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Dynamic Stability Improvement of a Smart Grid Using Neural Network Based STATCOM

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Abstract

Objectives: A micro grid is a cluster of loads and distributed resource units serviced by a distribution grid and capable of operation in a grid –connected mode, in an autonomous mode or a ride-through between the above two modes. **Methods:** Micro grids are significant for local reliability, considerable reduction of losses, different costs and continuity of service. Smart Grid is formed with the interconnection of different generating resources and loads, the characteristics of the grid can be modified according to the requirements. The major challenges are fault clearing, voltage regulation, islanding, and power quality and interfacing with the utility system in terms of its stability. **Findings:** This paper describes improvement of dynamic stability in interconnected on and off shore wind turbines with Proposed Artificial Neural Network Controller compared with the discrete Proportional–Integral–Derivative (PID) controller. As per the references indicated, the generators driven by OWF may be modeled as the parallel connection of several Doubly -Fed Induction Generators (DFIGs) and the generators driven by MCFs can be modeled by means of Squirrel Cage Induction Generators (SCIGs) well efficiently. Normally, STATCOMs or different combinations of Flexible AC Transmission System (FACTS) devices are used as large scale control devices in many applications. In the present work, Artificial Neural Network (ANN) based PID controller is used instead of Discrete PID controller for providing control pulses to the STATCOM connected to the grid system.

Keywords: Artificial Neural Network, Converter, Power System Stability, Smart Grid, Static Var Compensators

1. Introduction

In the present scenario, power quality and power supply are the main problems in power system. So that, the DG systems has got lot of importance because of the limitation of conventional power generation. The main advantage of DG system, it is more productive, high quality, and provides power to loads to maintain continuous administration.

Figure 1 shows the architecture of STATCOM based off-shore and on-shore wind turbine system. In order to improve the system performance by reducing disturbances in this system the PID controller is replaced by ANN controller[1]. And the performance of the system is verified using MATLAB/Simulink using both PID and ANN controller and also a comparison analysis is done for these two techniques.

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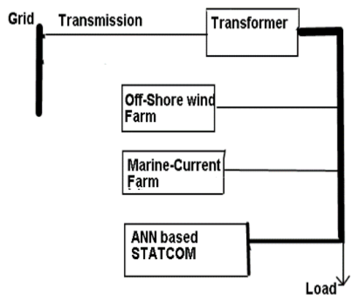

Figure 1. Proposed smart grid consisting of OWF and MCF generations.

2. Off-Shore Wind Farm

Offshore wind resources are vast and they are located near the fastest-growing electricity demand centers. Offshore wind development, therefore, offers valuable countries economy, environment, and national security. It provides a source of clean, domestic, inexhaustible energy with which to meet fast-growing electricity demand, in close proximity to population centers[2].

There are different offshore wind farms existing and under development in UK (4494MW), Belgium (712MW), China (670MW), Netherlands (247MW) and sweedon (212MW).

Wind turbines square measure classified into two types[5]: Horizontal and Vertical axis. A vertical axis machine has its blades rotating on AN axis perpendicular to the bottom. There square measure variety of obtainable styles for each and every kind has bound benefits and downsides. The numerous opportunities offered by wind power in the open sea are constant wind speed, increased turbine output due to low turbulence[3], reduced material and costs, cheaper turbines requirement, etc.

The expression for mechanical power from wind turbine is expressed as

$$P_m = \frac{1}{2} pAVC_p(\lambda, \beta)$$

3. Doubly Fed Induction Generator

An Induction machine is generally a rotating machine whose steady state speed is proportional to frequency of the armature current. The basic structure of the permanent magnet synchronous machine for wind system is shown in Figure 2. Generally, DFIG 6 machines are two types such as cylindrical and salient rotor types. The operational modes of DFIG is decided by the sign of electro-mechanical torque (such as +Ve sign for motoring operation and –Ve sign represents generating condition). For modeling DFIG machine the electrical and mechanical parts are indicated in the form of state space analysis 7. In case of DFIG machine the stator flux produced by the rotor is always sinusoidal.

