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Enriching the MPPT in Wind Plant by using PID and AI Controllers for Switched Reluctance Generator

Soma Swahith[1] | Dr. V Dega Rajaji[2]

[1]PG Scholar, Department of EEE, Dr. YSR ANUCET, Guntur, India.
[2]Assistant Professor, Department of EEE, Dr. YSR ANUCET, Guntur, India.
Corresponding Author : rajajiyadav@gmail.com

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ABSTRACT

One of the most significant forms of renewable energy is wind power, which has been the subject of in-depth study to develop more dependable and efficient ways. Numerous research on wind energy have been conducted in the recent years. The most often discussed subjects include maximum power point tracking (MPPT) systems,kinds of generators used in wind turbine applications,control and stability of wind plants. Recent research on the VSWT has centered on developing MPPT technology. For a switched reluctance generator (SRG) powered by a variable speed wind turbine to generate the most power. By detecting the wind speed and adjusting the wind turbine shaft speed for the ideal tip speed ratio, MPPT is accomplished for the wind turbine.By alteringSRG'sturn-off angle. The asymmetrical half-bridge converter system connected to the SRG. The MATLAB/Simulink environment is used to simulate the systems. This project presents PID and Artificial intelligent controllers as MPPT system. The PID and intelligent controllers regulate the SRG's output power. The outcomes demonstrate thatANN controller outperforms the FL controller and PID controller in terms of accuracy and efficiency.

KEYWORDS- The maximum power point tracking(MPPT), wind turbine, Switched reluctance generator (SRG),variable speed wind turbines(VSWT), proportional integral derivative (PID)Artificial neural network controller (ANN), Fuzzy logic controller (FLC).

1. INTRODUCTION

Fixed speed wind turbines (FSWT) and variable speed wind turbines(VSWT). are the two primary categories of wind turbines. The FSWT are easy and affordable. In contrast to FSWTs, the VSWT is more efficient despite being more complex and costly.The development of MPPT technologies has been the focus of recent VSWT research. With MPPT, the wind generator can absorb the greatest amount of energy from the wind, resulting in high efficiency.

Traditional controllers,such as proportional integral (PI), proportional derivative (PD), proportional integral derivative (PID) controllers, provide benefits such as robustness and broad margin stability. Nonetheless, these controllers have several drawbacks, including high sensitivity to parameter changes and high sensitivity to nonlinear dynamic systems. Intelligent controllers, on the other hand, operate a system without using dynamic equations and relying on some critical system attributes. Because of its advantages, the fuzzy logic controller (FLC) and artificial neural network controller (ANNC) have recently seen widespread use.

Several wind turbine generators have been investigated, including the induction generator (IG), doubly fed induction generator (DFIG), wound field synchronous generator (WFSG), permanent magnet synchronous generator (PMSG), and switching reluctance generator (SRG). For FSWT, IGs is employed. Because of its benefits, particularly in transitory situations, the DFIG is an appropriate candidate for VSWTs. In recent years, the SRG has been studied in order to apply for the VSWT and achieve optimum power efficiency.This is a great option since it has several advantages such as mechanical durability,high efficiency, performance across a wide range of speeds, high power density, and high fault tolerance. Based on the SRG's performance at various wind speeds, this generator may be a suitable replacement and function more efficiently.In wind turbine applications, the SRG also produces electricity from wind power without a gearbox. Recently, the SRG has been employed in the VSWT to get maximum power due to these benefits. The common research to achieve optimum efficiency in varying wind speeds is looking into the switching of SRG and the best turn-on and turn-off angle of the SRG asymmetric half bridge. To manage the SRG, rotor location is crucial. To optimize the amount of electricity sent to the grid, wind rotational speed control is explored.

