power of OWF fed to power grids due to the reactive power and harmonics. One of the solutions to overcome such adverse impacts to improve the damping of power system by introducing FACTS devices. With the help of FACTS devices the stability of the power system can be greatly improved and extract the effective control of the power flow and quality. The STATCOM is a shunt FACTS device that can effectively control the power flow by controlling reactive power of transmission lines [1].The STATCOM plays a role in enhancement of power system oscillations [2-3].This paper presents the damping-improvement results of DFIG OWFs using a STATCOM with a designed ANFIS and PID damping controller.

2. PROPOSEDTEST SYSTEM CONFIGURATION

Figure 1 shows representation of proposed test system. A OWF and STATCOM are connected between bus 6 and bus 9 of a proposed multi machine system. The OWF is fed with DFIG type of induction generator and run with variable-speed wind turbine (VSWT) with a proper gearbox. The required mathematical modeling of the system considered is described as below.

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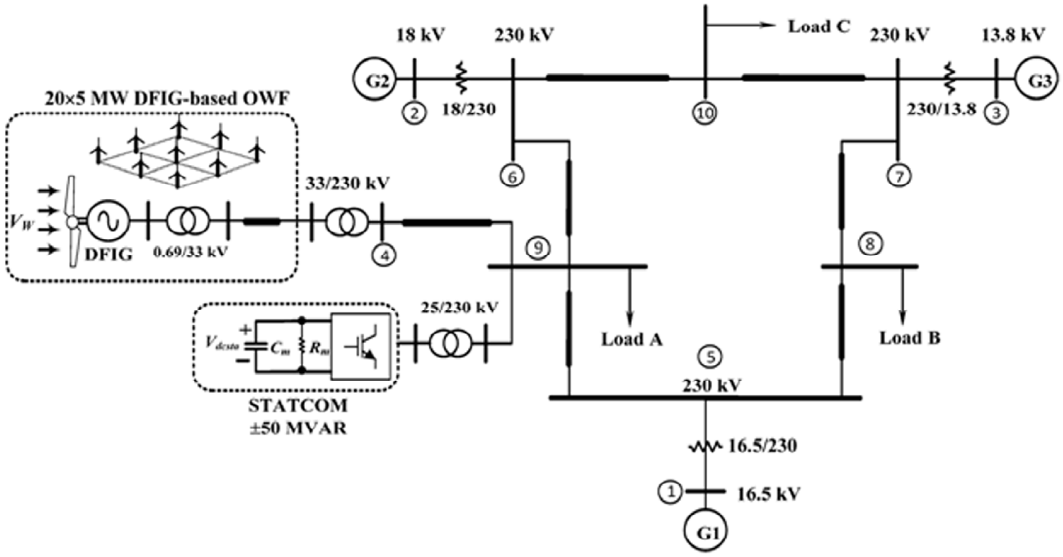

Figure 1: Single line diagram representation for proposed test system

2.1 Wind Turbine

The prime mover power captured (in *W*) by a variable-speed wind turbine (VSWT) can be written by

$$P = \frac{1}{2}\rho \bullet A \bullet V_{\omega}^{3} \bullet C_{p} \quad (1)$$

The power coefficient (C_p) of the VSWT is given by

$$C_P = 0.5\,[(116/\lambda_i) - 0.4 \times \beta - 5]e^{-21/\lambda I} + 0.0068 \bullet \lambda \quad (2)$$

Where λ is the Tip Speed ratio [7], β is the Pitch angle of the blade

$$\lambda = \frac{WR}{V\omega} \quad (3)$$

Where *W* is the Rotor angular speed in rad/sec, *R* is the Rotor blade radius in meter

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.088\beta} + \frac{0.035}{\beta^3 + 1} \quad (4)$$

Pitch Angle controller will starts at when the wind speed reaches to its rated or above rated value. Up to cut in to rated speed will maintain zero for optimum power extraction from the wind. The wind profiles of VSWT are 5, 12, and 19 m/s. When V_W > 14 m/s, $\beta = 0^0$. When V_W>14 m/s, the pitch-angle control is used to maintain constant turbine output power.

