Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 3, No. 5, March : 2024

STABILITY ANALYSIS IN MATHEMATICAL MODELED TYPE-III WIND TURBINE SYSTEM USING RBFN TECHNIQUE

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***Abstract:* Power smoothing approach is make the power system balanced. In wind energy conversion system under grid integrations, the controller optimization is necessarily implemented. Type-III wind turbine system is taken in this research which uses double fed induction generator. Double fed induction generators are useful for variable wind speed operations. For controlling power, in this paper radial basis function neural network optimization technique is used. To remove nonlinearities sliding mode controller is implemented with the optimization technique. To tune the controller conventional controllers are added to the proposed technique. For variable wind speed and under transients the model is tested and the power generations are presented. The active power enhanced using the proposed controller and the reactive power is compensated smoothly. Hence the model with the proposed controller effectively enhanced the efficiency of the wind power generations. This paper presents the robustness of the Type-III wind turbine system under grid integrations.**

***Keywords:* Type-III wind turbine, PAC, MPPT, Wind speed, Sliding mode controller, RBFN, Power smoothing, WECS.**

I. INTRODUCTION

Wind energy system now a day gets attraction because of its hazardous free power generation. The controller should be enhanced to get maximum power generation. The adaptive and predictive controllers are now used for power smoothing in machine side and grid side. To control the torque of the machine side, the controllers are using robust technology. In this paper sliding mode control technique is implemented to control the switching angle of the pitch during disturbances. [1-3][5-8]. SMC was used in this work to control and regulate nonlinearities in order to get the most power out of it [9-15]. To increase power smoothing under varying wind speeds, adaptive approaches can be combined with the sliding mode controller technique. Pitch angle control can be improved using genetic algorithm optimization techniques. Considering wind turbulence and disturbances this paper can be helpful to enhance the tuning process using radial basis function neural networks [16]. The modified rotor based Type-III wind turbine used in this paper where the proposed techniques are implemented. Different operating modes were used previously to improve the wind power generation by controlling the wind speeds. The nonlinearities can be reduced using RBFN technique used in wind turbine system. Particle Swarm Optimization technique used to improve the steady state and transient behavior of the wind power generations. In this paper RBFN technique is used with sliding mode control technique. This paper helps in minimizing the rotational error of the pitch angle and improves the transient stability. The stability of the system under transients and wind speed disturbances are validated using Bode Plot and Nyquist Plot. The power generation from this simulation work shown in the results section, where the comparisons are presented. The power smoothing characteristics is minimizing the active power loss and reactive power compensation is also highlighted in this research.

II. WIND ENERGY CONVERSION SYSTEMS

Efficient and quality power generation can be generated by control techniques used in the power generations. The pitch angle controller regulates the movement of the blades and activates when the wind speed is low or high. The blades spin due to wind turbulence and flow and the electromechanical hydraulic system inside the hub aids in the rotation of the wind turbine [17]. See the figure no. 1 shown below.

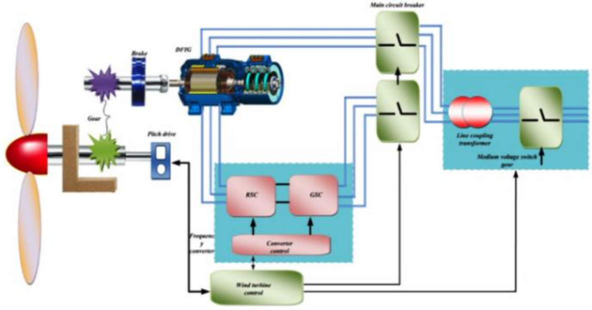

Figure 1: Block diagram of WECS

The synchronous generator utilized in the system generates emf as a result of this mechanical effect. There are two sections to the converter controls. The rotor side controller is the first, while the grid side controller is the second [18]. For procedures with varying speeds, DFIGs can be quite valuable. A capacitor bank connected in parallel can be used to attenuate transients and harmonics using simple. The pulse width harmonic minimization technique is used in the system for power smoothing [19-24]

III. MODIFIED TYPE III WIND TURBINE SYSTEMS

The double fed induction generators are used in maximum wind firms. These are variable wind speed operated generator system that is associated with the wind models. In this paper Type-3 wind turbines are used for power generation. The active power enhancements are studies in this paper using neural networks. The active power losses are minimized using the proposed controller highlighted in this research [15-30].