As MPPT techniques in the VSWT with the SRG coupled to the grid, one proportional controller and two intelligent controllers are provided in this work. The intelligence controllers are FLC and ANN controllers, whereas PID is the proportional controller. The SRG is governed by these three controllers. Comparisons of three suggested controllers' performances under identical circumstancesare made. The sophisticated controllers regulate the SRG's turn-on switching angle in order to keep the generator's rotational speed at the ideal level in VSWT. The intelligence controller's optimal point of generator rotational speed is superior to the PID controller’s optimum point of generator rotational speed. Through an asymmetric half bridge converter, DC-link, the SRG is linked to the grid.In a MATLAB/Simulink environment, proposed techniques are assessed. Results show that when compared to PID and FL controllers, the ANN controller is more accurate.

The wind turbine operation and characteristics are discussed in section II. And section III presents about the MPPT system. The PID and Artificial intelligence controller’s operation explained in section IV and section V respectively. Section VI introduces The SRG’s working anditscomfortsinwindenergyapplication.Thesimulation block and results are shown in section VI.In the end,sectionVIIcontainsthe conclusionsofthispaper.

2. WIND TURBINE:

A wind turbine derives kinetic energy from the swept area of its blades.Following is an equation that describes how powerful the airflow is.

$$P_{air} = \frac{1}{2}\rho A V^3 \qquad (2.1)$$

Where V represents the wind speed, D is the air density, and A is the area that the blades are sweeping, ρ is constant.

Wind power is reduced when it is transported to a wind turbine's rotor via a power coefficient, which is defined as follows:

$$C_P = \frac{P_{wind\ turbin\ e}}{P_{air}} \qquad (2.2)$$

Where Cp is the power coefficient, and it can never be larger than 59.3%. In reality, the wind turbine rotor coefficient ranges from 25 to 45%. Cp(λ, β) is determined by λ and β. λ is the tip speed ratio, and β is the blade pitch angle, and λ is calculated as follows:

$$\lambda = \frac{\omega R}{V} \qquad (2.3)$$

where ω is the wind turbine's rate of rotation. V is the wind speed, and R is the blade radius. If the wind speed is larger than the base speed, β can be regulated, and if the wind speed is lower than the base speed, β is considered to be zero. Using tip speed ratio instead of various pitch angles, below fig.2.1 displays the power coefficient graphs. The aerodynamic properties of the blade profile affect the power coefficient (Cp), a nonlinear function of λ and β. Keep in mind that the Cp(λ, β) is a function of the blade profile and is unaffected by the radius of the blade.

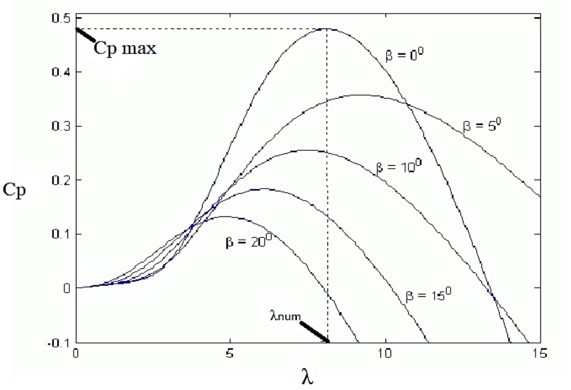

Fig. 2.1. The cp-λ characteristics, for different values of the pitch angle β, in MATLAB/Simulink.

Therefore, the wind turbine's output power is equal to:

$$P_{wind\ turbine} = \frac{1}{2}\pi\rho C_P(\lambda,\beta)R^2V^3 \qquad (2.4)$$

From above wind turbine power equation, the system may become quite nonlinear because the power of the wind turbine has a nonlinear relationship with wind speed.

3. MAXIMUM POWER POINT TRACKING (MPPT):

To obtain MPPT in a wind turbine with variable speed, the Cp(λ, β) must be regulated, according to the turbine power equation. The highest value of cp (C_{Pmax} = 0.48) is reached at β = 0 degree and λ = 8.1 when taking into account that the Cp(λ, β) relies on the tip speed ratio(λ) and the pitch angle(β). Pitch angle (β) is zero in this research since the wind speed is lower than the rated speed.The ideal value of λ is designated as this specific value (λ_nom). Because of this, is greatest when fixed tip speed ratio(λ) is equal to the nominal value (λ_nom). According to (C_{pmax}), the tip speed ratio (λ) depends on both the wind speed and the generator's rotating speed. As a result, the tip speed ratio (λ) may be set to the nominal value (λ_nom) to access the maximum power coefficient (C_{pmax}) by controlling the generator's rotating speed in the various wind speeds. The power of the wind turbine is maximised as a result.

