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Research Paper

ANN Control Based Variable Speed PMSG-Based Wind Energy Conversion System

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Abstract

This paper presents a comparative analysis of three control algorithms for a wind turbine generator using a variable speed permanent magnet synchronous generator (PMSG). The design methodologies of the conventional PI based controller, the Taylor series expansion linear approximation based (TSLA-based) controller and the feedback linearization based (FL-based) nonlinear controller are provided. The objective is to keep the wind turbine operating at normal speed of the rotor at maximum power extraction (MPPT control), while insuring the power extracting from the turbine to the generator, regardless of the wind speed. The controller gains of the nonlinear controller are extended with Artificial Intelligence controller approach. The results show a better control performance for the ANN controller. This performance of Ann controller can be characterized by fast and smooth transient responses as well as a zero steady state error and reference tracking quality.

Keywords: *Ann Controller, PI Controller, Permanent Magnet Synchronous Generator, Wind Energy System, Wind Turbine.*

1. Introduction

In the present scenario, wind energy system is fast growing power generation system in renewable energy systems[1]. Wind-turbine systems can work in two modes of operation: grid-connected and stand-alone. However, the majority of them operating in the field are grid-connected. In this mode, the power generated is directly uploaded to the grid. When WT are not generating enough energy in low wind time intervals, electricity from the grid supplies costumer needs. WT in stand-alone mode are usually employed as small power consumption to power homes, farms, and isolated areas where access to the utility grid is remote or costly. Since the power generated from the wind is not always available, other energy sources are commonly required in stand-alone systems. For maintaining reliability in DG system, the Wind Energy system is operated with combination of Diesel Generator.

Due to their random nature, wind-turbine systems are characterized by an unpredictable output. Hence, a suitable control system is required to ensure a good system dynamic behavior and an efficient extraction of the power from a wind turbine. This has been the subject of several recent research investigations. Most of the proposed control methods for WECS in the literature employed the conventional PI-based control method with different techniques [1],[5]. Methods of nonlinear control that use input-output feedback linearization method for WECS have been reported. Feedback linearization control method has the advantage of being able to be used to both stabilize a nonlinear system, such as WECS, simultaneously tracking many control reference signals. Also, it allows the user to have a complete decoupled control system where each variable can be controlled independently [12].

2. Architecture of the proposed grid connected wind system

2.1. Grid integration

Figure 1 shows the grid interconnected Wind Energy system. The main components in this configuration are 1) PMSG generator, 2) Pitch angle Controller, 3) Converters, and 4) Filters.

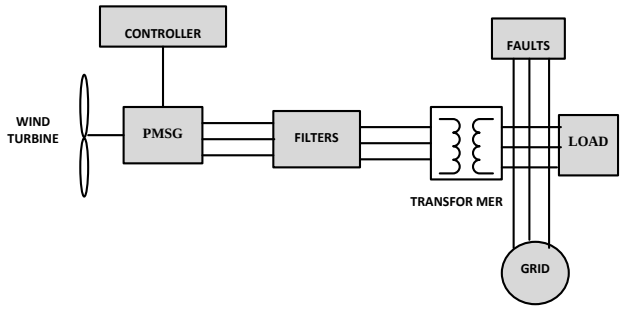


Fig.1 Hybrid system**.**

2.2. Wind turbine

Generally, wind turbine converts wind energy to mechanical (Kinetic) energy and it further converted into electrical energy with the help of generator. Wind turbines are mainly characterized into two categories namely a) Horizontal axis wind turbine and b) Vertical axis wind turbine. The main components of the wind energy system are a) Turbine Shaft,