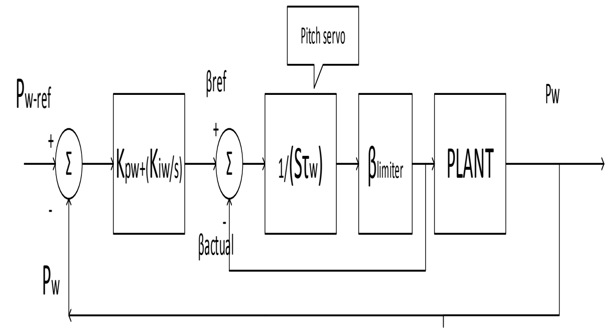

Figure 2. Block diagram of the pitch-angle control system of the studied WT.

Table 1. Transmission line parameters connecting OWF to the grid

Resistance/ph	0.02pu	0.004761Ω
Inductance/ph	0.4 pu	0.09522H

Table 2. Transmission line parameters connecting STATCOM to the grid

Resistance/ph	0.05pu	0.005951Ω
Inductance/ph	0.2 pu	0.0238H

Table 3. Load (RL load) parameters

Resistance	1.9Ω
Inductance/ph	0.9522H

4. Power Converters of DFIG

An Induction machine is generally a rotating machine whose steady state speed is proportional to frequency of the armature current. The basic structure of the Induction machine for wind system is shown in Figure 3. Generally, DFIG machines are two types such as cylindrical and salient rotor types. The operational modes of DFIG is decided by the sign of electro-mechanical torque (such as +Ve sign for motoring operation and –Ve sign represents generating condition). For modelling DFIG machine the electrical and mechanical parts are indicated in the form of state space analysis 7. In case of DFIG machine the stator flux produced by the permanent magnet is always sinusoidal.

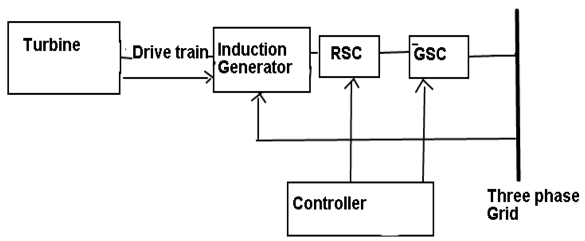

Figure 3. DFIG based wind turbine.

5. Control Block Diagrams of RSC and GSC

The control strategy for the PMSG machine is shown in Figure 4. This control structure is designed by the help of d-q transformation technique 8-9. A general PI controller is used in this paper for controlling unbalanced voltages.

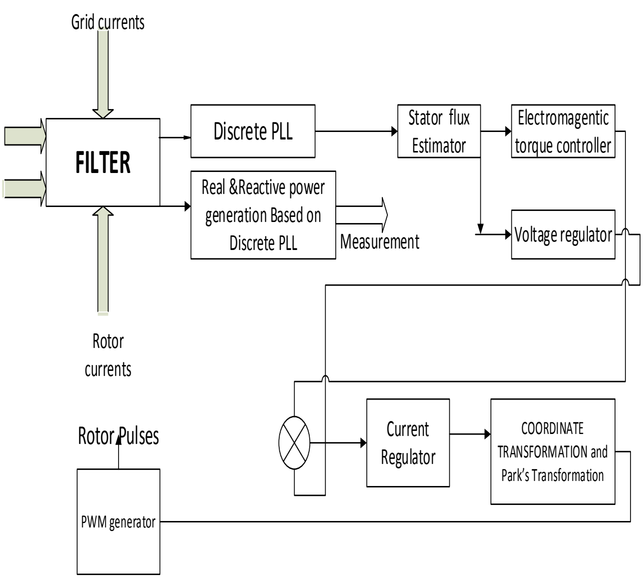

Figure 4. Control block diagrams of RSC.

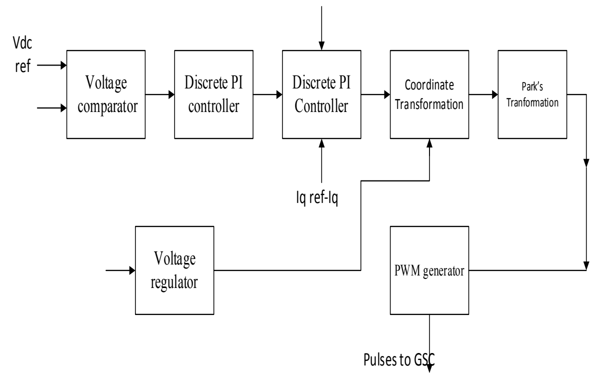

Figure 5. Control block diagrams of GSC.