The below following Equation is used to compute the wind turbine's maximum power:

$$\mathrm{PWT}(\mathrm{max}) = \frac{1}{2}\pi\varrho \mathrm{Cp}_{\mathrm{max}}(\lambda\mathrm{nom}, \beta = 0)\mathrm{R}^2V^3 \qquad (3.1)$$

Below fig 3.1 shows the ideal rotational speed depending on the output power of the turbine at various wind speeds to reach MPPT. It demonstrates that the turbine draws its most power when the wind speed is 14 m/s and rotates at a speed of 1pu. In order to generate the most power at different wind speeds, the turbine's ideal rotational speed should be less than 1pu. To achieve MPPT, the turbine must, however, revolve at its ideal speed.

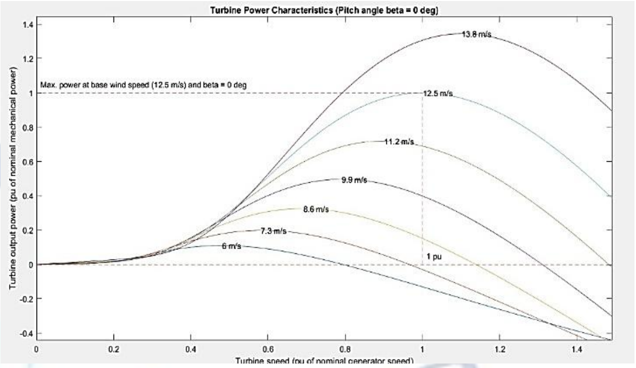

Fig. 3.1The generator rotational optimum speed in difference wind speeds to access MPPT.

4. PID CONTROLLER:

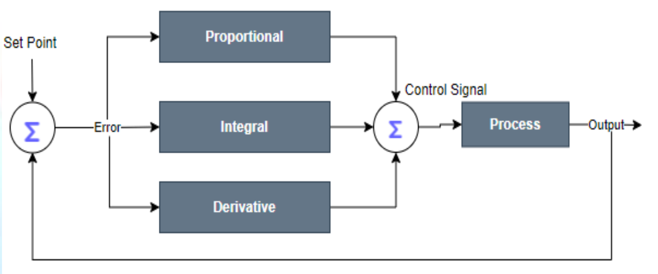

Fig. 4.1Structure of PID controller

PID stands for Proportional Integral Derivative. It is the device used in industrial regulatory applications to regulate process variables such as pressure, temperature, speed, flow, and others. Thisprocess variables using a control closed loop feedback method and produces more exact results. The PID instrument calculates the error by determining the difference between the desired and actual values and then evaluating the decision parametersaccordingly. The error computation continues until the process is completed.Using the proportionate, one may determine the mistake, which aids in supplying the corrective response value. The prior error values are known and integrated using integral. When the erroneous values are removed from the system, the integral value rises. And, using the derivative, the future error values are predicted based on the existing values.PID may also be used with higher level control systems such as model predictive control, adaptive controllers, fuzzy logic control. But fuzzy and ANN controller are most efficient then the PID controller.

5. ARTIFICIAL INTELLIGENCE:

A. Fuzzy Logic Controller:

Four fundamental building blocks—the fuzzification,Inference or interpretation and defuzzification units—make up the framework of a comprehensive fuzzy control system.In conclusion, the first step in creating a fuzzy system is to acquire a set of fuzzy IF-THEN rules from human experts or based on domain expertise. The next stage is to combine these regulations into a single system. three steps typically make up this process:

1. Fuzzification
2. Inference or interpretation
3. Defuzzification.

Fuzzification: In the initial phase of FLC, the uncertain input values are transformed into a fuzzy variable termed "fuzzification." A discourse universe based on membership functions is used in this.The kind of relationship function might be Gaussian, triangular, or exponential. Furthermore, it is possible to combine several membership functions for usage in more complex systems. The way in which membership duties are performed depends on the system in which they are to be used.