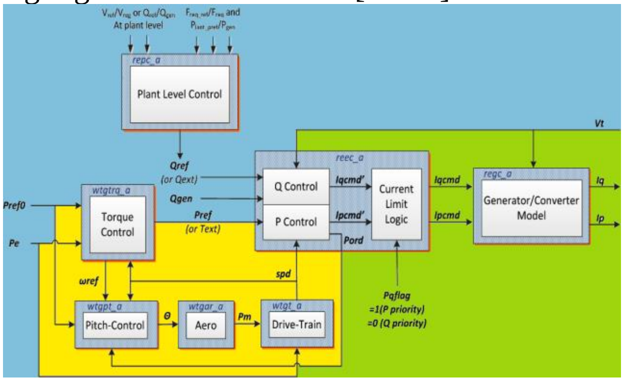

Figure 2: Power Analysis in Type III Wind Turbine Model

The above figure 2 illustrates the modeling of wind turbine system that used active pitch control and machine side power control using adaptive algorithms [13-17][30-33]. Matlab simulink based designs are generated for both machine side and grid side for power controls [35].

Radial Basis Function Neural Network

This neural network based predictive controller is used to tune the active power for the generation by smoothing the input feedback system. The active control of torque also taken care using proposed technique. The gain values and the gain parameters are compared with the reference data and the conditioning of the feedback parameters are taken for wind power generation.

The multivariable NARX (nonlinear autoregressive exogenous model) model illustrated below following form may be used to represent the nonlinear system.

$$y(k) = f[y(k-1), \ldots, y(k-ny), u(k-1-d), \ldots, u(k-nu-d)] + e(k)$$

where $u \in \Re m$, $y,e \in \Re p$ are the process input, output and noise vectors respectively with m and p being the number of inputs and outputs; ny and nu are the maximum lags in the outputs and inputs respectively, d is a deadtime vector representing delayed time to different control variables, $f(*)$ is a vector-valued nonlinear function.

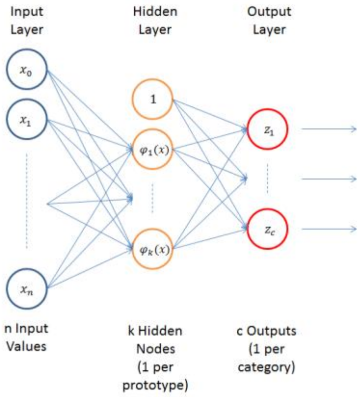

Fig. 3. RBF Network Structure

The flowchart of RBFN optimization technique is shown below in figure no. 4.

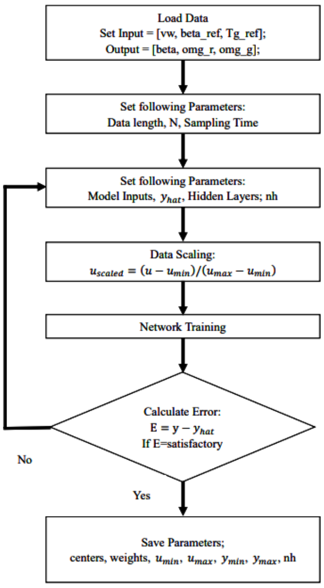

Fig. 4. Flow Chart for RBFN Technique

RBFN Wind Turbine Model

All raw data samples were standardized into the range of [0, 1] after data collection. The parameters before the training condition and testing condition is used to improve the NN's accuracy and reduce error. The RBFN Optimized SMC in a wind turbine is shown in Figure 5.