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b) Gear ratio Control (which Converts low speed shaft to high speed shaft), c) generator, d) Wind Vane and Anemometer, and e) Pitch Controller.[6]

$$P_m = \frac{1}{2}\rho A V^3 C_p(\lambda,\beta) \quad (1)$$

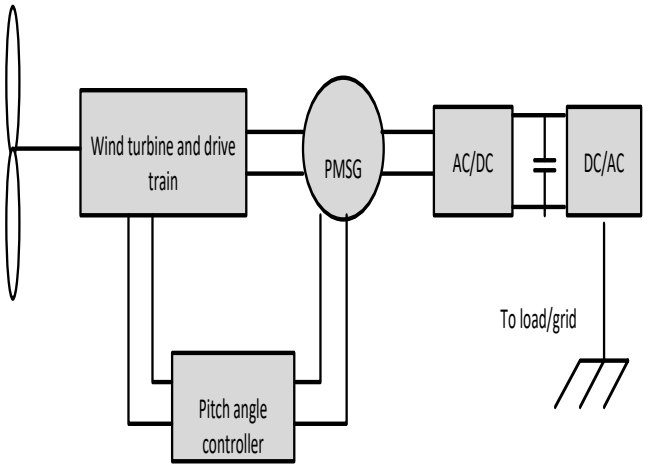


Fig.2 PMSG based wind turbine system.

Mathematical modelling PMSG system is obtained by using differential equation approach. The expressions for direct and quadrature axis parameters are shown below[10]

$$\frac{di_{sd}}{dt} = -\frac{R_{sa}}{L_{sd}} i_{sd} + w_s \frac{L_{sq}}{L_{sd}} i_{sq} + \frac{1}{L_{sd}} u_{sd} \quad (2)$$

$$\frac{di_{sq}}{dt} = -\frac{R_{sa}}{L_{sq}} i_{sq} - w_s \left(\frac{L_{sd}}{L_{sq}} i_{sd} + \frac{1}{L_{sq}} \varphi_p\right) + \frac{1}{L_{sq}} u_{sd} \quad (3)$$

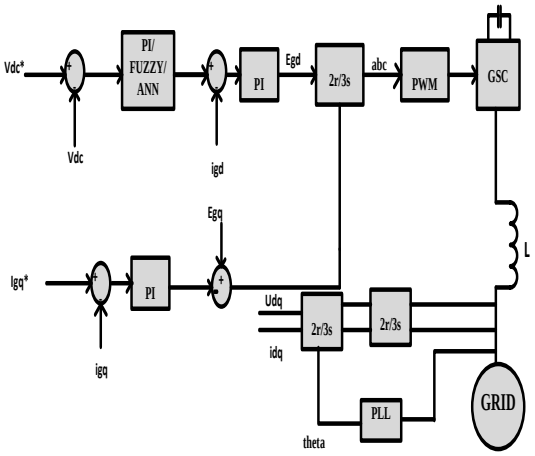


Fig.3 Control circuit for PMSG Grid side converter.

Figure 3 shows the control circuit for PMSG grid side converter. The reference signal required for PWM controller is generated from DC-link capacitor voltage of the three phase converter. Parks transformation is considered to convert grid voltage and current into dq-axis frame.

3. Controlling methods

3.1. PI Controller

A PI Controller (proportional-integral controller) is a combination of proportional and integral controller which is used for eliminating steady state error and peak overshoots 10-11.

The absence of derivative controller shows more stability under noise conditions. This is because the derivative controller is more sensitive under high frequency systems[4].
The general expression for PI controller is expressed as,

$$K_P \Delta + K_I \int \Delta dt \quad (4)$$

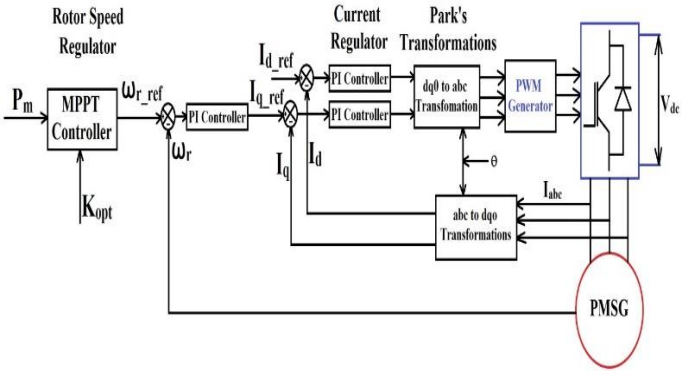


Fig.4 Block diagram for conventional control scheme.