2.2. OWF Model with DFIG

DFIG stator and rotor is fed to primary side of 0.69/33-kV step-up three phase transformer and the rotor is fed withan inverter, a grid-side rectifier, DC link betweenGSC and RSCand a transmission line. For rated operation of a DFIG, inverter and rectifier effectively controls the real and reactive power. Figure 2 represents controller designed for inverter control, and the working of inverter depends on i_{qrw} and i_{drw} to track the required reference position based on system real power and the t/f primary side voltage at the pre mentioned reference values. The voltage need for the inverter (v_{rw}) is getting by adjusting Ipu of d-axis and q-axis of the inverter.

The controller used for grid-side converter is given in Figure 3. The Ipu of d-axis and q-axis of rectifier, i_{qgw} and i_{dgw}, are track to get required values that are calculated by tracking the DC line voltage V_{dcw} at pre-

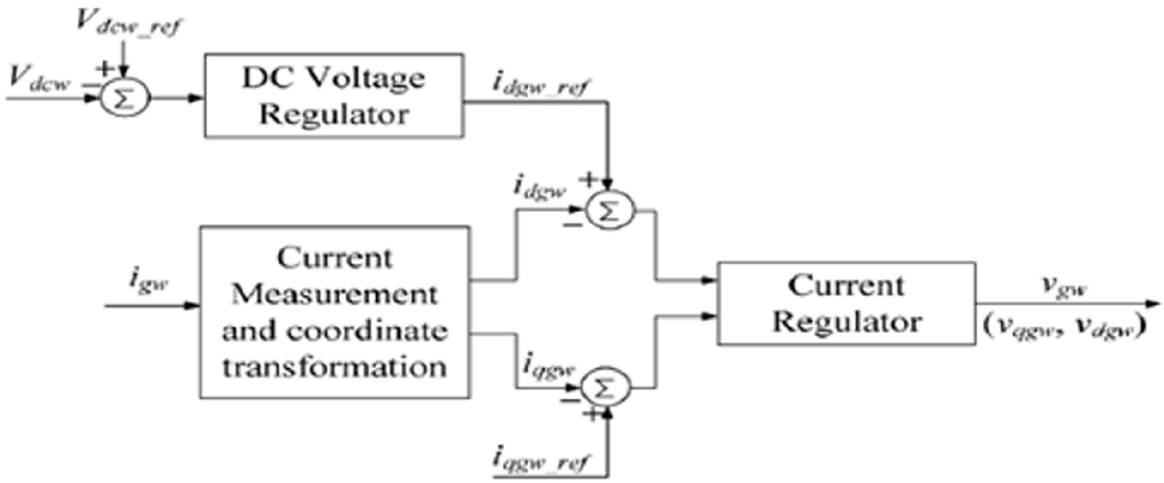

Figure 2: Current controller for the GSC of the proposed system

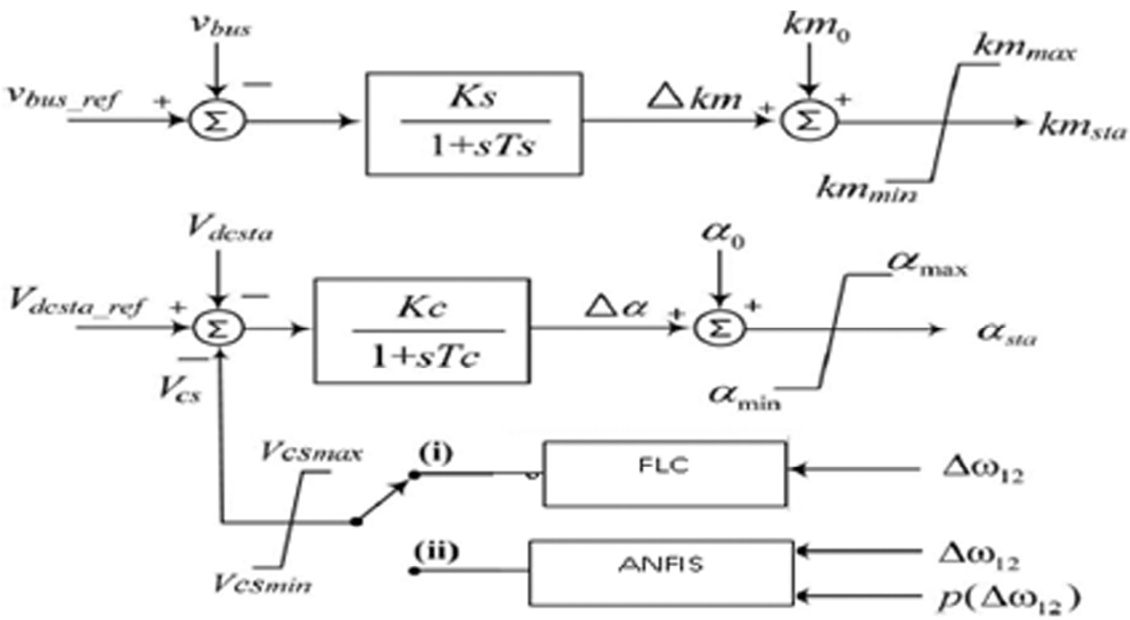

Figure 3: Controller block diagram for STATCOM with FLC and ANFIS

determined reference point to maintain rectifier voltage (V_{gw}) at UPF. The needed voltage level of the rectifier is getting by maintain the Ipu of d-axis and q-axis rectifier [3].

2.3. STATCOM Model