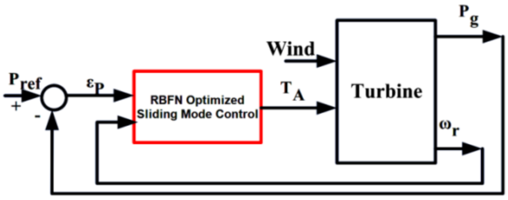

Fig. 5. RBFN Optimized SMC in wind turbine

The linear scale normalized data sequence was done using the following equations:

$uscale(k) = u(k) - umin\ umax - umin\ yscale(k) = y(k) - ymin\ ymax - ymin$

Where umi , $umax$, $ymin$ and $ymax$ are the minimum and maximum inputs outputs of data set, while $uscale$ and $yscale$ are the scaled input and outputs respectively.

Simulink Results and Analysis

The model used sliding mode controller for monitoring nonlinear behavior in torque and power. See figure no. 6 and 7 present below.

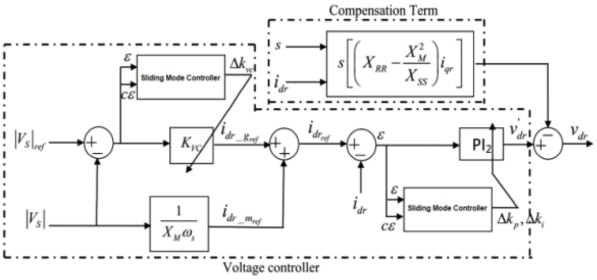

Fig. 6. Voltage Control using SMC

Using PI and fuzzy the voltage is controlled in the above conditioning model illustrated in figure 6. Using sliding mode the torque of the machine is regulated using conventional PI and fuzzy system shown in figure no. 7.

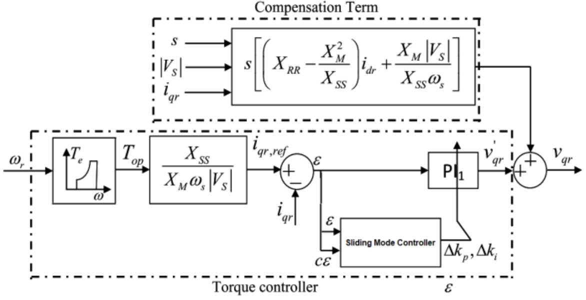

Fig. 7. Torque Control using SMC

Figures 8 to 15 shown below illustrate the comparative results under an operating speed of 8 m/s. The torque and machine side power utilizing a Sliding Mode controller are shown in figures 16 and 17.

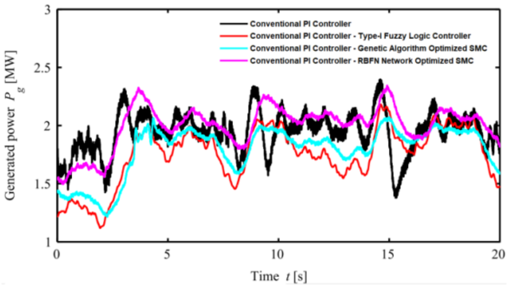

Fig. 8. Comparison on Generated Power

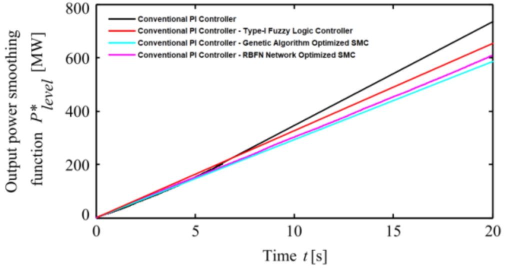

Fig. 9. Comparison on Output Power (Smoothing in Reactive power Compensation)