3.2. TSLA based controller design

The linearized model that approximates the system behavior around the operating point using Taylor series expansion is expressed as follows:

$$\frac{d}{dt}\begin{bmatrix} \hat{i}_{ds} \\ \hat{i}_{qs} \\ \hat{\omega}_r \end{bmatrix} = \begin{bmatrix} -\frac{R_S}{L_d} & \frac{L_q}{L_d}\omega_{r0} & 0 \\ -\frac{L_d}{L_q}\omega_{r0} & -\frac{R_S}{L_q} & \frac{-\lambda_r + L_d i_{ds0}}{L_q} \\ 0 & \frac{3p^2}{2J}\lambda_R & K_{\omega t}\frac{p^2}{J}\frac{V_{\omega 0}{}^3}{\omega_{r0}{}^2} \end{bmatrix} \begin{bmatrix} \hat{i}_{ds} \\ \hat{i}_{qs} \\ \hat{\omega}_r \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{u}_{ds} \\ \hat{u}_{qs} \end{bmatrix} + \begin{bmatrix} E_1(i_{ds0}) \\ E_2(i_{ds0}) \\ E_3(\omega_{r0}) \end{bmatrix} \quad (5)$$

To stabilize the system at the operating point, it is use of state feedback controller for the design of TSLA-based Controller. The control input is as follows

$$\begin{bmatrix} \hat{u}_{ds} \\ \hat{u}_{qs} \end{bmatrix} = -K_{ts} \begin{bmatrix} i_{ds} - i_{ds0} \\ i_{qs} - i_{qs0} \\ \omega_r - \omega_{r0} \end{bmatrix} \quad (6)$$

3.3. Feedback linearization controller

For the design of the MIMO nonlinear controller, two control specific end goal to: 1) keep the breeze turbine working at its greatest power by controlling ωr ; 2) controlling of electromagnetic torque by using direct and quadrature axis currents.[8]

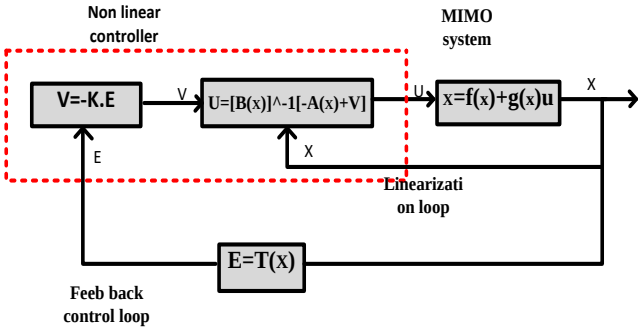


Fig.5 Feedback linearization Controller structure.

One of the advantages of feedback linearization versus traditional PI-based method, is that it is possible to reduction the number of gains of controller with feedback linearization. In the traditional schemes, at the generator side, PI controllers are used in cascade with two gains each (kp and ki) for controlling system active power and rotor speed. In contrast, in the feedback linearization method proposed in this paper, only three gains are needed (instead of six in the case of PI) to perform the same task.[7]

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ \omega_r \end{bmatrix} = \begin{bmatrix} -\frac{R_S}{L_d} & \frac{L_q}{L_d}\omega_{r0} & 0 \\ -\frac{L_d}{L_q}\omega_{r0} & -\frac{R_S}{L_q} & \frac{-\lambda_r + L_d i_{ds0}}{L_q} \\ 0 & \frac{3p^2}{2J}\lambda_R & K_{\omega t}\frac{p^2}{J}\frac{V_{\omega 0}^{\ 3}}{\omega_{r0}^{\ 2}} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ \omega_r \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_{ds} \\ u_{qs} \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} \dot{y}_1 \\ \ddot{y}_2 \end{bmatrix} = \begin{bmatrix} A_1(x) \\ A_2(x) \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{3p^2}{2JL_q}\lambda_r \end{bmatrix} \begin{bmatrix} u_{ds} \\ u_{qs} \end{bmatrix} \quad (7)$$

3.4. ANN based controller

The neuron controller is one of the important controllers in adaptive techniques. The input and output parameters are called as neurons in the neural network [13-19]. This neural controller has 2 inputs that are Δe (x) and Δde (y) and it has 1 output that is f ∈ {x, y}.

