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Artificial Neural Network based Controller system for Maximum Power Point tracking in Grid Connected Wind Plant

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Abstract:*This paper highlights a system for maximum power output of wind plant by investigating a proper maximum power point tracking (MPPT) using intelligent controller and switched reluctance generator (SRG). Artificial neural network (ANN) controller is very popular controlling method of the intelligent controller system. By changing the turn off angle of SRG by means of the controller, the rotational speed of wind turbine is change. Integration of wind generation to the grid through a DC-AC inverter system and two - step up power transformer results in maximum power point tracking with a novel application of intelligent method.*

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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.

Various factors, which make switch reluctance generator a distinct machine are nonlinearity, exquisite current communication requirement apart from its unique structural configuration with accelerating technological breakthrough in power electronics and MCV in recent years, SRG attained a benchmark in various application ranging from aerospace ,power system, starter/alternator for hybrid vehicles and wind energy conversion system. Predominantly built as motor drives, SRM can also showcase full four quadrant operation by controlling turn on and turn off angles of converter switches relative to rotor position. This transitional nature of SRG makes rheostatic speed operation possible and feasible for prime movers with varying speed range such as wind turbines.

Uneven patterns of wind speed throughout the day records a varying wind generated output, wind being the significant source of energy. Various feasible methods are available to trace the point on curve of IV characteristic, corresponding maximum power of wind turbine at the current wind speed. Such control systems are governed by the principle of maximum power point tracking.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.

Rotor position plays vital role in control of SRG. Artificial neural network helps to omit the SRG rotor position sensor and non-linear performance of the traditional PI,PD,PID controllers that are highly sensitive to parameter changes.Artificial neural network as intelligent controller presented to control the SRG, which is connected to the grid. The output of the ANNC shows its superior performance to track the maximum power. 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. Wind turbine with 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. Here it is taken as 113.5
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
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. This is calledpower coefficient.

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

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. $C_p$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. The maximum power of the wind turbine is calculated by the following equation.

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

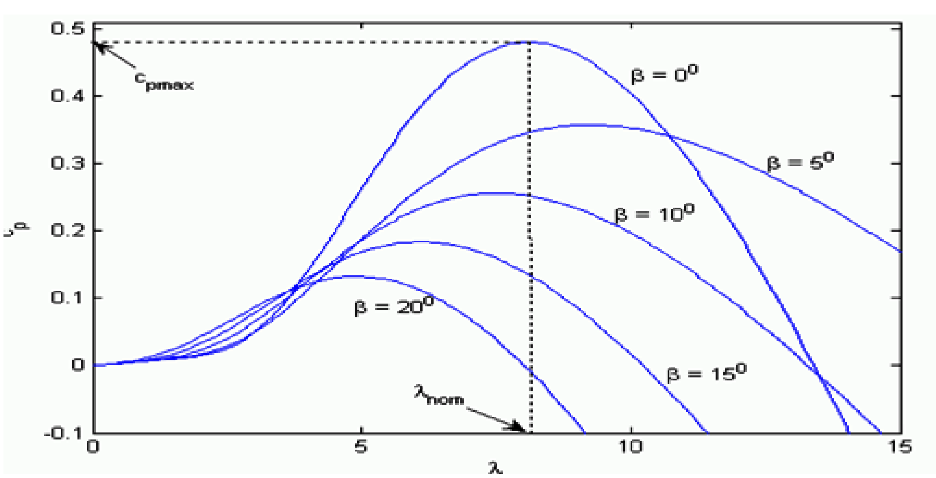

Fig. 1. The C_p-λ characteristics, for different values of the pitch angle β in MATLAB/Simulink

Fig. 2 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.

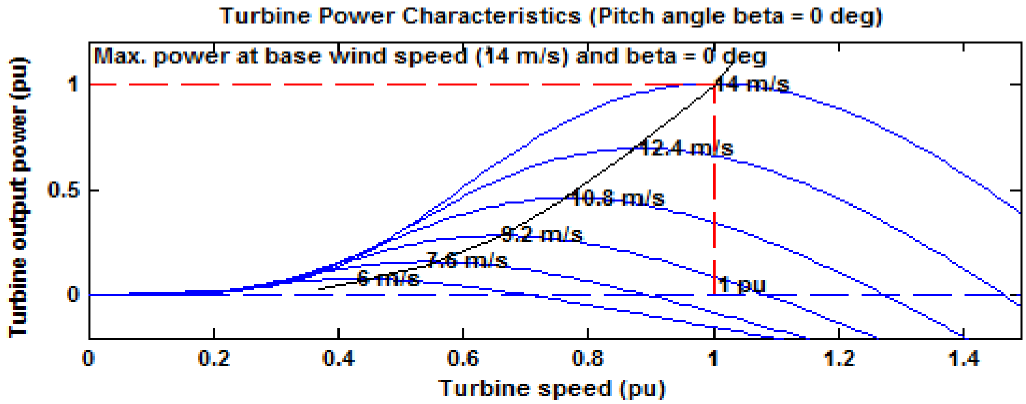

Fig. 2. The generator rotational optimum speed in different wind speed to access MPPT

Fig.3. 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 turn 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.