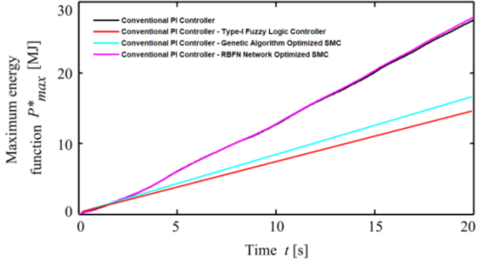

Fig. 10. Maximum Energy Comparison with respect to Active Power Loss Function

a. Wind speed at 8m/s operating

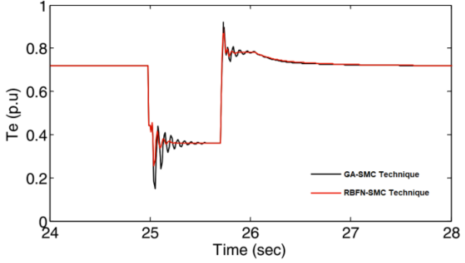

Fig. 11. Torque Nonlinearity wrt time

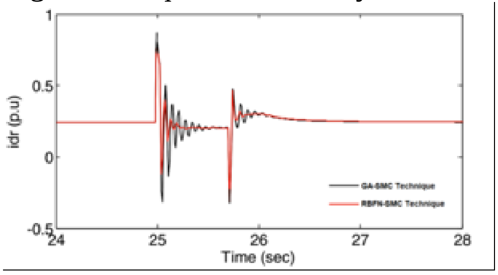

Fig. 12. d axis rotor current Nonlinearity

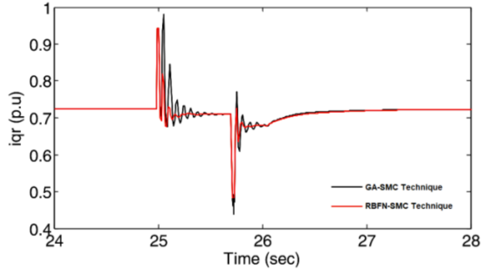

Fig. 13. q axis rotor current Nonlinearity

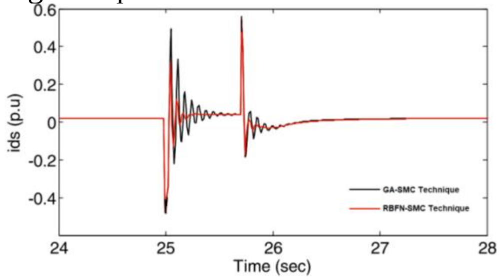

Fig. 14. d axis stator current Nonlinearity

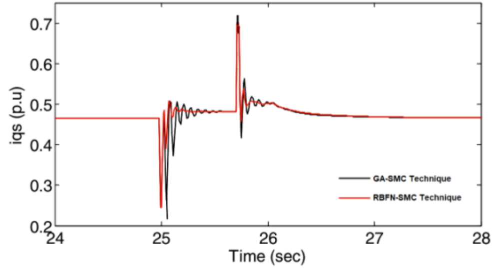

Fig. 15. q axis stator current Nonlinearity

b. Comparative Analysis using Sliding Mode Controller optimized by RBFN

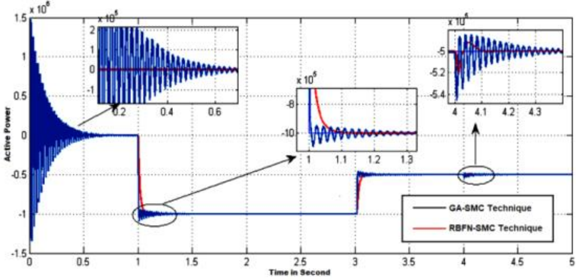

Fig. 16. Active Power wrt time

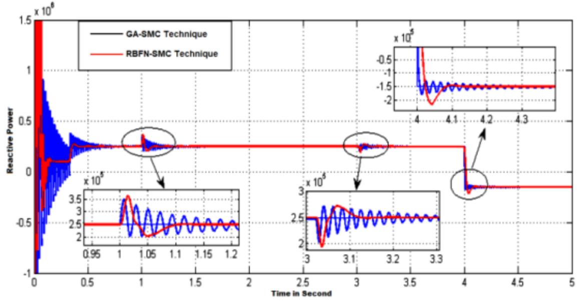

Fig. 17. Reactive Power wrt time

Stability analysis using RBFN ANN technique illustrated in figure 18 to 21 shown below illustrates the stabilities under various control modes.