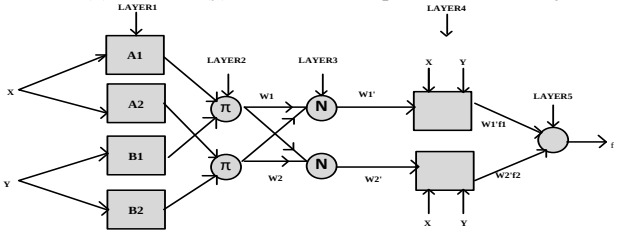


Fig.6 ANN Architecture.

Generally, ANN is a multi-layer network, called as input, output and hidden layers. ANN networks are classified into two type's i.e a) Forward network b) Back Propagation Network. In ANN the signal generally transfers from front to back with multiple of weighted values. The objective of the neural system is to solve issues similarly that the human mind would, although a few neural systems are considerably more theoretically [7].

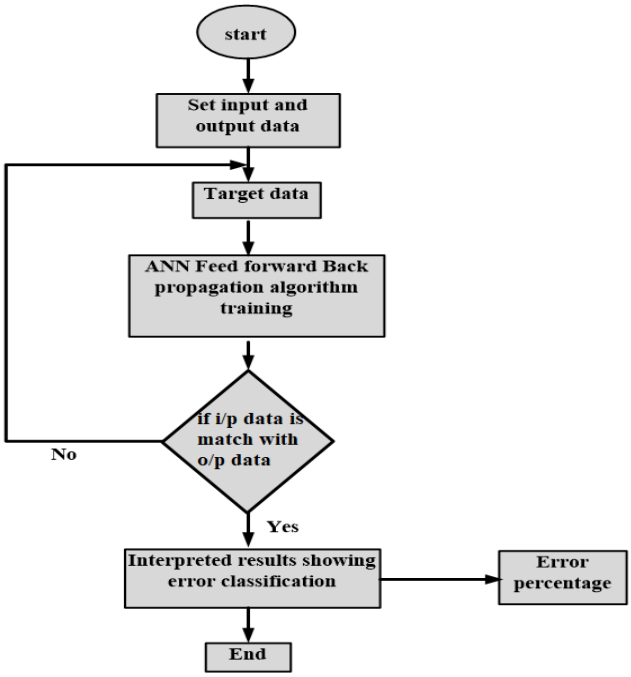


Fig.7 ANN Flowchart.

4. Simulation diagram and results

The performance of nonlinear MIMO control feedback linearization based scheme (FL-based) is observed in matlab, and simulations have been carried out using Matlab/Simulink. The generator used in the study is a variable speed non-salient-pole PMSG driven by a wind turbine.

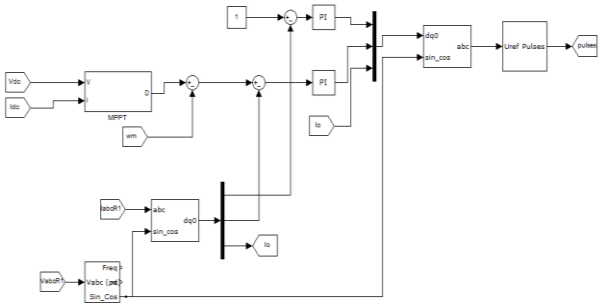


Fig.8 Simulink model for PI controller based WECS.

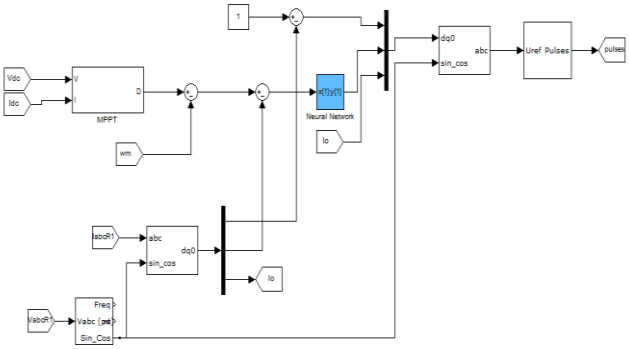


Fig.9 Simulink model for ANN controller based WECS.

