Design and Simulation of Intelligent Controller for MPPT in Grid Connected Wind Plant using SRG

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Abstract : In wind generation system, output of wind turbine is varying which is unacceptable by the output side load and can affect the stability and reliability of the overall system and difficult to achieve the maximum power output. Purpose of this study is investigating a proper maximum power point tracking (MPPT) with the help of intelligent controller and switch reluctance generator (SRG) which overcomes the disadvantage of classic controllers like PI,PD, PID. The intelligent controllers used are artificial neural network controller (ANNC) and fuzzy logic controller (FLC). The response of both controllers are compared together. The systems are simulated in MATLAB/ Simulink environment.

***IndexTerms* – Maximum power point tracking, Artificial neural network, Fuzzy logic controller, Wind plant, Switch reluctance generator**

I. INTRODUCTION

’’Nothing is too wonderful to be true if it be consistent with the laws of nature.’’ Imagine that we have entered in the coveted 51st century, an era of advanced modern technology but looking at other side of the coin we can’t ignore other major problems of population swell, hyperbolic relation in demand-supply curve putting a strain on non- renewable resources coal, gas ,oil which are on verge of extinction considering present trends of its usage. Such merciless usage of resources creates an ecological imbalance soaring global warming and constituting uneven seasonal patterns witnessed across the world. Therefore, renewable energies like wind power and solar energies grabbing the researchers attention most. Wind power is the fastest growing power generation technology owing to its targeted and current development and gaining the momentum in power industry. Wind energy is the most adaptive and lucrative option, when a glimpse at the havoc inflicted by non-renewable sources in the form of CO2 emission, reduction in demand, soaring oil prices is taken.

A simple mechanism of wind turbine coupled to electric generator is required to seize and convert wind energy into electric energy. Two main groups of wind turbine are fixed speed wind turbine (FSWT) and variable speed wind turbines. Variable speed operation of horizontal axis wind turbines has several potential advantages over fixed speed machines of which some frequently mentioned ones are, additional energy capture below rated wind speed, additional power-train compliance with associated load alleviation above rated wind speed and reduction in audible noise particularly at low wind speed. For proper operation of wind plant various generators studied such as induction generator (IG), doubly fed induction generator (DFIG), wound field synchronous generator (WFSG), permanent magnet synchronous generator (PMSG) and switch reluctance generator (SRG).

In order to limit the mechanical stresses into the system along with maximum extraction of energy from wind stream, variable speed operation is the only panacea. All these advantages go in vain because SRG is still far away from mainstream wind energy application. Control of angle being the key factor when it comes to difficulties concerned. SRG prominently a doubly excited salient machine being subjected to excessive magnetic saturation. Rotor position and phase currents hold the flux linkage, inductance and torque. These features have a cumulative effect of nonlinearity to the SRG. Control performance is deteriorated by the nonlinear behavior with the use of traditional linear control methods such as PD, PI and PID controllers. Thus to promote SRG, a very noble control strategy needs to be implemented.

Duo of SRG paired with MPPT will facilitate in meliorating energy performances of wind energy conversion system enabling it to be used in wider application. In addition to this SRG has many advantages such as high efficiency, mechanical robustness, performing in a wide range of speed, high fault tolerances, high power density and again it does not uses gearbox in wind turbine application. For achieving maximum efficiency in variable wind speeds, the study on switching of SRG and optimal turn- on and turn- off angle of the asymmetric half bridge are getting popular

ANNC and FLC are the two intelligence controllers presented to control the SRG, which is connected to the grid. The output of the ANNC and FLC are compared with each other for the same performances. In the proposed controlling method the turn-on switching angle of SRG is control by the intelligence controller to maintain the rotational speed at the optimum point.

II. RESEARCH METHODOLOGY

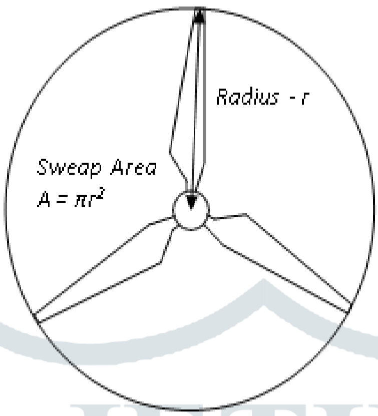
In this project, two intelligence controllers are presented as MPPT methods in the VSWT with the SRG connected to the grid. The ANNC and FLC are applied to control the SRG. Performances are compared between two proposed controllers in the same conditions. The intelligent controllers control the turn-on switching angle of SRG for maintaining the generator rotational speed at the optimum point in VSWT. The SRG is connected to the grid through an asymmetric half bridge converter, DC-link, and DC–AC inverter system with a pulse- width modulation (PWM) technique. Generated electric power is delivered to the grid by a three-phase inverter. Proposed methods are evaluated in MATLAB / Simulink environment. Results demonstrate that the ANN controller has more accuracy in comparison with FL controller.

III. VARIABLE SPEED WIND TURBINE AND MPPT

In wind turbine the kinetic energy in the wind is first convert into rotational kinetic energy in the turbine and then in electrical energy. The energy conversion depends on swept area of blades and wind speed. The swept area is defined as the plane of wind intersected by the generator and it is calculated from the length of the turbine blades using equation for the area of a circle.

$$A = \pi r^2$$

Where the radius is equal to the blade length as shown below



Airflow power is given by following equation

$$P_{air} = \frac{1}{2} \rho A V^3$$

Where ρ is the air density, A is swept area of blade and V is the wind speed

$$C_p = \frac{Electricity\ produced\ by\ wind\ turbine}{Total\ energy\ available\ in\ the\ wind}$$

$$C_p = \frac{P_{wind\ turbine}}{P_{air}}$$

Another term that is tip speed ratio (λ) is also essential factor in determining the performance of wind turbine. Coefficient of power is depend on the value of tip speed ratio (λ) and pitch angle (β).

$$\lambda = \frac{\omega R}{V}$$

Where λ is the tip speed ratio, ω is the wind turbine rotational speed, V is the wind speed and R is the blade radius. Pitch angle (β) depend upon the relation of wind speed with base speed, if wind speed is greater than base speed then β can be controlled otherwise it is considered as zero.

According to German physicist Albert Betz who concluded in 1919 , that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. Therefore, 59%is the maximum power efficiency of any design wind turbine. This is called power coefficient which show the efficiency of wind turbine in the conversion of wind into electricity.

As we know the coefficient of performance is defined as the fraction of energy extracted by the wind turbine of the total energy that would have flown through the area swept by the rotor if the turbine had not been there. C_p is a non -linear function of λ and β, and it is independent of blade radius. Fig.1 shows the C_P-λ characteristics for different values of the pitch angle (β). Wind turbine power is equal to:

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

From above equation it is shown that wind turbine power has non- linear relationship with wind speed which make the system highly non-linear. From fig 1, at the values of $\beta = 0$ and $\lambda = 8.1$ the coefficient of power becomes maximum $(Cpmax)$. Here, wind speed is less than the rated speed hence β is zero. The value of λ obtained here is termed as the nominal or optimal value (λ_nom) therefore, C_{pmax} can be achieved only when λ becomes $\lambda_{\_nom}$.From equation it is clear that controlling the generator rotational speed, tip speed ratio can be set on the λ_nom to access maximum power coefficient (C_{p_max}) hence power of wind turbine maximizes.