Implementation of proposed STATCOM model [17] mathematical format is, respectively,

$$V_{dsta} = V_{dcsta}.Km_{sta}.\sin(\theta_{bus} + \alpha_{sta}) \tag{5}$$

$$V_{qsta} = V_{dcsta}.Km_{sta}.\cos(\theta_{bus} + \alpha_{sta}) \tag{6}$$

Here V_{dsta} and V_{qsta} are the direct axis and quadrature component of STATCOM. Km_{sta} and α_{sta} are the angle and index for PWM of STATCOM

$$(C_m)\, p(V_{dcsta}) = W_b\left[I_{dcsta} - \left(\frac{V_{dcsta}}{R_m}\right)\right] \tag{7}$$

Here p is a differential component of time t and; electrical losses of the STATCOM is

$$I_{dcsta} = i_{dsta}.Km_{sta}.\sin(\theta_{bus} + \alpha_{sta}) + i_{qsta}.Km_{sta}.Cos(\theta_{bus} + \alpha_{sta}) \tag{8}$$

3. DESIGN OF DAMPING CONTROLLERS FOR STATCOM

3.1. Fuzzy Logic Controller (FLC) Design

These employs mathematical analysis of Fuzzy logic controller design, the steps included in Fuzzy logic controller design [13] and [14] are: 1) Fuzzification 2) Decision-making logic 3) knowledge base and 4) Defuzzification. This paper utilizes the Sugeno-type fuzzy inference system when compared to the mamdani type fuzzy inference system since Sugeno-type fuzzy inference system works well with soft computing techniques.

3.2. Adaptive Neuro-Fuzzy Mechanism

Adaptive neuro-fuzzy technique (or Adaptive neuro-fuzzy inference controlling system, ANFIS) has been suitably involved in the designing [15] of Fuzzy inference system (FIS).