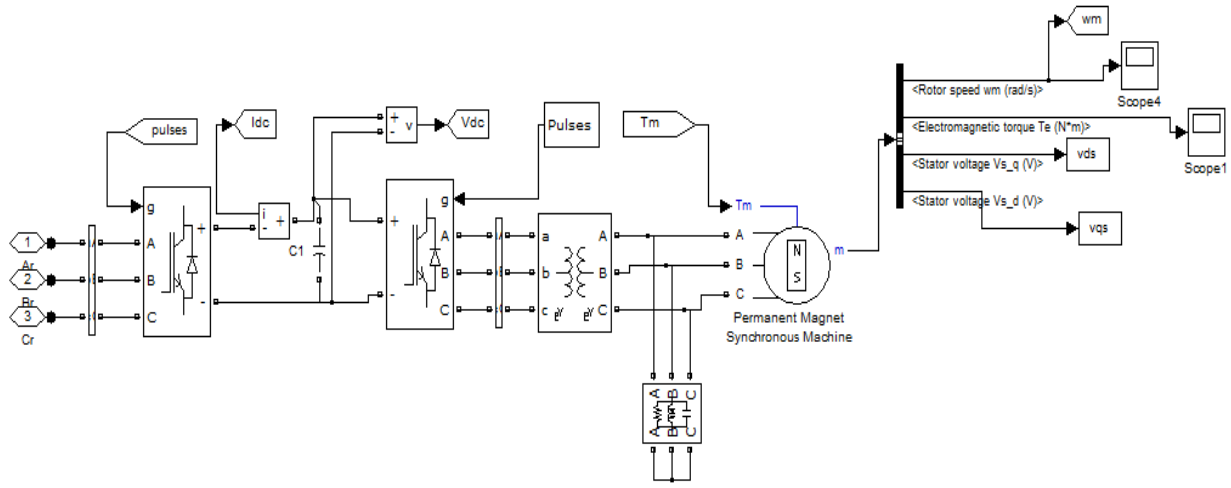


Fig.10 Simulink model for WECS.

4.1.Case-1:Simulink Results for PI Controller

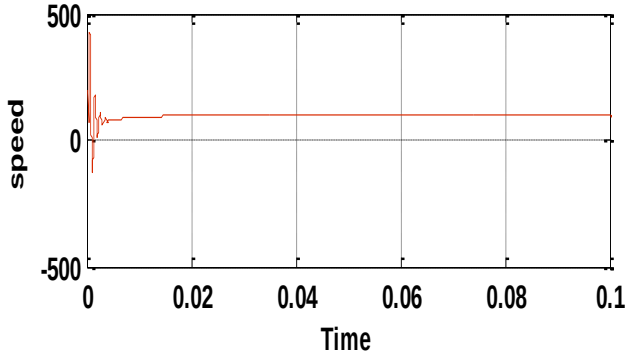


Fig.11 Rotor speed wave form with conventional controller.

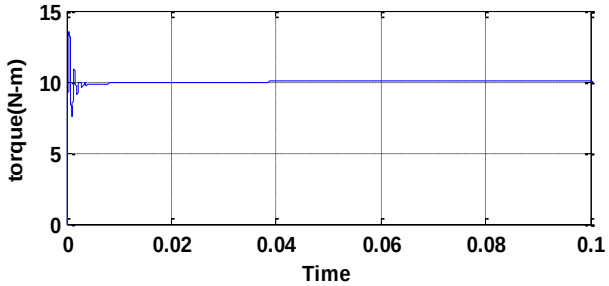


Fig.12 Torque wave form with conventional controller.