Now, maximum power of the wind turbine is calculated by the following equation:

$$P_{WT(max)} = \frac{1}{2} C_{p\_\max}(\lambda_{nom}, \beta = 0) R^2 V^3$$

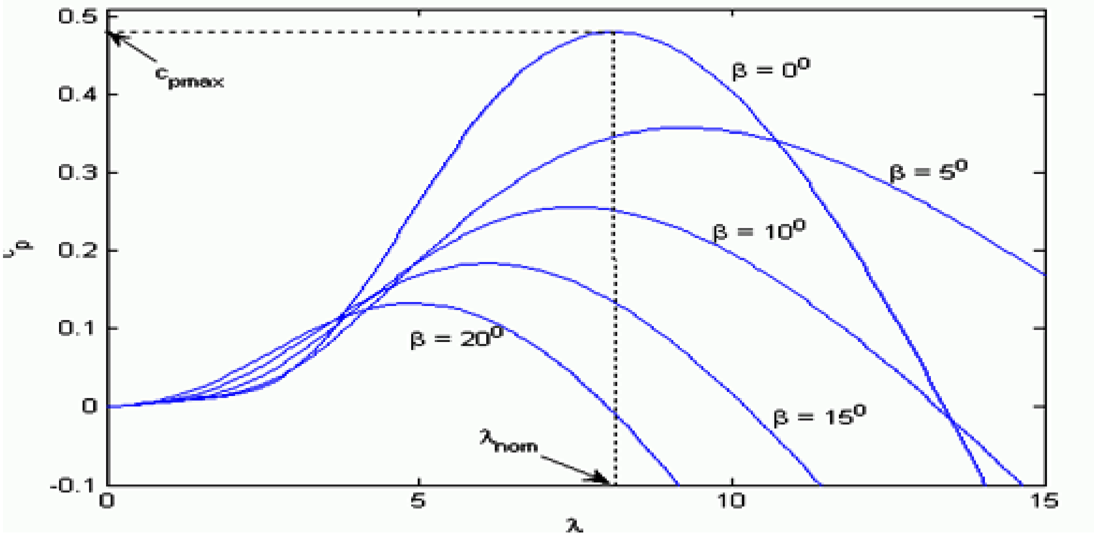


Fig. 1. The C_p-λ characteristics, for different values of the pitch angle β in MATLAB/Simulink

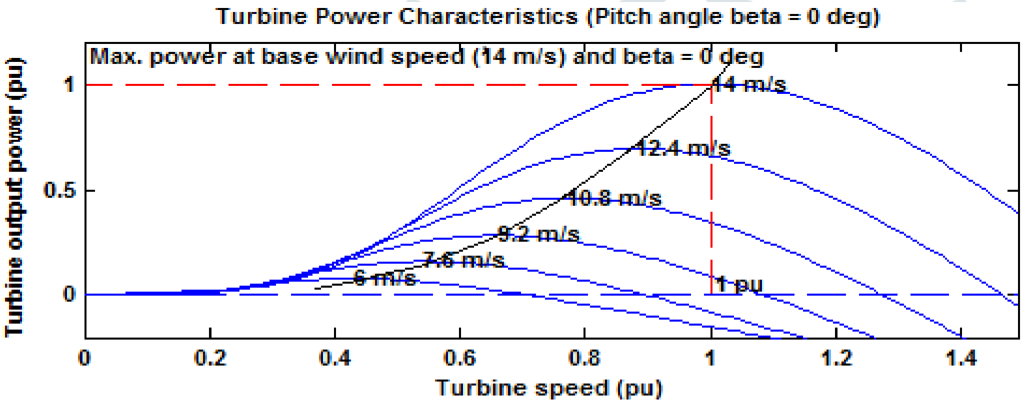


Fig.2. The generator rotational optimum speed in different wind speed to access MPPT

Fig. 2 shows the generator rotational optimum speed in different wind speed to access MPPT. At wind speed of 14 m/s the maximum power of wind turbine is achieved and turbine rotates at the speed of 1 pu.

IV. SWITCH RELUCTANCE GENERATOR

Switched reluctance generators have simplified construction as there is absence of magnets or conductor in the rotor , they are low cost, easy to manufacture and can operate in high speed and high temperature environments. Torque produced by the SRG is independent of current direction. SRG possesses advantage such as robustness and the rotor of the SRG have low inertia which allow machine to respond to rapid load variations. Absence of brushes, rotor has neither windings nor permanent magnets and consist of any laminated steel reduces the manufacturing cost in application of wind generation.
Excitation windings are placed on the stator poles and phase windings are set diametrically opposite to each other and connected in series. The configuration of SRG are depend on the supply phases and stator and rotor poles number. The configuration can be 6/4,8/4,10/4.

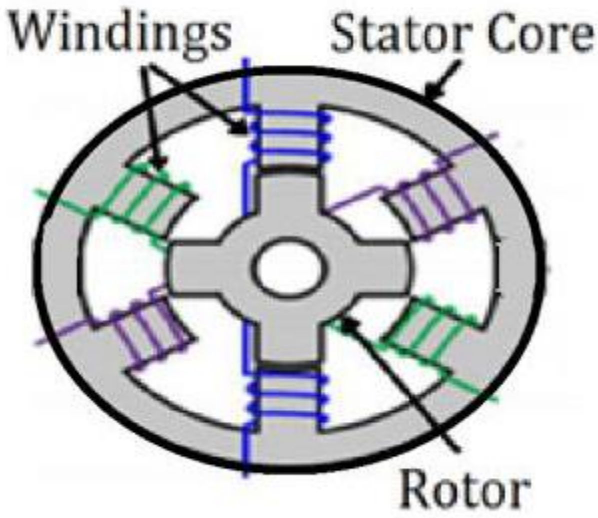


Fig. 3 Basic structure of SRG 6/4

Fig. illustrates a basic configuration of normal 6/4 – three phase SRG used in this study. The switch reluctance generator has a converter system shown in fig. This converter comprised of two diodes and two controllable power semiconductor switches per phase. The purpose of this power semiconductor switches are for generator excitation and diodes are for electrical output. As soon as the switches are turned on current passed through the phase windings. Further, when the power switches are turned off the excitation energy and additional energy are returned back to the DC link through the two flywheel diodes. This circuit is also called as asymmetric half bridge of the three phase Inverter for SRG.

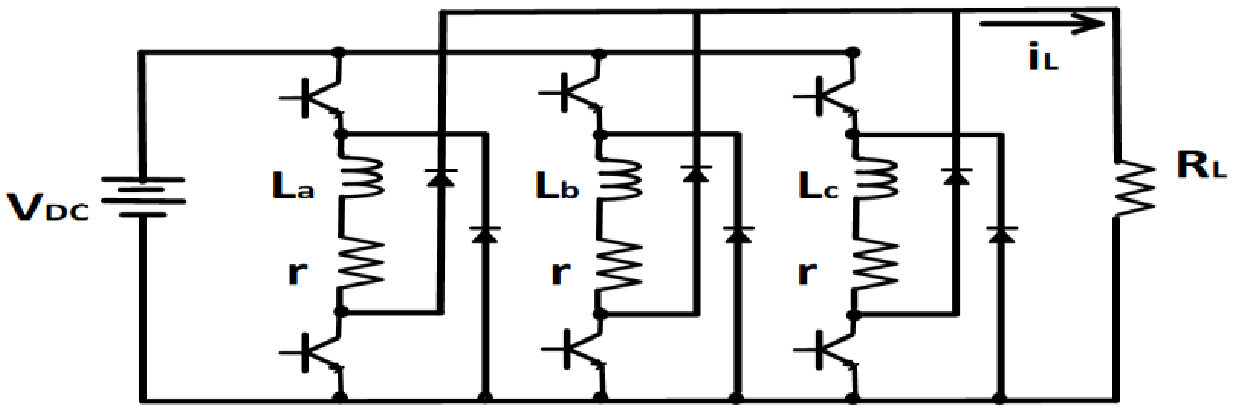


Fig.4 Circuit diagram of three phase converter for SRG

The voltage for each phase of the SRG is given by the following equation

$$V = Ri + \frac{\partial\psi}{\partial t} = Ri + \frac{\partial\psi}{\partial t}\frac{\partial i}{\partial t} + \frac{\partial\psi}{\partial\theta}\omega$$

Where ψ is the flux linkage , i is the phase current, R is the phase resistance , $\partial\psi/\partial i$ is the inductance, ω is the rotor angular velocity, and θ is the rotor position.