6. RSC Control

The Grid Voltages and Currents are measured and are given to filter to remove any Harmonics present in them and the signals are allowed to pass through Discrete three phase PLL, which generates frequency, wind speed W_t in rad/sec and Sinθ, Cos θ pair and these Quantities are again given to Discrete three phase PLL driven positive sequence Active and Reactive power generator which computes Real and Reactive powers P and Q based on the grid voltage and current parameters[8,9]. For Three phase voltages and currents the park's transformation is applied individually and the transformed current vector can be applied for the stator of DFIG employed. Based on the transformed values, Stator flux is estimated. From the Estimated stator flux, by applying Voltage Regulator, Rotor reference frame currents were calculated in d-q-0 terms. By applying current regulator and with the help of coordinate transformation techniques, by using PWM generator, the rotor control pulses were developed for RSC. The system parameters for wind control and its drive system is shown in Table 4 and Table 5.

Table 4. Wind turbine parameters

Nominal Mechanical output	1.5MVA
Base power of Electric generator	1.67MVA
Maximum power at base wind speed	0.73pu of Nominal Mechanical output
Base rotational speed	1.2pu of generator speed

Table 5. Drive train parameters

Wind turbine inertia constant	4.32 s
Shaft spring constant	80.27pu of Mechanical Torque/rad
Maximum power at base wind speed	0.73pu of Nominal Mechanical output
Base rotational speed	1.2pu of generator speed
Shaft mutual damping	1.5pu of Nominal Mechanical torque / pu DW
Turbine initial speed	1.2 pu of nominal speed
Initial output of turbine	0.83pu of nominal mechanical torque

7. GSC Control

The reference voltage is compared with measured voltage and based on the error, the Discrete PI controller reference currents are generated in d-q-0 reference frame. The measured grid voltages and reference currents are applied for current regulator for the generation of control voltage pulses for the Grid side converter. By applying Modulation index technique and Coordinate transformation, The PWM generator generates the pulses for Grid side Converter. Three phase asynchronous machine used in conjunction with DFIG[10]. The system parameters for DFIG are represented in Table 6.

Table 6. Asynchronous generator parameters used in DFIG

Nominal power	1.567MVA
Nominal voltage (line-line)	1.975KV
Stator resistance and inductance	0.045 and 0.000673pu
Rotor resistance and inductance	0.0666 and 0.00049pu
Mutual inductance	0.0442pu
Inertia constant	0.685s
Friction factor	0.01pu
Number of pole pairs	3

8. Marine Current Farm

Marine current power is a form of energy obtained by harnessing the kinetic energy of marine currents. Although not widely used at present, marine current power plays important role in future electricity generation. Marine currents are more predictable than wind and solar power. The overall marine current energy production can be cost-effective and therefore suitable for a grid connection.

The marine-current speeds under the knowing tide coefficients as follows:

$$V_{MR} = V_{nt} + \frac{(C_{MR} - 45)(V_{st} - V_{nt})}{95 - 45}$$

Where C_{MR} is the Marine Coefficient,
V_{ST} and V_{nt} are the spring and Neap Marine Current Speeds, 95 and 45 are spring and Neap tide Medium constants. The mechanical power (in W) generated by the studied MCT can be expressed by

$$P_{mmr} = (1/2)\,\rho_{mr}.\,A_{mr}.\,V_{mr}^{\,3}.\,C_{pmr}.(\lambda_{mr}, \beta_{mr})$$

The MCF parameters are shown in Table 7.

Table 7. Asynchronous generator used in MCF modeling

Nominal power	40MVA
Nominal voltage (line-line)	480
Stator resistance and inductance	0.016,0.06pu respectively
Rotor resistance and inductance	0.015,0.06 pu respectively
Mutual inductance	3.5pu
Inertia constant	2
Friction factor	0
Number of pole pairs	2

9. STATCOM

In order to control the reactive power, FACTS controller is better solution. STATCOM is one of the type in FACTS controllers for compensating harmonics in current for improving the power quality. STATCOM mainly consists of two elements such as voltage source converter for controlling purpose and DC-Link capacitor for the purpose of compensation. The basic structure and control diagram of STATCOM is shown in Figure 6. In this paper the STATCOM is proposed using both ANN and PID controller for tuning the harmonics present in the system. The parameters of the PID controller are given underneath:

Kp = 10.5, KI = 2.37, KD = 0.06, TW = 0.08s

The system is simulated for different disturbances and the outputs are obtained[6–8]. The control scheme used here is shown in the Figure 6 . Table 8 shows the STATCOM parameters.