4.2.Case-2:Simulink Results for Non Linear Controller

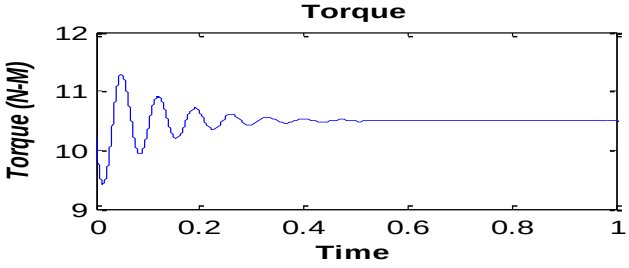


Fig 13: Electromagnetic torque waveform with NL-Controller

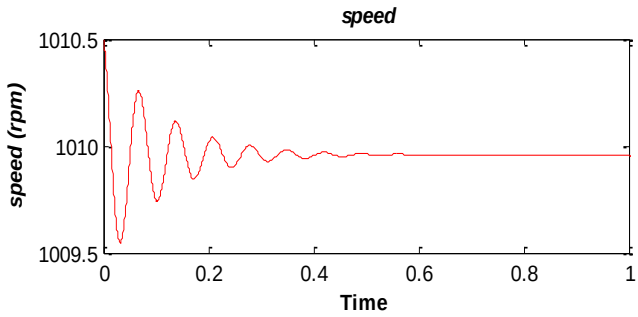


Fig 14: Simulation result for rotor speed NL-Controller

4.4.3.Case-3:Simulink Results for PI Controller

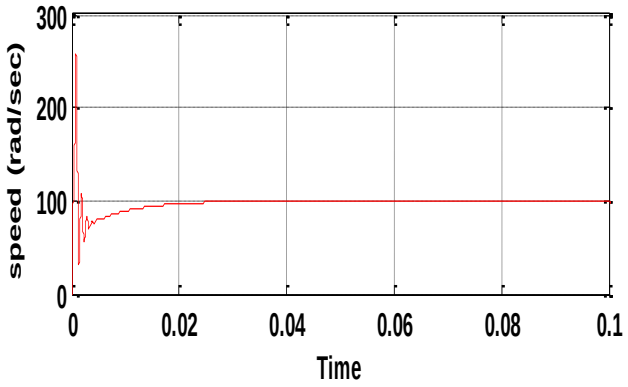


Fig 15: Simulation result for rotor speed with ANN Controller

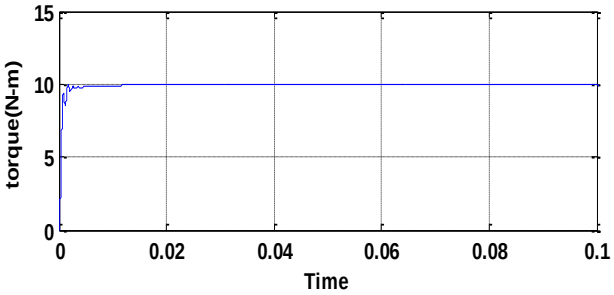


Fig 16: Simulation result for Torque with ANN Controller

4.4.Case-4:Comparison to PI-based and FL-based linear controllers

Comparison can be made based on the torque and rotor speed of the wind turbine generator from the simulation results it shows that both controllers are very close at steady-state response of the system. When coming to transient response of the system is very smoother for FL-based controller compare to conventional PI-controller

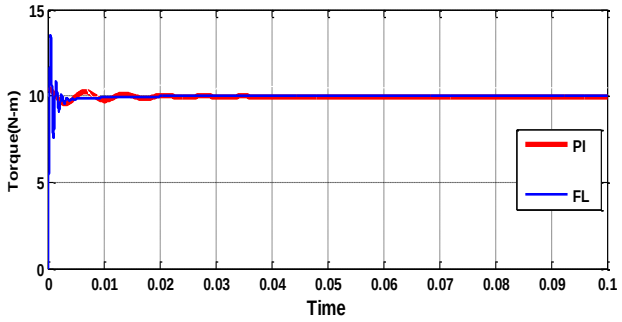


Fig 17: comparison of Simulation result for Electromagnetic torque.

4.5.Case 5: Comparison to Ann-based and FL-based linear controllers

Comparison of Ann controller with FL-based controller has same closed steady state response as shown in the comparison of PI-controller with FL-based controller and change in transient response is very smooth in Ann controller compare to FL-based and PI-based.