Instantaneous electromagnetic torque is given by

$$Te = \frac{1}{2}i^2\frac{dL}{d\theta}$$

To get to generator mode operation , winding is energized in the drooping inductance region of the inductance profile and. Variation of inductance with respect to the rotor position is negative $(dL/d\theta < 0)$. The sign of the generated torque is negative , and thereby it extracts energy from the wind turbine.

The excitation and the output current are calculated with switching angle and phase current as follows

$$I_{exc} = \frac{1}{\theta_{per}}\int_{\theta_{on}}^{\theta_{off}} i(\theta)d\theta$$

$$I_{out} = \frac{1}{\theta_{per}}\int_{\theta_{off}}^{\theta_{ext}} i(\theta)d\theta$$

According to above four equation the average power per phase is defined as follows

$$P_{ave} = \frac{V_{DC}}{\theta_{per}}\left[\int_{\theta_{on}}^{\theta_{off}} i(\theta)d\theta - \int_{\theta_{off}}^{\theta_{ext}} i(\theta)d\theta\right]$$

The average power of the SRG is controlled with turned on and off angles of controller power conductor switches. The period from θ_{on} to θ_{off} is excitation period and the period from θ_{off} to θ_{ext} is active period.

V. FUZZY LOGIC CONTROLLER

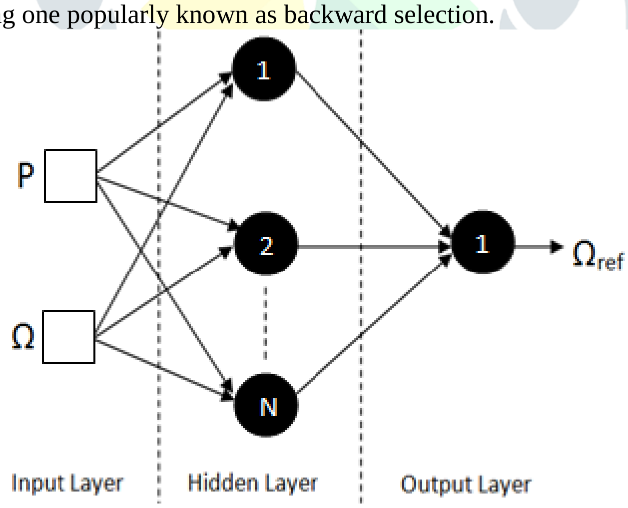
Fuzzy logic was first introduced by Zadeh in the year 1970. FLC commonly perform important role in the controlling application of non-linear and complex system. FLC is nothing but an artificial decision maker. Such like human behavior FLC also makes decision using linguistic rules and not on the analytic modules of mathematical equations. This logic controller is generally works on the four basic blocks which are Fuzzification, Knowledge base, Inference engine and Defuzzification units.
After obtaining a collection a collection of fuzzy IF-THEN rules based on domain knowledge, these if then rules are bring together into a single system. This process include five steps.
STEPS:

1. Fuzzify Inputs Fuzzy operator
2. Apply Fuzzy operator Agrreregation
3. Apply Implication Method
4. Aggregate All Outputs
5. Defuzzify

In this proposed FLC, input is eight trapezoidal shape membership function and triangular shape membership function. Output is eight z-shaped membership function. When optimal rotational speed is given as input the output is turn off angle for IGBT's. The optimal rotational speed is between 0-1 and output is turn off angle in the range 15-40.

VI. ARTIFICIAL NEURAL NETWORK CONTROLLER

Fabrication of intelligent system requires conglomeration of various features such as, linear independence, vital data from previous system. Minimal error and miniscule size is to be taken into consideration for artificial neural network (ANN). Structural elevation in ANN aids in minimizing an error thereby soaring computations volume. Thus a negotiation between the two cases is not possible.
Designing of ANN can be done as follows
Initially all input variables affecting output are gathered. Two available methods for input selection are present. In first method, a bifurcation of input variable as most valuable and least valuable input is done. Then most significant input are selected popularly known as forward selection. In another method, initially least valuable input are removed and a lo is applied until least valuable input are removed from the remaining one popularly known as backward selection.



After appropriate selection of input variables, number of neuron layers and activation function are designed. ANN architecture and optimal quantity of neurons is generally acquired by trial and error process till ANN error reduces substantially. Hidden layers are estimated after locating optimal quantity of neurons. Nevertheless an escalation in hidden layers may sweep less errors. But in most cases ANN is restricted to four layers or less, reason being the introduction of large computational volume and notable rise in processing time. On accomplishment of structural fabrication of ANN, ANN is trained.

Myriad algorithms may be put to application for appropriate training of ANN. Back propagation algorithm serves as backdrop to ANN. Feed forward network along with back propagation learning algorithm commands the structure of artificial neural network controller. This method involves elimination of least valuable input and choosing all input parameter effecting on achieving MPPT. After this the ANNC input are chosen to be most significant input. Optimal rotational speed, turbine mechanical torque and deviation between optimal rotational speed and real rotational speed contributes to input parameters of applied ANNC.
The quintessential process in ANN architecture involves trial and error which aids in selection of number of hidden layers and neurons in each hidden layer.

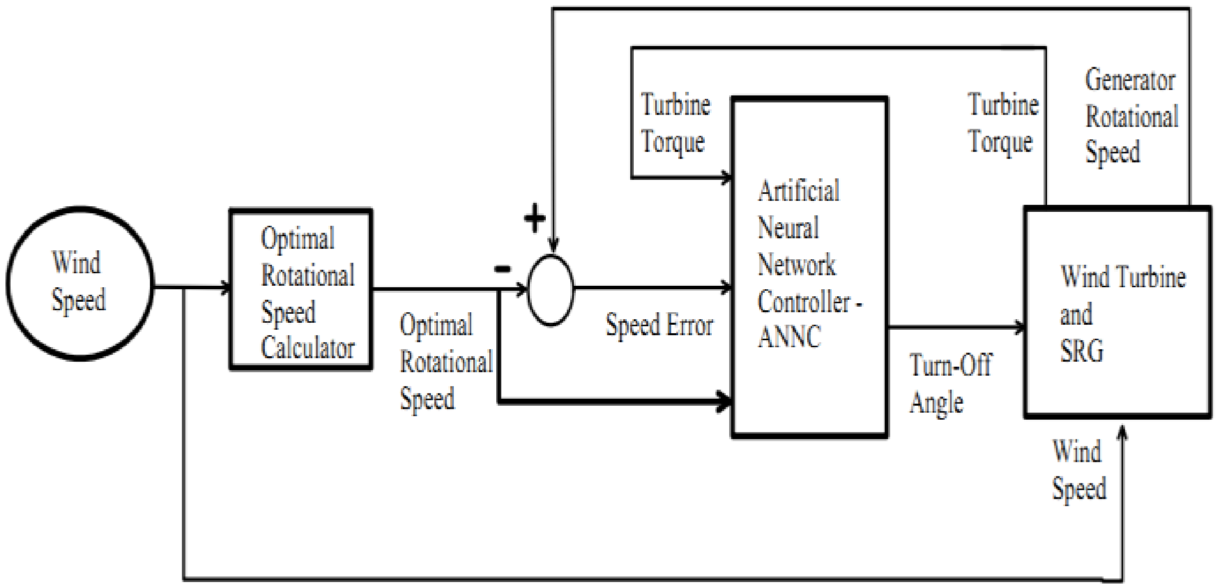


Fig. 6. Block diagram of proposed ANNC system

VII. GRID CONNECTING METHOD

In the generation of wind power, the output of wind turbine is not constant as wind is varying due to which the SRG behaves like a grid connected DG injecting active power to the grid. Therefore, to overcome above problem and achieving a proper MPPT, controlling the inverter is necessary by grid connecting strategy. Phase locked lop method is used for synchronization of inverter output with the grid. Again to inject active power into the grid Parks transformation is applied. The inverter controller system shown in fig.