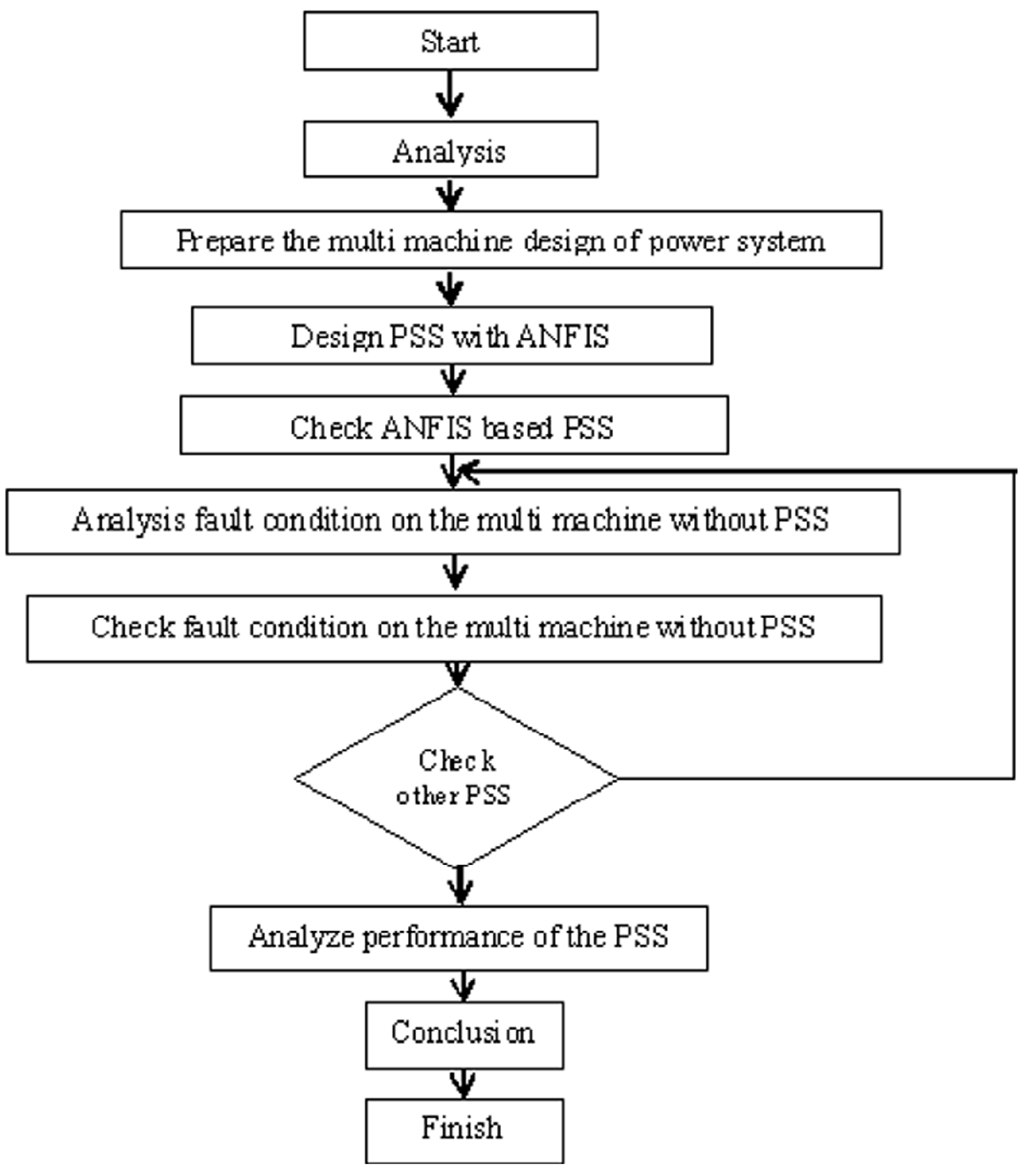

Figure 4: Flow chart of the proposed method

In this context, the designing has been accomplished with sugeno type technique that lines out the input characteristics to input membership functions. Then it indicates input membership function to rule base and rules to a set of outputs. It represents output characteristics to output membership functions, and the membership function to a single output or a decision interacts with output. Fuzzy inference is applicable to only modeling system whose structure is virtually designed by the users perception of the variable characteristics modeled in the inference system. In some sort of designing conditions it may not be easy to analyze the data of the membership functions it should be more correlate with the membership function promptly. Neuro-adaptive learning techniques accommodate a method for the fuzzy modeling procedure to memorize information about the feed data of output or input. It measures the membership function parameters that best allow the combine fuzzy inference system to record the given input/output data.A network-type structure similar to that of a neural network system has been adopted to strengthen and improvise the input/ output map such a way that it is ample to measure the input units through the pre mentioned membership functions of input/output parameters that are correlated with the membership functions which can be altered through the learning procedure. In the process of calculation, the variable parameter changes are supplemented with a gradient vector, which has been used as reference to the FIS to measure the input/output data in correspondence with the pre-determined parameters. In this study, we present [16] an adaptive neuro-fuzzy approach for the design of power system stabilizer (PSS). The Flow chart of the proposed method is shown in Figure 4.