Inference or interpretation: The rules are developed in terms of linguistic variables in the second FLC stage depending on the system's performance and prior knowledge. The interpreter is used to make decisions based on the input and rulebasis that are provided.

Defuzzification: The conclusion made by the inference block is translated into its corresponding numerical values in the FLC's last phase, which is referred to as defuzzification.By giving accurate values for additional processing, this block serves as the interface between the controller and the real system.

B. Artificial Neural Networks:

A successful combination of inputs with the following characteristics must be provided as the initial step in developing an intelligent system. Their linear independence should come first. Additionally, each of them includes pertinent data from the prior system. It's crucial to construct ANNs with the least amount of size and error possible, which is another key consideration. Although an increase in ANN structure often reduces ANN error, it also increases computation volume. Therefore, reaching a compromise between the two instances is an important factor.

First, all the input factors influencing the output ANN are gathered in order to create the ANN system. There are two ways to choose input variables. One approach classifies input variables from most useful to least valuable, after which the most crucial inputs are chosen.Forward selection is the name of this technique. In the following procedure, the least valuable input is first eliminated, and then it is eliminated from the remaining input variables.The least significant input variables are gradually eliminated through this method. Backward selection is the name of this technique.

The number of neurons, the number of layers, and the activation functions are designed once the input variables are chosen. The ANN architecture is developed by trial and error. Trial and error are used to determine the ideal number of neurons, up till the ANN error is small. Hidden layers are developed after determining the ideal number of neurons. Even while adding hidden layers helps reduce error, typically ANNs with more than four layers are seldom used since they need a lot of computing resources and take a long time to process.The ANN is trained once its structure has been designed. The training of the ANN may be done using many algorithms. The Back-Propagation (BP) Algorithm serves as the standard foundation for ANNs.

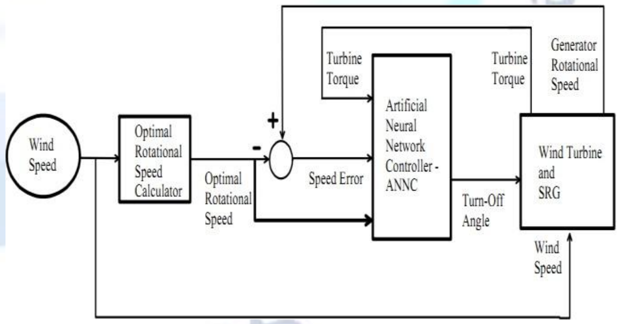

Fig. 5.1 The block diagram of the proposed ANNC system.

With this approach, the least important input is eliminated, and all input parameters that have an impact on obtaining MPPT are selected. The ANNC input is then selected as the input of greatest significance. The applied ANNC's input parameters include the ideal rotational speed, the mechanical torque of the turbine, and the difference between the ideal and actual rotating speeds.

Trial and error are the fundamental process in ANN construction, which helps in choosing the number of hidden layers and neurons in each hidden layer.

6. SWITCHED RELUCTANCE GENERATOR:

The basis for the operation of switched reluctance machines is the alteration of magnetic reluctance in response to rotor position. A torque is created as the rotor attempts to move into place with the least amount of magnetic resistance. For a generator that receives torque from a driving device, the stator winding will generate a voltage that will result in a current. The output current and excitation current must come from the same winding since the rotor poles are not wound. As a result, depending on the rotor position, it is necessary to alter the current in each phase.