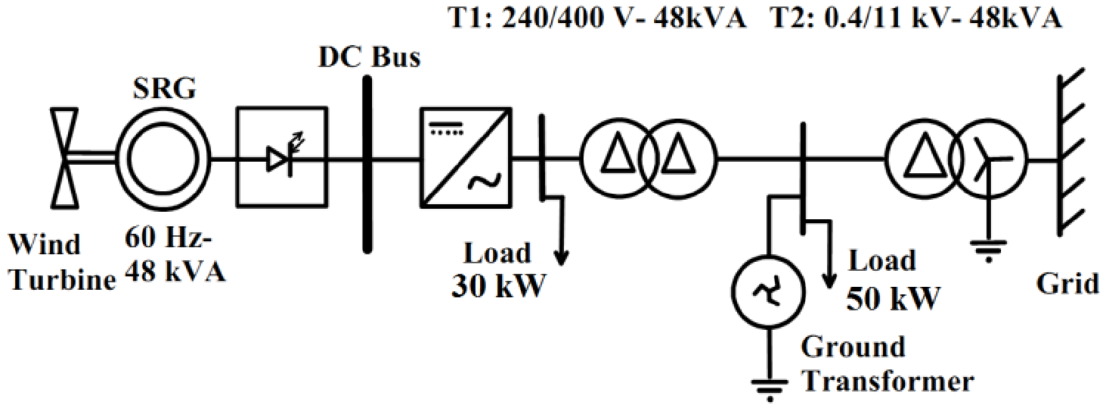


Fig. 7. Single line diagram of simulated system

The single line diagram is divided into two section. One is converter side and other is inverter side. Converter side have SRG and wind turbine. The combination of SRG and wind turbine is fed by three- phase power converter. The output of power converter is given to DC bus of 400 V. The obtained power from DC bus is converted to AC by DC/AC inverter. The generated power is increased from 240 V to 11 KV with the help of step up transformer and given to the grid.

Single line diagram of simulated system is depicted in fig. This is evaluated by using MATLAB/Simulink environment. Rated power of wind turbine is 48 kw and rated wind speed is14 m/s. The variation of wind speed is in the range of 9.5 m/s to 14 m/s with pitch angle zero.

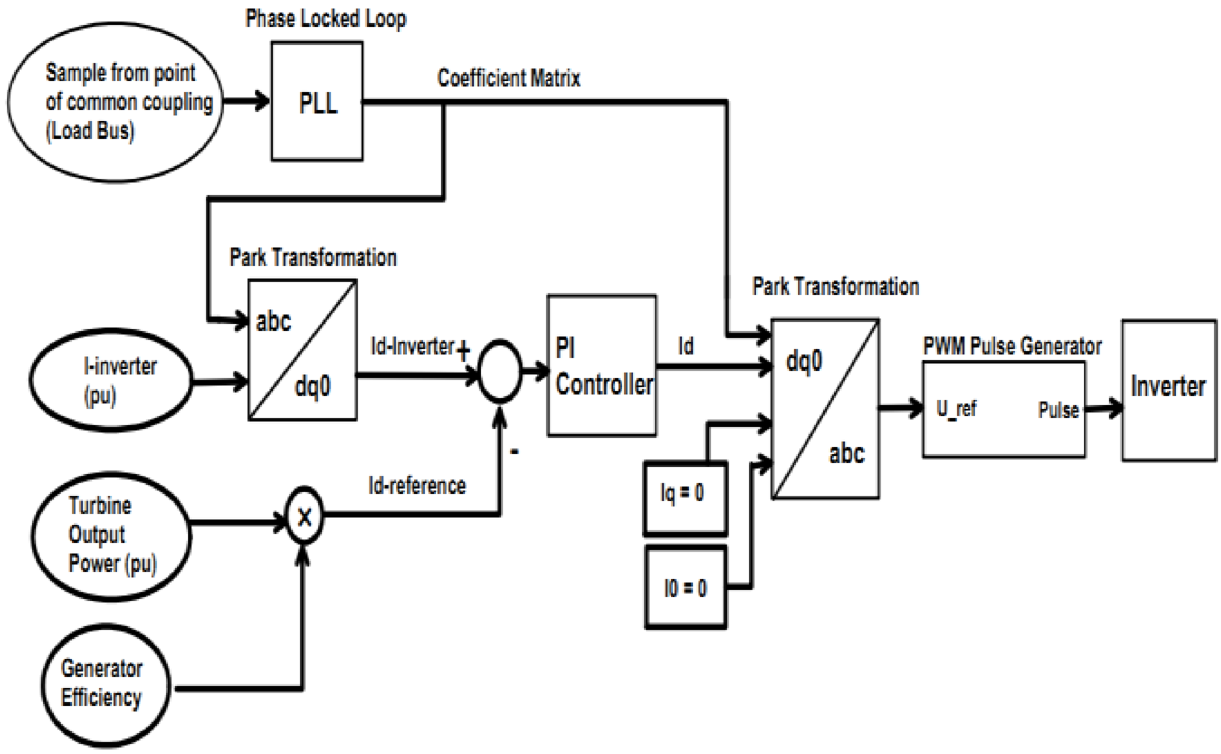


Fig. 8. Inverter controller block diagram

VIII. SIMULATION RESULTS

The main objective of this paper is to carry out the MPPT by applying intelligent controller. The speed of wind is not constant, it changes with the rate of change of time and wind flows. So waveform in fig.9 is taken as reference speed waveform which shows wind speed characteristics.