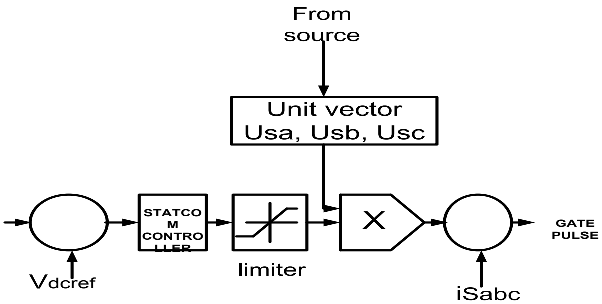

Figure 6. Control scheme of STATCOM.

Table 8. STATCOM parameters

DC voltage	100v Provided by capacitor
Capacitance value	0.074F
Resistance	119Ω
Number of arms in the universal bridge	3
Power Electronic devices used are	IGBT
ON resistance	1mV
Device forward voltage	0v
Transition times	1μs and 2μs respectively

10. ANN Based PI Controller

The basic architecture of the ANN is shown in Figure 7. In this architecture the hidden layer and adaptive node is represented by circle and square respectively. In this structure hidden layers are presented in between input and output layer, these nodes are functioning as membership functions.

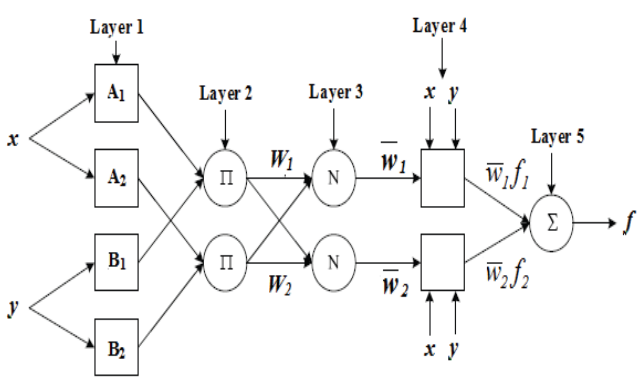

Figure 7. ANN architecture for a two-input multi-layer network.

Where the two crisp inputs are x and y, the linguistic variables associated with the node function are Ai and Bi. The system has a total of five layers are shown in Figure 7.

Step by step procedure for implementing ANN:

1. Assume the input and output parameters of the system.
2. Assign the number of input variables.
3. Assign the hidden layer count.
4. Create the new feed forward network using poslin and transig commands.
5. Choose the learning rate count as 0.02.
6. Assign the number of iteration count.
7. Train the network and set the goal.
8. using 'gensim' command generates the simulation with sample rate as -1.

11. Results and Discussions

Both the systems developed with Discrete PID controller based STATCOM and ANN Based STATCOM Controller are simulated. From the results it can be shown that the Real and Reactive powers of the entire system are very better in the case of the new design based on neural networks.

In this paper, Off-Shore wind farm (0.69KV) and Marine current farm (0.69KV) are connected to the grid of capacity 23KV and for the stability of the grid, the STATCOM controller was developed. The controller was first developed with discrete PID controller and then designed with ANN based PID controller was developed. Both are simulated separately using MATLAB SIMULINK R2009b software. The grid disturbances can be of the form that variations in the wind speed. The different faults at various locations (three phase/single phase etc.). In the present case the single phase fault is applied at the OWF generation point. And the real and reactive powers are observed at various points. It can be evident from the results that In the case of ANN based PID controller for production of grid pulses, the dynamic stability can be enhanced in a very efficient manner. Figure 8, Figure 9 and Figure 10 shows the simulation results for active and reactive power distribuance for proposed STATCOM based OWCT+MCT system.