The SRG is in the development stage for applications requiring changing speeds, where its innate qualities provide it a competitive edge. As of right now, the SRG is used in wind energy converters, hybrid car starter/alternators, and aerospace power systems. The aerospace and automotive applications are typically defined by high-speed operation, whereas the wind energy application is characterised by low-speed, high-torque operation. Applications that are demanding can be used with the SRG. The rotor's lack of windings and permanent magnets enables operation at high temperatures as well as high rotating speeds. Additionally, the lack of windings on the rotor helps to increase the machine's energy density by lowering copper loss.Every application that needs variable-speed operation can use the SRG because to its switching nature. Variable-speed operation is required in order for the engine that powers the SRG to function properly in aeronautical and automotive applications. Variable speed operation is required in wind energy applications to maximise energy recovery from the wind stream and to reduce mechanical loads.

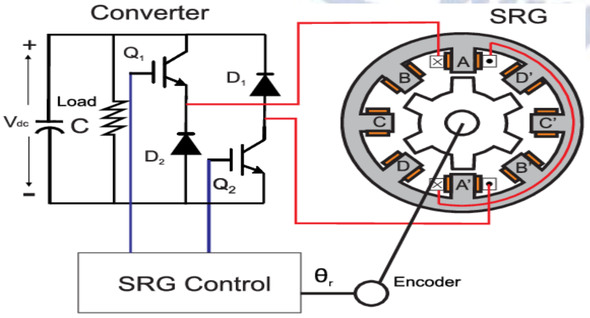

Fig.6.1 Basic structure of the 8/6 SRG

A fundamental arrangement of the conventional 8/6 three-phase SRG employed in this investigation is shown in Fig.6.1. both the stator and the rotor have prominent poles in SRG. There are no windings on the rotor. On specific poles, the stator coils are focused. It has a three-phase asymmetrical power converter system. that has three legs and twocontrolled power semiconductor switches and two free-wheeling diodes in each of them supplies the SRM. To push positive currents into the phase windings during conduction periods, the active switch delivers positive source voltage to the stator windings. Negative voltage is provided to the windings during free-wheeling times, and the diodes then transfer the energy that has been stored back to the power DC source. In motor windings, this can shorten the period when currents decline. the phase winding receives the electricity when the two power switches are activated. It is possible to precisely enforce the turn-on and turn-off angles of the motor phases by utilising a position sensor fastened to the rotor. To regulate the generated torque waveforms, utilise these switching angles.By comparing the measured currents with the references, three hysteresis controllers separately regulate the phase currents and provide the driving signals for the switches.The hysteresis band is the primary factor that affects controlled power semiconductor switching frequency.

7. SIMULATION AND RESULTS:

A. Simulation block

The block diagram of the simulated system is depicted in Fig. 7.1. This is evaluated by using MATLAB/Simulink environment.

The wind turbine's output mechanical power is tuned at 745Was 1pu in the Simulink per-unit model at a rated wind speed of 12.5 m/s. And input wind speed characteristics shown in below Fig. 7.2

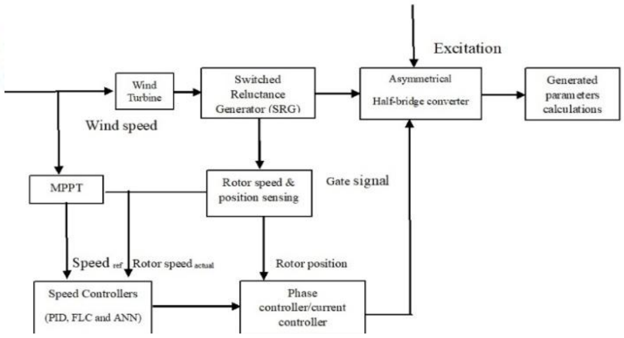

Fig.7.1 Block diagram of simulation circuit.

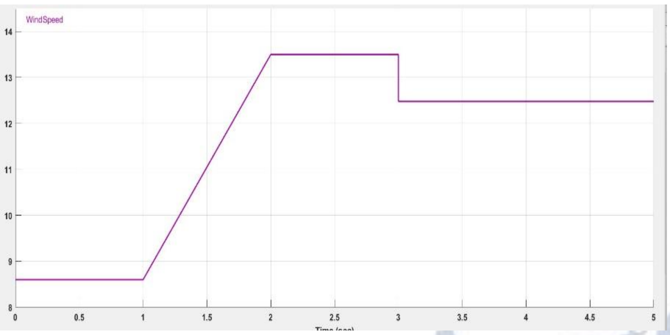

Fig.7.2 Input wind speed characteristics.