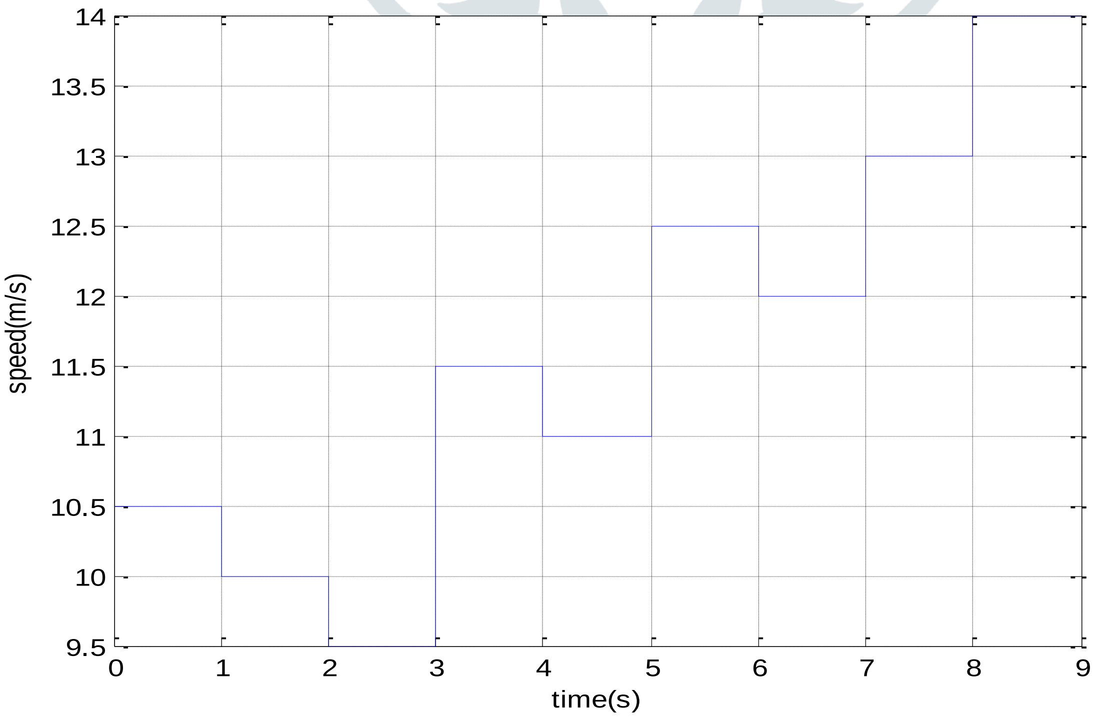


Fig.9 Input wind speed characteristics (Reference speed

The two intelligent controller ANNC and FLC observe and results obtained from observation are compared together. The MPPT eventuate at desirable rotational speed for different wind speed. After manipulation of ANN and FLC controller, the parameters value set in the simulation model and analyzed. In fig. 10 the graph shows the optimal rotational speed at various wind speed to acquire MPPT with the help of liner piecewise method. Without using speed controller, tracking of maximum power is difficult that means generating power is not equal to required power.

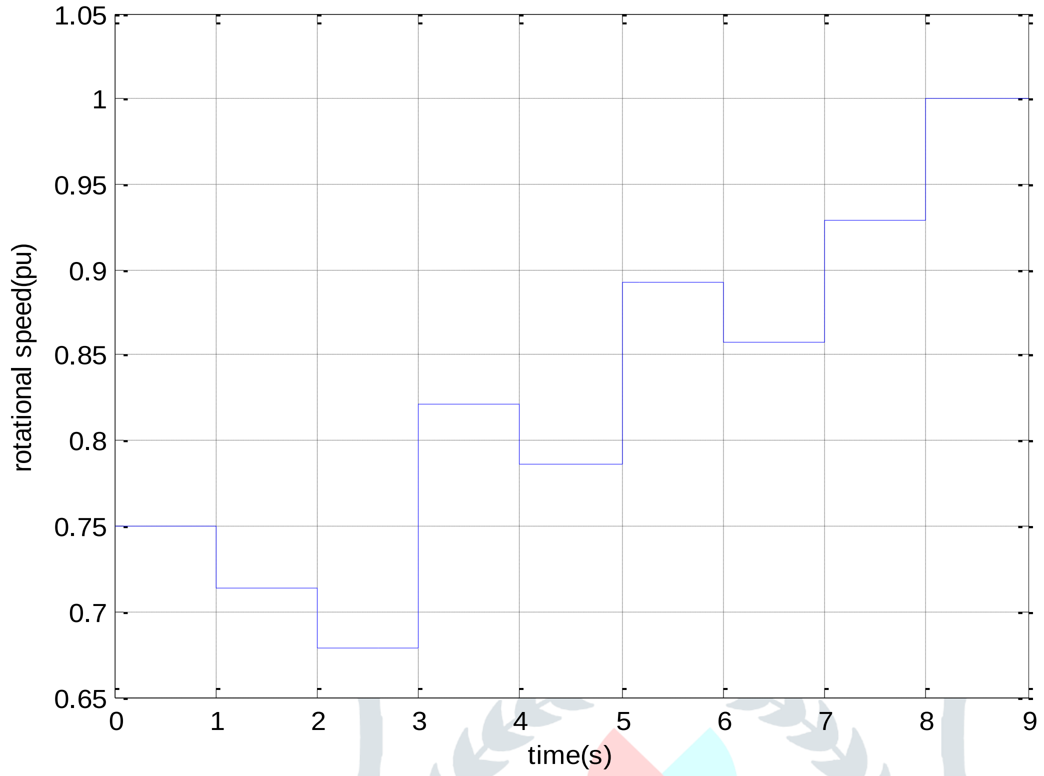


Fig. 10. The turbine optimum rotational speed for the wind speed (optimum speed)

Actual generating power depends on the wind turbine rotation. In order to getting required power from the wind turbine, controlling the rotating speed of wind turbine is must. So optimal or required power depends on rotating speed controller that is both the intelligent controller shown in fig 11 and 12. The ANNC can track MPPT better than FLC.