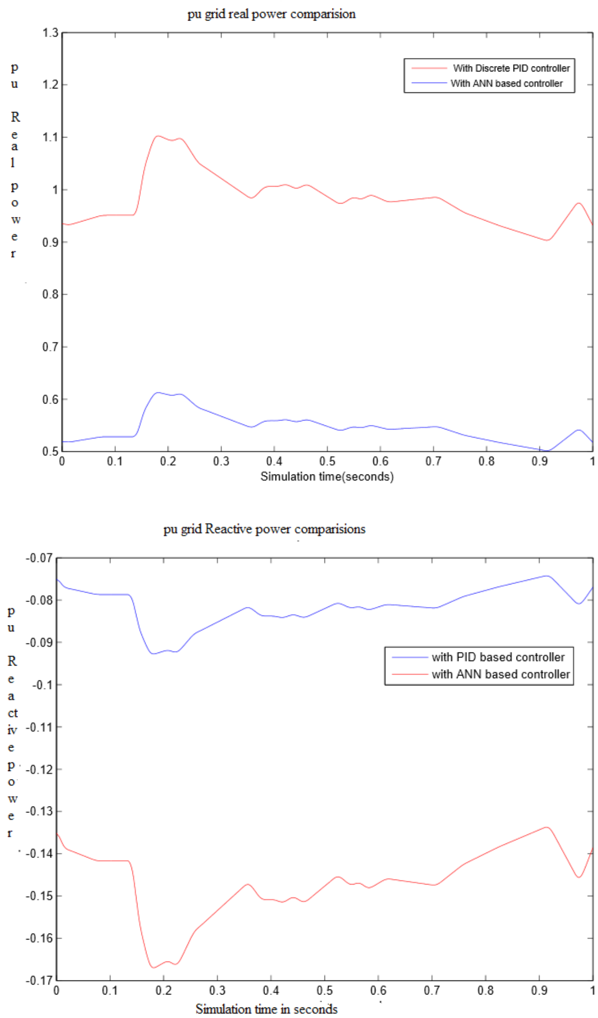

Figure 8. Grid real and reactive power variations with two controllers.

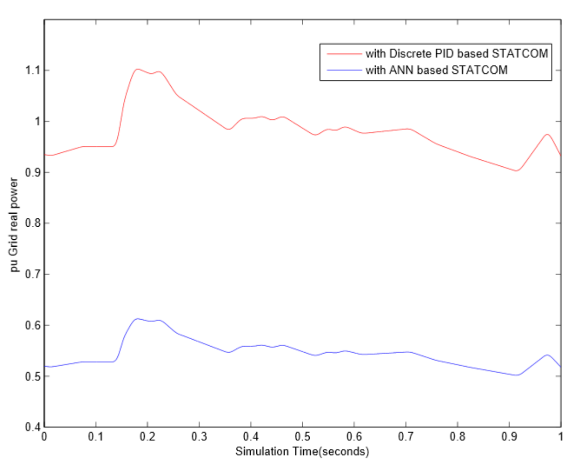

Figure 9. Grid real power disturbance in case of single phase fault at OWF transmission line at 0.1seconds.

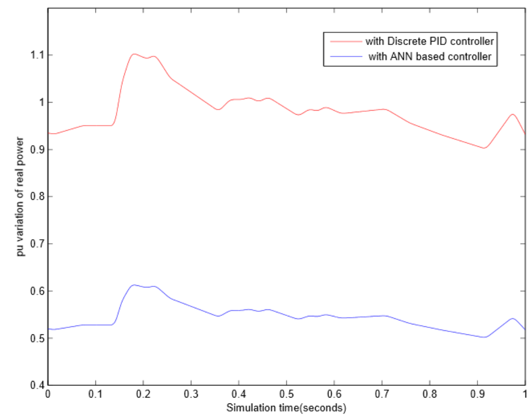

Figure 10. Grid real power disturbance with single phase fault at OWF transmission line and change in the MCF parameter (wind turbine input from 12 to 15m/s).

12. Conclusion

Enhancement of Power Quality for integrated grid connected OWF and MCF using ANN based STATCOM controller is proposed in this paper. The proposed system can be tested using MATLAB/Simulink environment. From this experimental result we conclude that the ANN based STATCOM controller provides the better result as compared with general PI controller.

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