4. SIMULATION RESULTS

In this section a nonlinear model is used to compare the damping characteristics modified by the proposed STATCOM joined with the designed FLC controller and PID plus ANFIS controller to improve stability of the system under 3-Φ short-circuit fault at bus 9 of Figure 1. The three phase short-circuit fault has applied to bus 9 during *t* =1*s* to 1.1*s*. While this type of fault suddenly occurs in real power systems, it is the most danger and heavy fault to check system withstand capability at these faults. If the system taken as stable when this hazardous suddenly happened faults are cleared by different safety methods, i.e. the system considered have ability to maintain the system in healthy condition at systems are subject to different types faults like single L-G fault, L-L fault, etc. Let us take base wind speed of DFIG OWF is 12m/s while nine bus three machine system is in stable operation. The simulation results of the implemented system represented in Figure 5. This Figure 5 shows comparative response of STATCOM based system with FLC and PID plus ANFIS controller. It is observed from the comparative analysis in Figure 5 that the proposed STATCOM with PID plus ANFIS controller can offer better damping performance.

5. CONCLUSION

This paper has describes the damping controller performance improvement with ANFIS based DFIG using a STATCOM. STATCOM is connected at optimal position to compensate reactive power. Damping controller

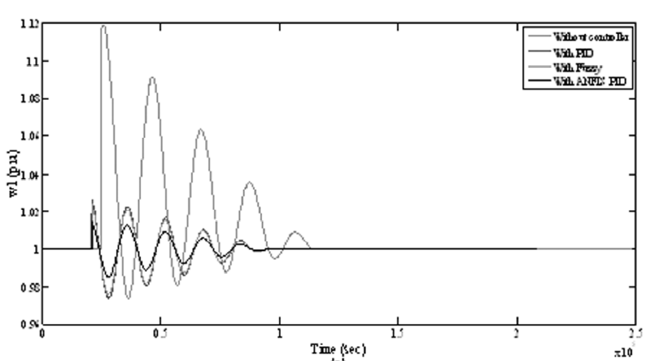

Figure 5 (a): Rotor Speed of Generator 1

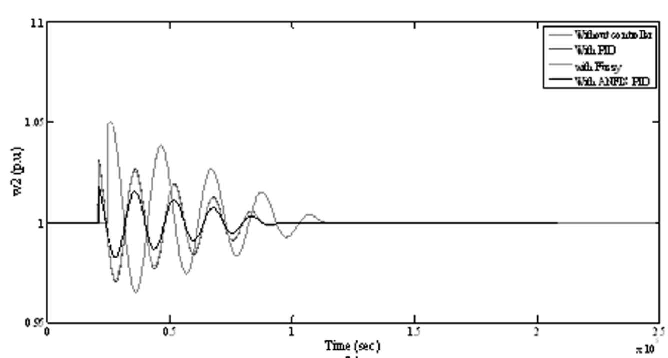

Figure 5 (b): Rotor Speed of Generator 2

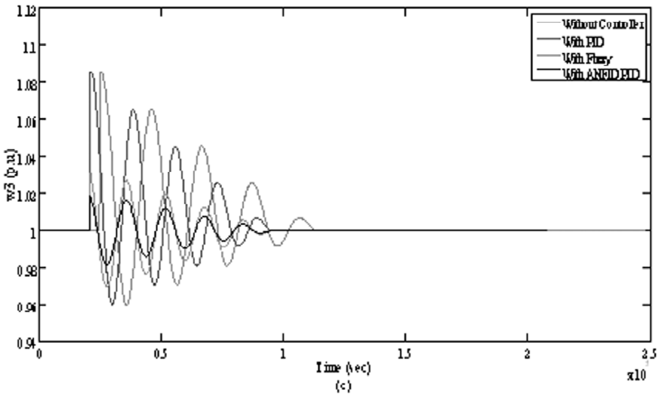

Figure 5 (c): Rotor Speed of Generator 3

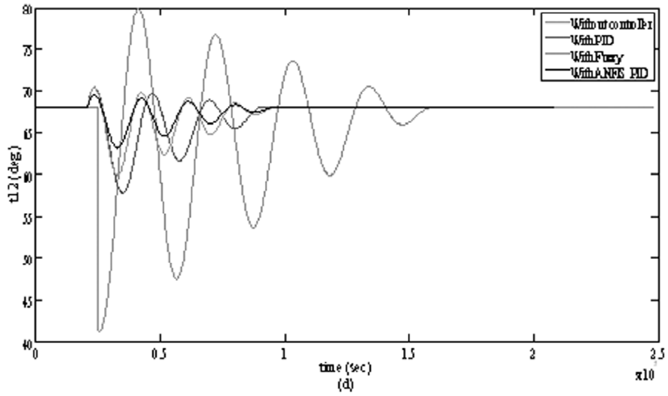

Figure 5 (d): Rotor angle deviation between Generator 1 to Generator 2

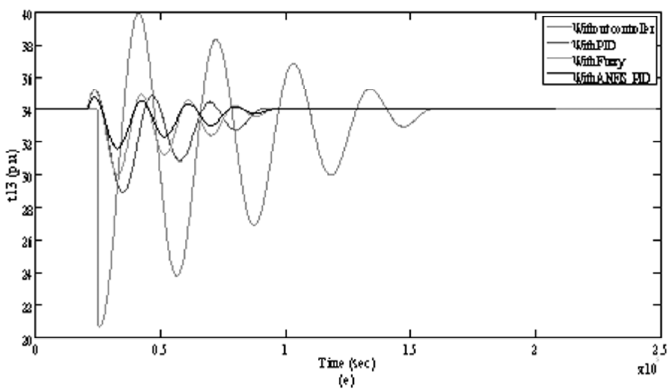

Figure 5 (e): Rotor angle deviation between Generator 1

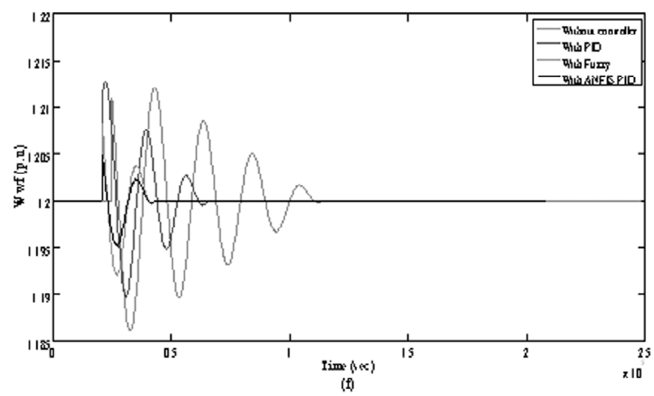