The SRG utilised in this type is set up as an 8/6 machine. An asymmetrical three-phase power converter with four legs that each include two IGBTs and two free-wheeling diodes supplies power to the SRG.Use of the tip speed ratio is by the MPPT controller. Calculating the ideal SRG speed after sensing the wind speed.The SRG speed controller calculates the current reference from the speed error by comparing the actual SRG shaft speed to the speed reference provided by the MPPT controller. This comparison is done using controllers (PID, FUZZY, and ANN).

To determine the mechanical angular position, the position sensing logic incorporates the speed. In the current controller blockthe proper angular location of the phase is enabled by the phase commutation controller (PCC).The phase hysteresis current controller(HCC) accepts the speed controller's current reference as well as the phase enable signal. When the phase is activated, the HCC output is utilised as the gate signal to operate the asymmetric half bridge converter's switches (AHBC). And the converter feeds the input supply to SRG. The generator output power is managed in order to regulate the rotating speed.The generator output power is managed in order to regulate the rotating speed.

B. Simulation results

The simulated model is examined once controllers have been trained and simulation settings have been specified. Plotting shows the outcomes. and they are compared for PID, FLC and as well as ANN controller.

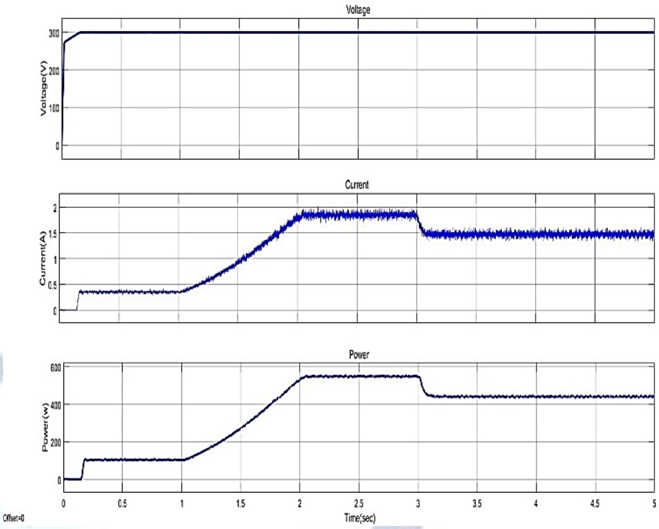

Fig.7.3 Simulation results output parameters with PID controller

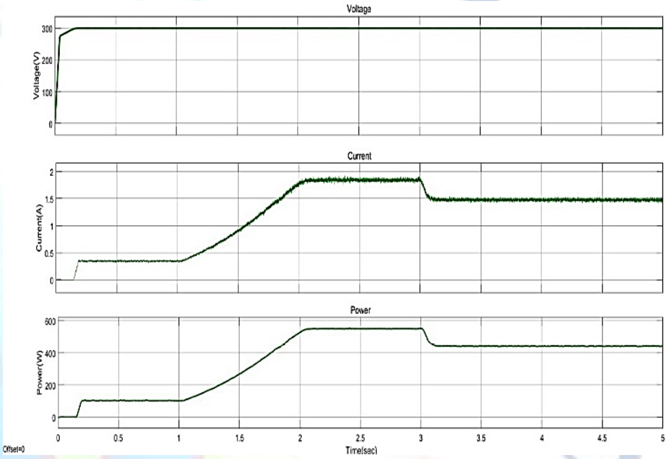

Fig.7.4 Simulation results output parameters with FUZZY controller

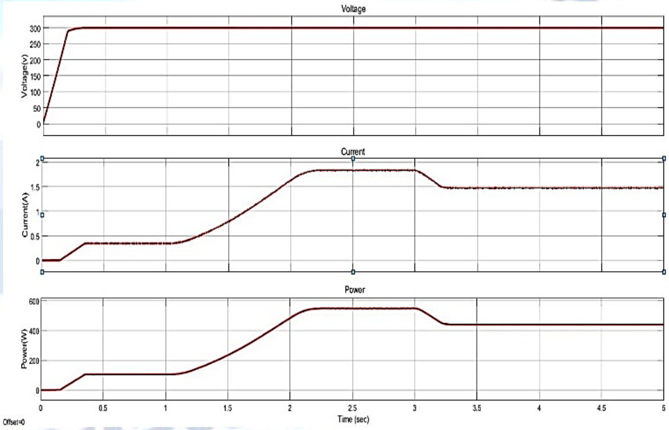

Fig.7.5 Simulation results output parameters with ANN controller

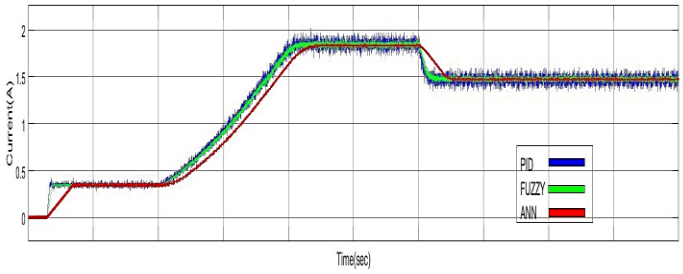

Fig.7.5 Comparison of output currents (I_{DC})

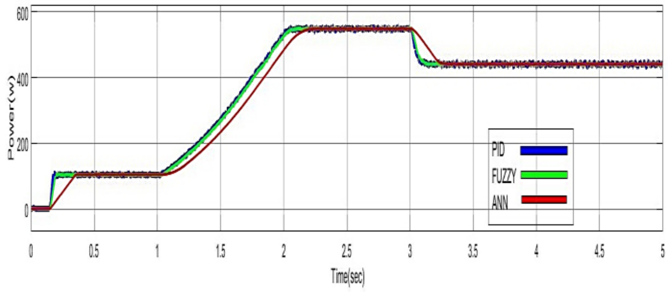

Fig.7.6 Comparison of output power (P)