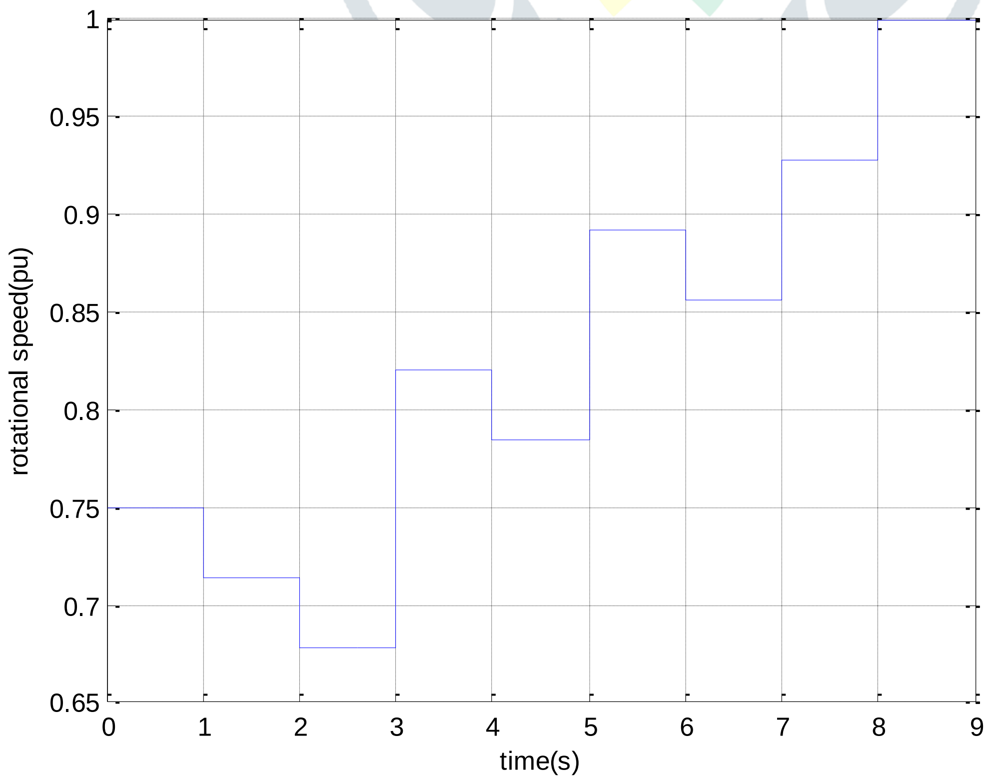


Fig.11. Turbine optimum speed for ANNC controller

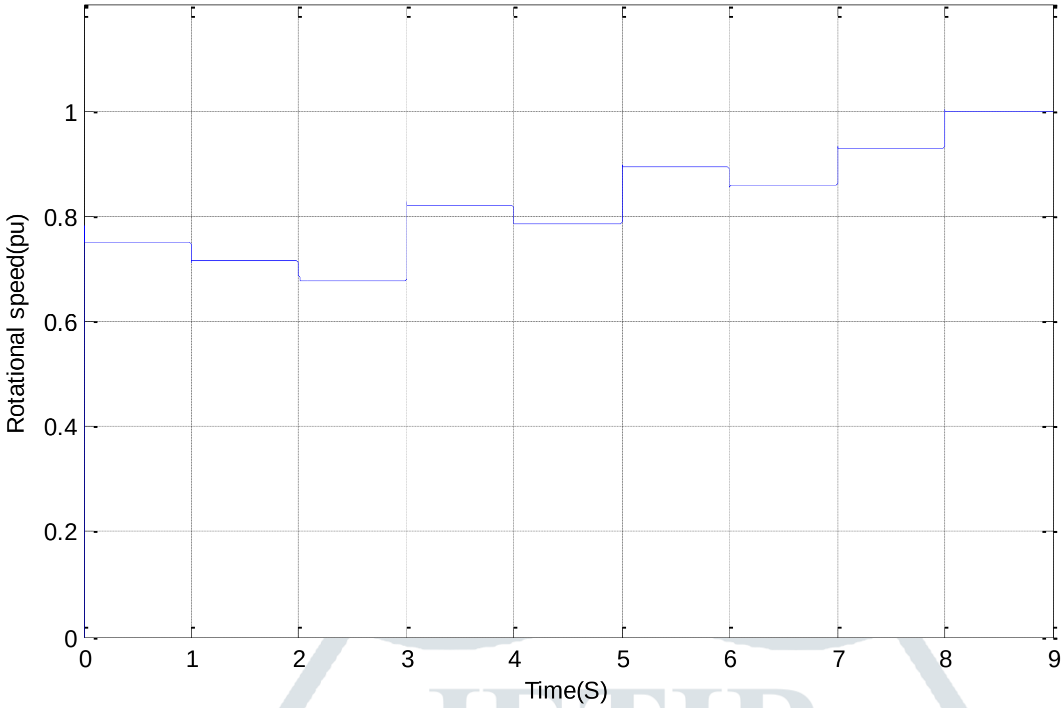


Fig.12. Turbine optimum speed for FLC controller

Turbine output torque for ANN and FL controller are shown in fig.13 and fig. 14 respectively.Torque is inversely proportional to the wind speed so as wind turbine torque decreases, rotating speed of the wind turbine increases and vice versa. Torque parameter changes the coupling parameter through where it is connected. The value of SRG torque is negative, because the machine is in generating mode.

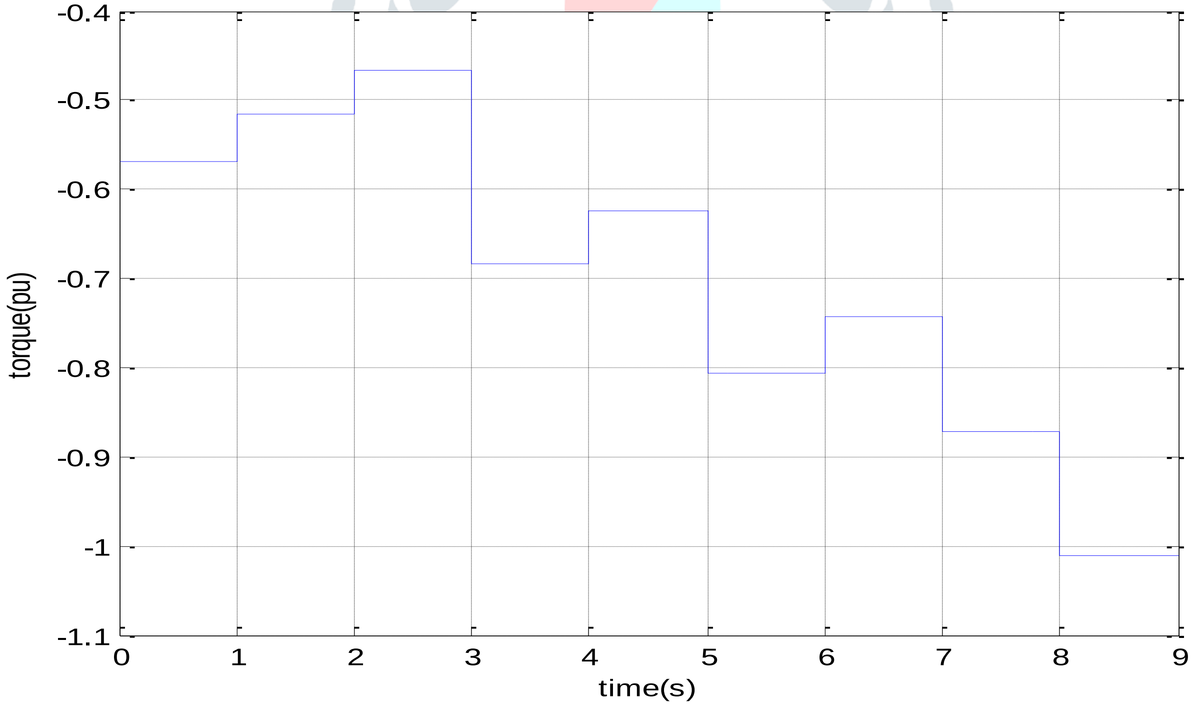


Fig. 13. The turbine output torque for ANN controller

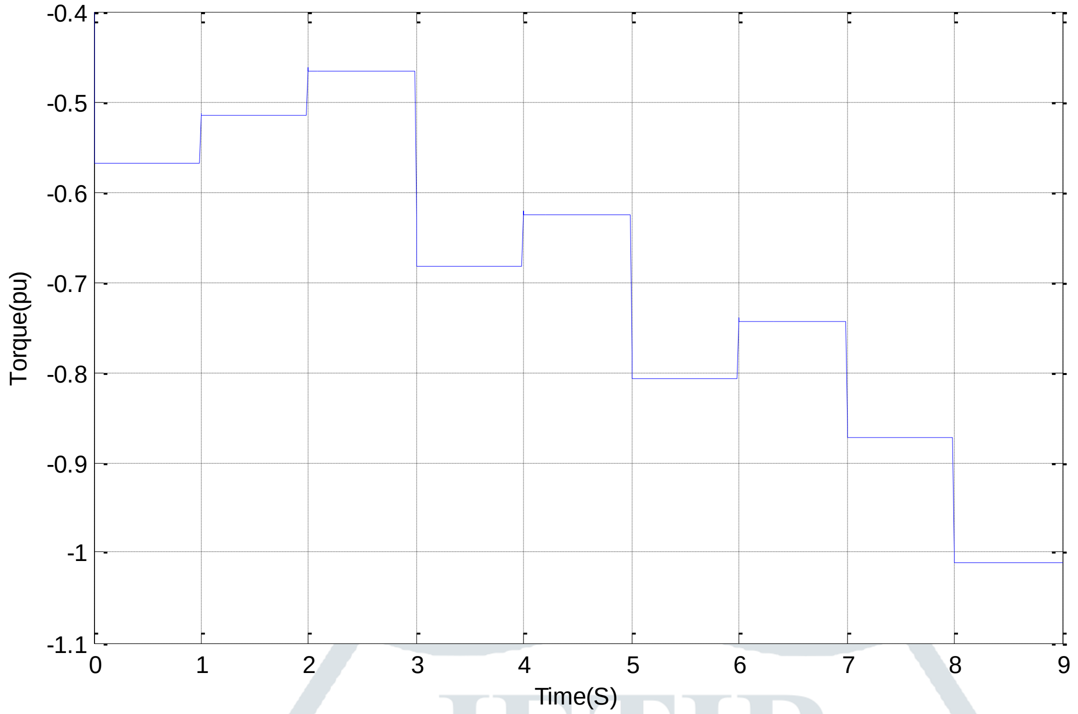


Fig. 14. The turbine output torque for FL controller

Rotation of wind turbine is directly coupled with the switched reluctance generator through power converter switches. The average power of the SRG is controlled with turned on and turn off angles of converter switches. The MPPT output (turn off angle) shown in fig. 15 and 16 respectively. After getting turn off angle, SRG flux linkages of all three phases are obtained. SRG current waveforms consist of harmonic component due to leakage currents flowing in the circuit and circulating current creates voltage drop which indirectly creates peak overshoots.