c. Stability Analysis using Bode Plot and Nyquist Plot

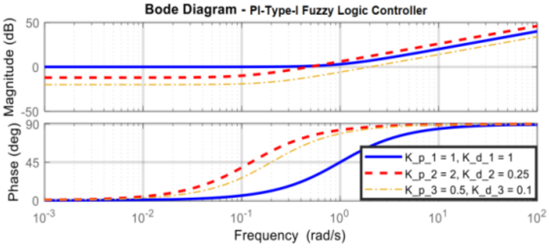

Fig. 18. Bode Plot Stability Analysis using PI-Type-I FLC

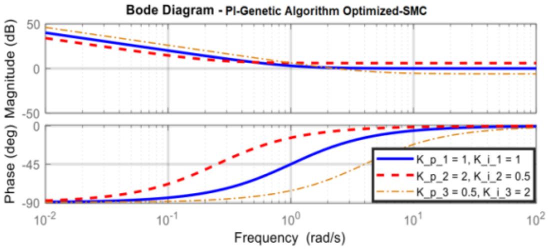

Fig. 19. Bode Plot Stability Analysis using PI-GA-SMC

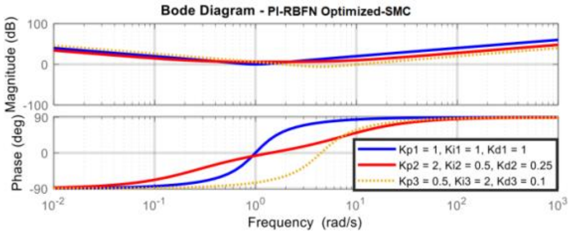

Fig. 20. Bode Plot Stability Analysis using PI-RBFN-SMC

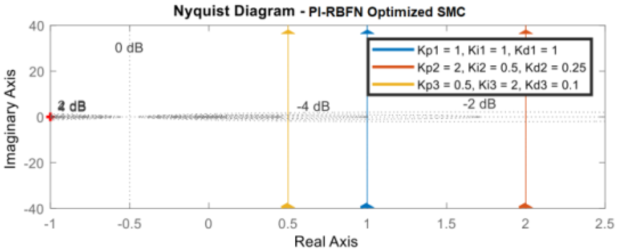

Fig. 21. Nyquist Plot Stability Analysis using PI-Type-I FLC

From the above Bode Plots and Nyquist plot it is observed that using PI-RBFN-SMC technique shows better steady state and transient stability under change in parameters of wind energy system with respect to GA based SMC technique. The nonlinearities due to parameters like wind speed, mechanical torque of the rotor, converter harmonics and reactive power taken into consideration to study and validate the model. The simulink results are presented in below in the form of tabulation.

TABLE 1 COMPARATIVE ANALYSIS USING VARIOUS CONTROLLERS

Controller	**Conventional PI Controller**	**PI-Fuzzy**	**PI-Mode-4- Fuzzy**	**GA in pi-m4 Fuzzy**	**PI-SMC in GA-PI m4 Fuzzy**	**RBFN in SMC**
Wind Power Coefficient	-0.447	-0.352	-0.375	-0.013	-0.015	-0.0151
Wind Torque	-0.290	-0.280	-0.271	+0.049	+0.056	+0.057
Wind Power Error	-0.286	-0.275	-0.270	+0.052	+0.058	+0.060
Efficiency (P_{eff})	-70.5	-79.5	-80.5	-81.6	+0.09	+0.095
P_{sm}	+70.20	+79.25	+80.25	+80.26	+0.05	+0.052

The evaluation table 1 shown above presents various wind energy characteristics shows that the proposed technique is effective in reducing nonlinearities and increasing rotor torque and power. Under abrupt wind speed variations, the wind efficiency of a modified Type-III wind turbine system rose by up to 95% employing the RBFN-sliding mode control technology.