The results show that the ANNC performs better than both the PID and FLC in terms of efficiency. Every non-linear function can be approximated by an ANN, which also has the ability to learn. Therefore, the PID and FLC in this study, the ANNC is more effective and appropriate. As a result, ANN can be more reliable and stable under a variety of circumstances.

The below table is the comparison of output parameter's overshoot % and peak overshoot value. Here observe the table, the parameter's overshoot % and peak overshoot values are enriched.

	CURRENT (I_{load} = 1.84 A)		POWER (P_{load} = 549 W)	
	Overshoot (%)	Peak Overshoot Value	Overshoot (%)	Peak Overshoot Value
PID	9.73	2.14	3.60	52.9
FUZZY	0.51	1.91	2.32	51.6
ANN	3.60	1.85	1.45	49.3

Table 7.1 Comparison of output parameter's quality with different controller

8. CONCLUSION

In this study, we constructed a mathematical model for the wind turbine pitch control system and used MATLAB/Simulink to simulate it using conventional PID, fuzzy, ANN controllers to get the best response. For base speed (12.5m/s) input to wind turbine, we enrich the SRG output power using conventional PID, fuzzy, and ANN controllers. While using PID controller the generated output power response with a reduced rise and delay times, it oscillates with a peak overshoot of 2.01 A, which has a negative impact on the system's performance. So, the fuzzy logic is introduced. The usage of a fuzzy logic controller is suggested to stop these oscillations. But it is generated an output power response oscillates with a peak overshoot of 1.91 A, which has also a negative impact on the system's performance. Here introduced the most efficient controller ANN, the usage of ANN is to enrich the output characteristics.The findings show that this controller is capable of the smooth response and successful oscillation suppression come at the reduces it oscillates with the peak overshoot of 1.85 A. this is the better enrichment of generated output power. This method is far more effective at achieving pitch system management and ensuring the stability of wind turbine output power.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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