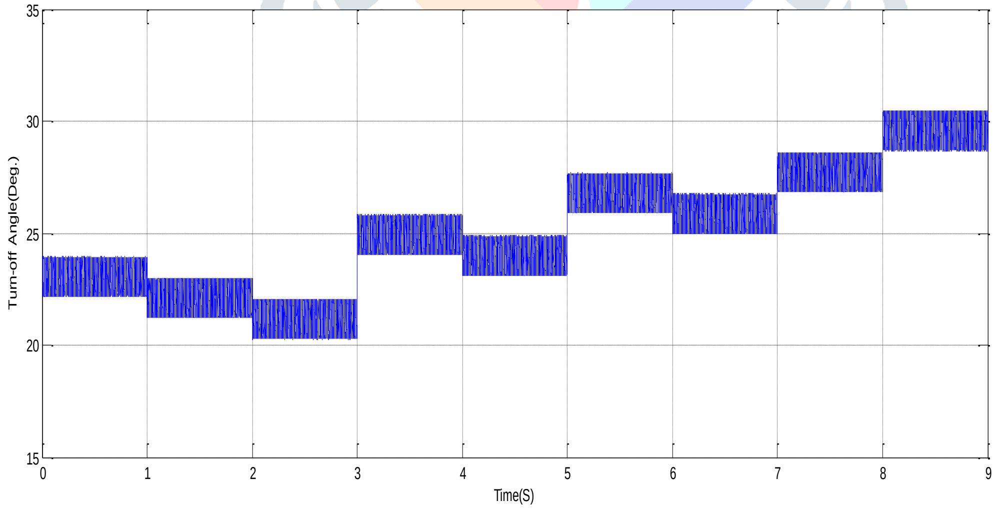


Fig. 15. The intelligent controller output for ANNC

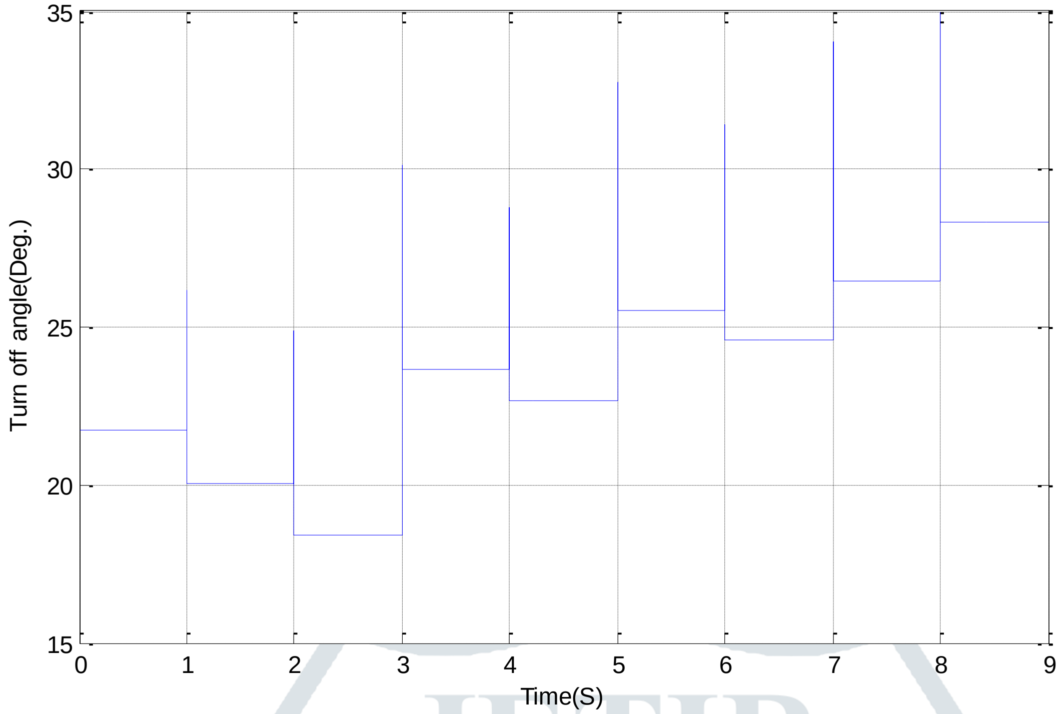


Fig. 16. The intelligent controller output for FLC

Torque waveform of SRG changes with variation in speed. Voltage waveforms based on the power converter turn on and turn off of the converter switches. Total harmonic distortion defines harmonic component present in the inverter output current and depends on the average and RMS values of the current waveforms.