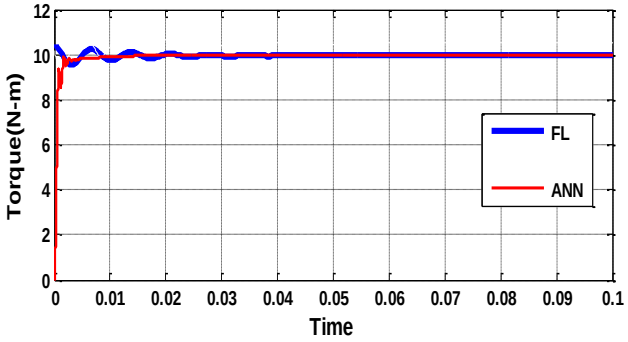


Fig 18: comparison of Simulation result for Electromagnetic torque

4.6.Case 6: Comparison to Ann-based and PI-based linear controllers

In the previous section discussed comparisons from that FL- based controller is better response compare to PI- based controller and finally PI-controller compare with Ann controller. Then Ann controller has better response compare to PI-based controller. Three controllers are have closed steady state response and change in transient response. Ann has fast and good dynamic stability and smooth transient response compare to other techniques and faster response.

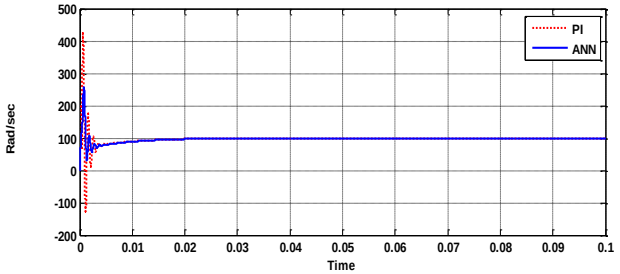


Fig-19 :Pi Vs Ann Controller :Rotor Speed

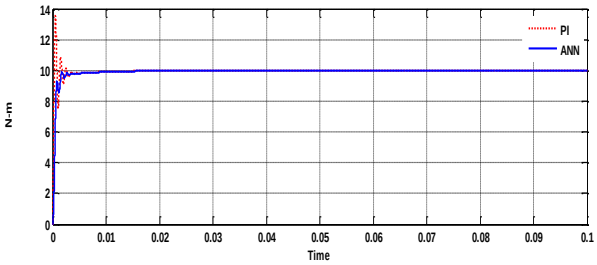


Fig-20 :Pi Vs Ann Controller :Torque

Appendix

Table 1: System Limitations

Parameters	specifications	value
P_m	Rated mechanical power in watts	3230
ω_m	Rated rotor speed in radians/sec	89
λ_r	Rated rotor flux linkage in weber	0.175
P	No.of pole pairs	4
J	Generator Inertia (kg.m^2)	0.0008
R_S	Stator resistance in ohm's	2.875
L_{ds}	d-axis inductance in henry	0.0085
L_{qs}	q-axis inductance in henry	0.0085
v_ω	Rated wind speed in meter/sec	14
R	Blade radius in meters	1
β	Pitch angle in degree	0
Rho	Air density factor	1.25
λ_{opt}	Tip speed ratio	8.1

5. Conclusion

This paper has proposed an ANN Controller along with nonlinear MIMO controller based on feedback linearization theory to regulate the generator current and rotor speed of a WECS. The controller gains have been selected by using optimal control. The performance and robustness of the proposed ANN controller have been compared to those of the traditional PI-based controller and the feedback controller based Taylor series expansion linear approximation (TSLA-based). For this purpose, full detailed PI-based and TSLA-based control schemes for WECS have also been given. The comparison has been done under three case of studies: 1) constant wind speed, 2) variable wind speed with constant generator parameters and The simulation results show that applying ANN based control strategy combined with optimal control, while keeping the wind turbine operating at its optimal maximum power and controlling the generator active power, provides a better control performance compare to the PI, TSLA and non-linear MIMO based control systems.

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