TABLE 2 PERFORMANCE CRITERIA ANALYSIS USING VARIOUS CONTROLLERS

Controller	**Conventional PI Controller**	**PI-Fuzzy**	**PI-Mode-4-Fuzzy**	**GA in pi-m4 Fuzzy**	**PI-SMC in GA-PI m4 Fuzzy**	**RBFN in SMC**
ISE	9.5420	8.3035	8.3235	8.0012	6.7505	6.711
ITAE	75.5567	70.7890	69.1005	63.7652	63.8086	62.7660

Integral absolute error (IAE), Integral time square error (ITSE), Integral time absolute error (ITAE) and Integral square error (ISE) are some of the most commonly utilized performance criteria in stability analysis.

Table 3 Power Smoothing Analysis under Cut in speed (4m/s)

Controller Software	**Conventional PI Controller**	**PI-Fuzzy**	**PI-Mode-4-Fuzzy**	**GA in pi-m4 Fuzzy**	**PI-SMC in GA-PI m4 Fuzzy**
Active (P) Power	1.25	1.26	1.25	1.26	1.265
Reactive (Q) Power	0.85	0.91	1.01	1.13	1.154
Active (P) Power Loss	0.40	0.35	0.24	0.13	0.111
Settling (t) Time	12.077 sec	11.35sec	10.75 sec	10.70 sec	10.69 sec

Table 4 Power Smoothing Analysis under Operating speed (8m/s)

Controller Software	**Conventional PI Controller**	**PI-Fuzzy**	**PI-Mode-4-Fuzzy**	**GA in pi-m4 Fuzzy**	**PI-SMC in GA-PI m4 Fuzzy**
Active (P) Power	1.25	1.26	1.25	1.27	1.275
Reactive (Q) Power	0.89	1.05	1.10	1.14	1.156
Active (P) Power Loss	0.36	0.21	0.15	0.13	0.119
Settling (t) Time	12.075 sec	11.86sec	10.58 sec	10.55 sec	10.52 sec

Table 5 Power Smoothing Analysis under Cut Out speed (12m/s)

Controller Software	**Conventional PI Controller**	**PI-Fuzzy**	**PI-Mode-4-Fuzzy**	**GA in pi-m4 Fuzzy**	**PI-SMC in GA-PI m4 Fuzzy**
Active (P) Power	1.25	1.26	1.25	1.29	1.31
Reactive (Q) Power	0.89	1.05	1.10	1.148	1.163
Active (P) Power Loss	0.36	0.21	0.15	0.142	0.147
Settling (t) Time	12.075 sec	11.86sec	10.58 sec	10.549 sec	10.521 sec

Conclusion

Electricity production from wind energy system is the most economical and freely available source of generation for the modern power system, with no harmful emissions. As a result, by upgrading this renewable source with innovative technology, we may increase power production while retaining the stability of our contemporary power grid. This suggested control method, when combined with a sliding mode controller, significantly improves power efficiency. Minimizing active power losses caused by wind speed changes is extremely efficient indirectly. It is possible to decrease power loss by 85-95 percent of its generation using RBFN artificial neural network optimization. Wind speed fluctuation causes rotor torque nonlinearities, which may be successfully minimized and torque increased up to 40% of rated torque by removing wind speed fluctuation nonlinearities. Using SMC-RBFN, rotor power may be boosted by 50-60% of rated power. The steady state was attained 25-35 percent quicker utilizing SMC-RBFN than that of SMC-GA and settling time under transient condition also improved 20% with respect to conventional controllers. As a result, researchers will be able to use this study to design alternative evolutionary algorithms that use SMC and ANN to reduce nonlinearities and improve both steady state and transient power system stability.

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