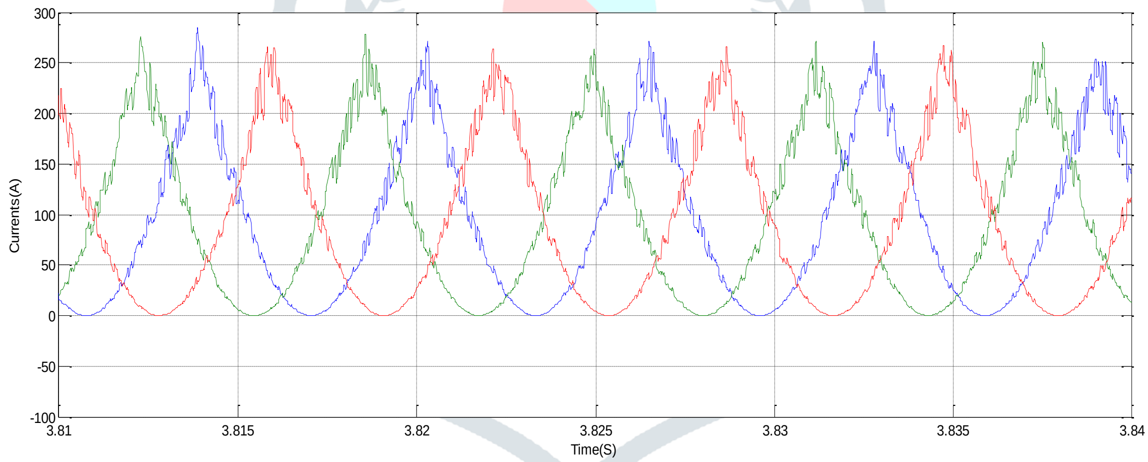


Fig.17. The SRG phase current

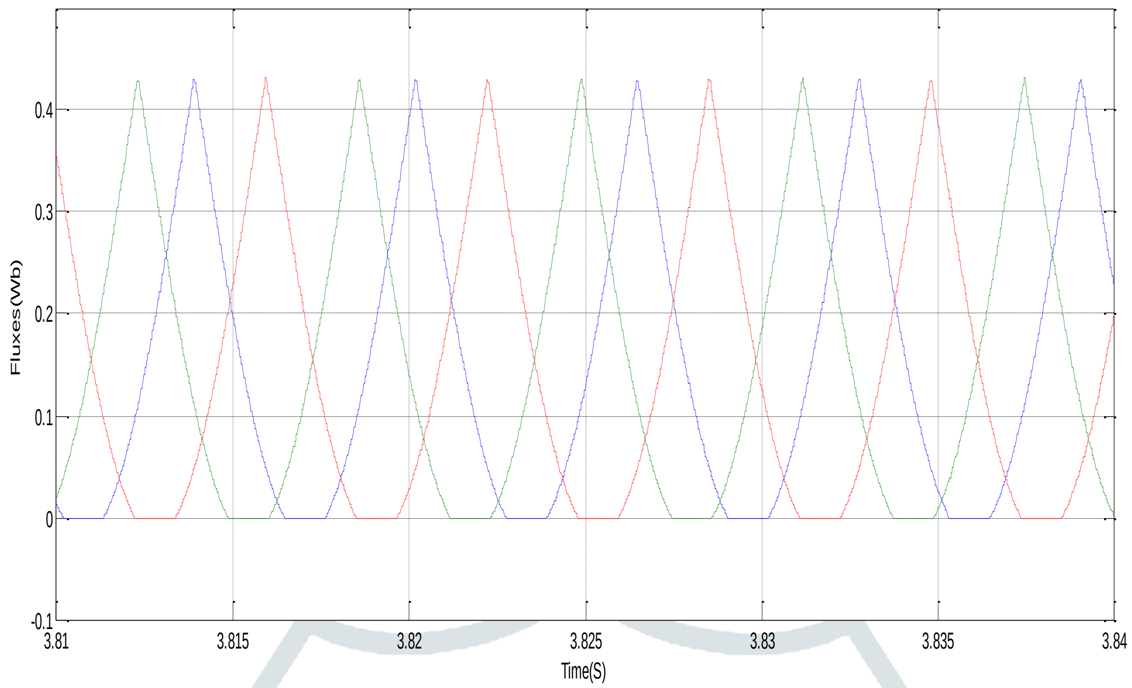


Fig. 18. The flux linkages in the SRG phases

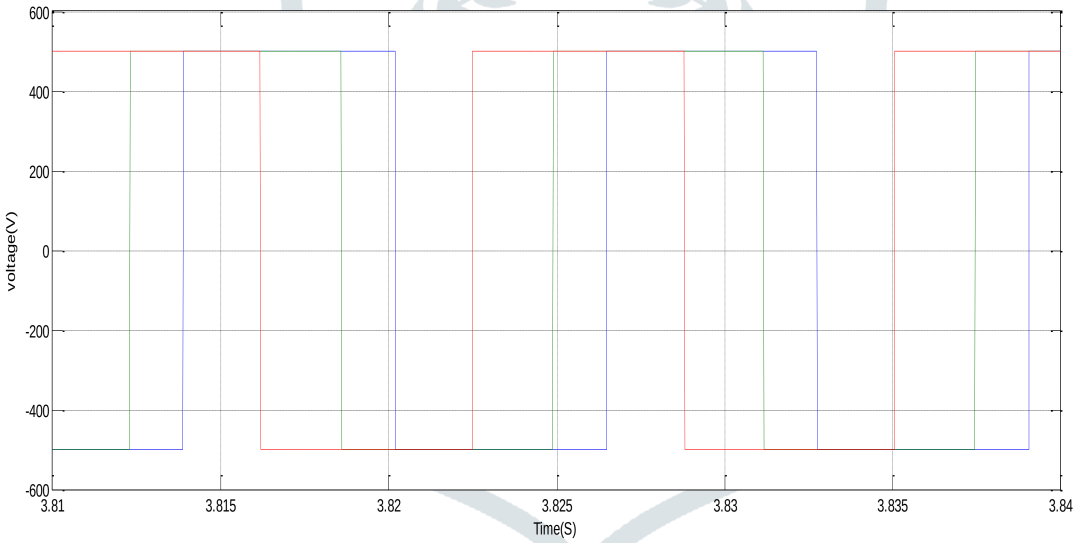


Fig. 19. The SRG phase voltages

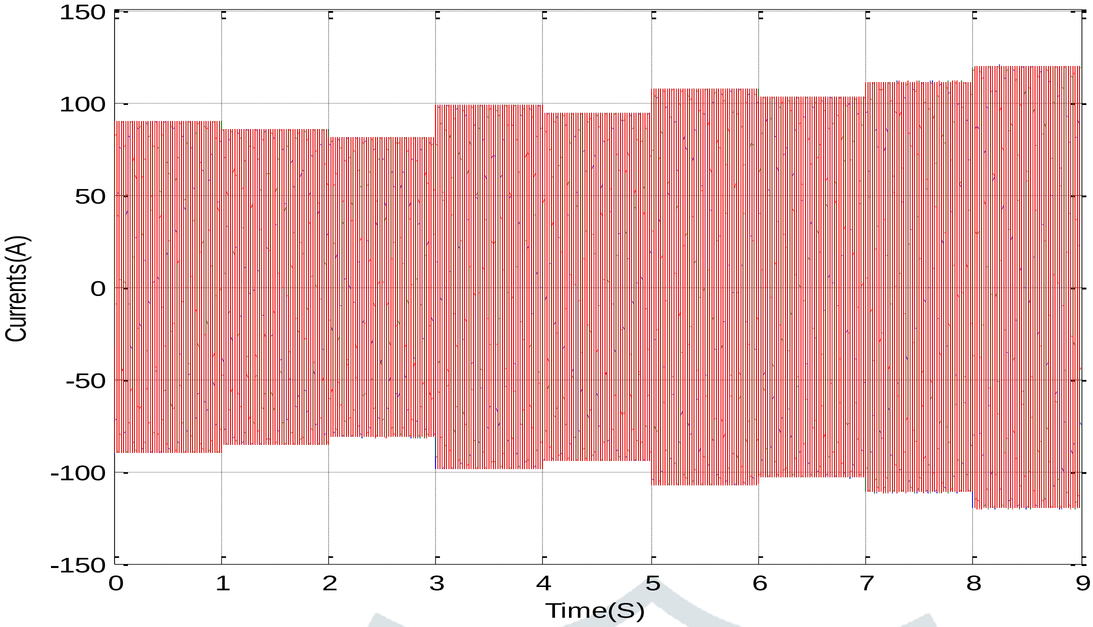


Fig.20. Inverter output current

IX. CONCLUSION

This paper highlights, a SRG run by VSWT powered by AC grid. SRG directs wind energy transmutation to electrical energy. A combination of three-phase inverter and step up transformer transmits generated electricity through SRG to the grid. A discrete PWM and voltage regulator curbs the inverter. LCI filter performs filtration of inverted power. With the innovative of adept methods in order to achieve MPPT by substantial control of rotational speed of turbine.

The duo of ANN and fuzzy logic controller constitutes intelligent controllers. Manipulation of turn off angle of IGBT in SRG's asymmetrical half bridge mode is the vital feature of both these controllers. Above discussed methods are then put to simulation in the backdrop of MATLAB.

Yielded output of controller are effectively equated together and illustrate that ANNC can obtain MPPT more skillfully in contrast with FLC. Added that ANNC performance is also superlative to FLC. Apparent effect on the absorbed power from wind turbine is witnessed from the conclusions revealing unevenness between the turbine rotational speed and the optimal rotational speed. In essence, transmuted/converted power from the wind turbine crawls to the apex value provided the variations between turbine and optimal rotational speed are nullified to the maximum extent.

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