Figure 5 (f): Proposed Off Shore Wind Farm (OWF) to Generator3 DFIG Rotor Speed

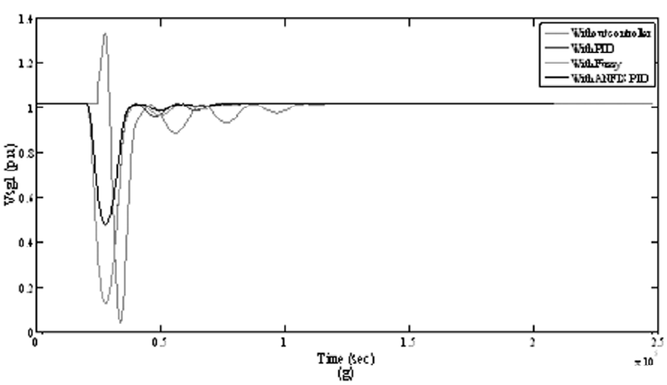

Figure 5 (g): Generator 1 Terminal voltage

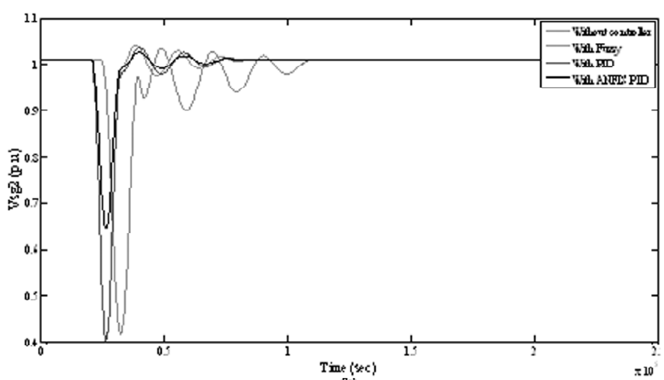

Figure 5 (h): Generator 2 Terminal voltage

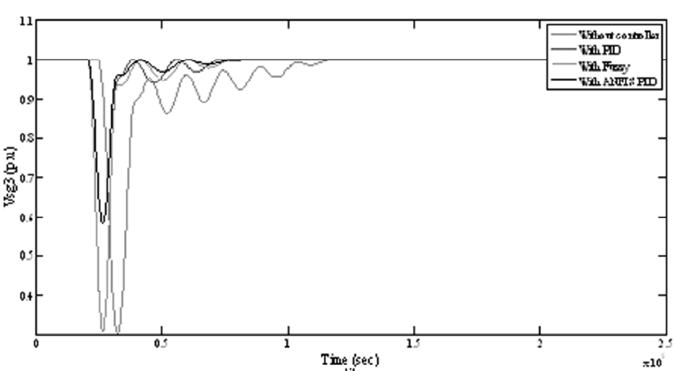

Figure 5 (i): Generator 3 Terminal voltage

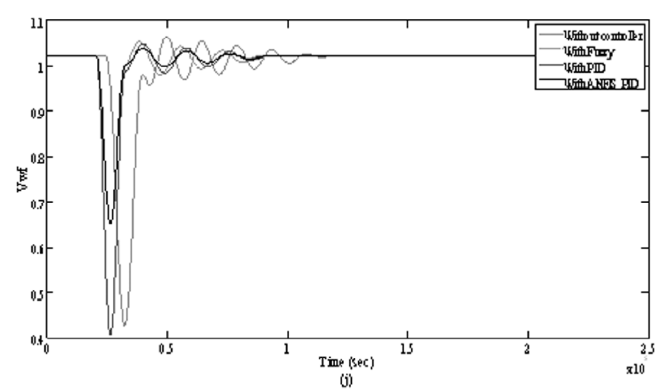

Figure 5 (j): Off Shore Wind Farm (OWF) Voltage

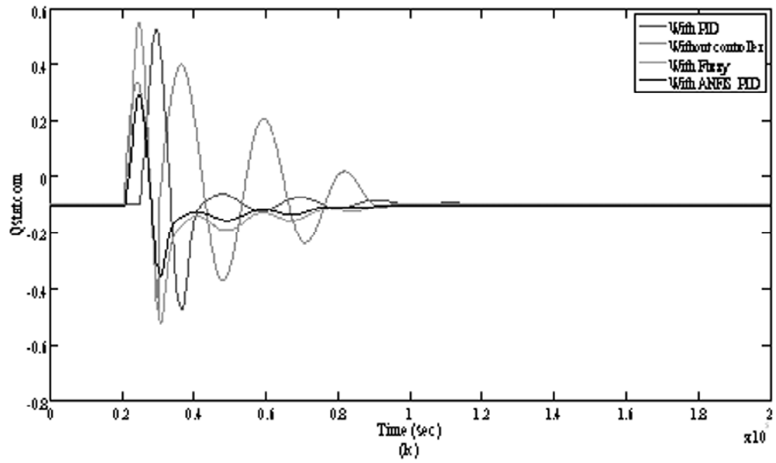

Figure 5 (k): Reactive power supplied by STATCOM

is developed to track the power oscillations of the DFIG based WT as feedback control designed. The comparative analysis performed on the effect of STATCOM with PID and with ANFIS controller at faulted condition on stability point of system. Finally it was justified from system response that suggests SATCOM with PID plus ANFIS can give better damping behavior than conventional methods when the DFIG based OWF connected to power system.

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