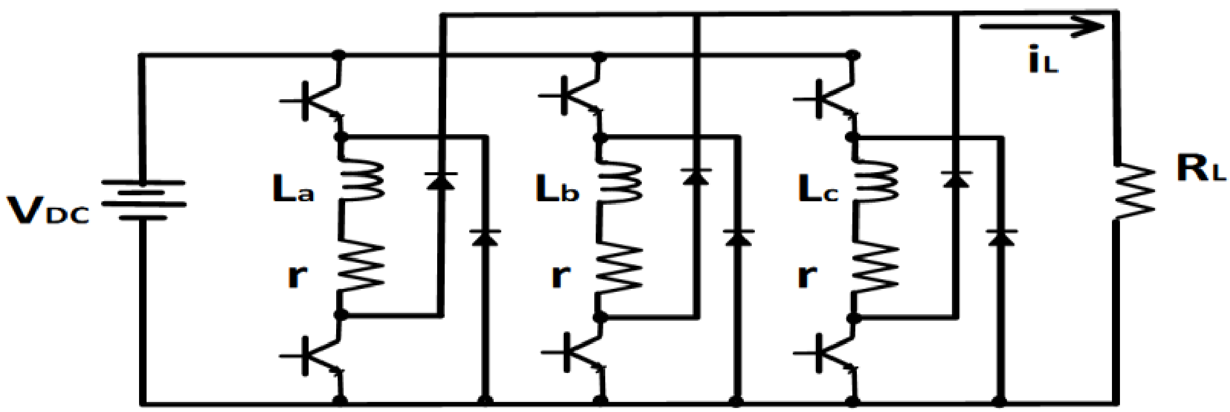

Fig.3. Circuit diagram of the three - phase converter for SRG

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/dθ<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.

III. Artificial intelligent controller

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.

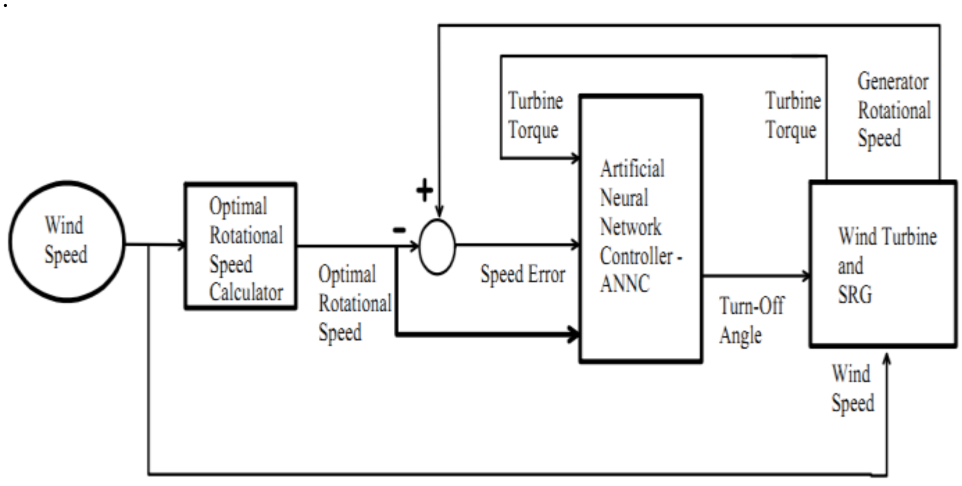

Fig. 4. Block diagram of proposed ANNC system

Table no.1 : The ANN controller structure

Items	Values
No. of hidden layers	2
No. of neurons in the input layer	7
No. of neurons in the second hidden layer	3
No. of neurons in the output layer	1
Learning rate	0.1
No. of epochs	200
Training error	0.0001

IV. Procedure methodology

The main objective of this paper is to track the maximum power point with the help of intelligent controller in the variable speed wind turbine (VSWT) with the SRG connected to the grid. The artificial neural network controller control the turn-on switching angle of SRG for maintain 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.

Results demonstrate that the ANN controller has acquisition ability and can imprecise any non-linear function.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.

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.

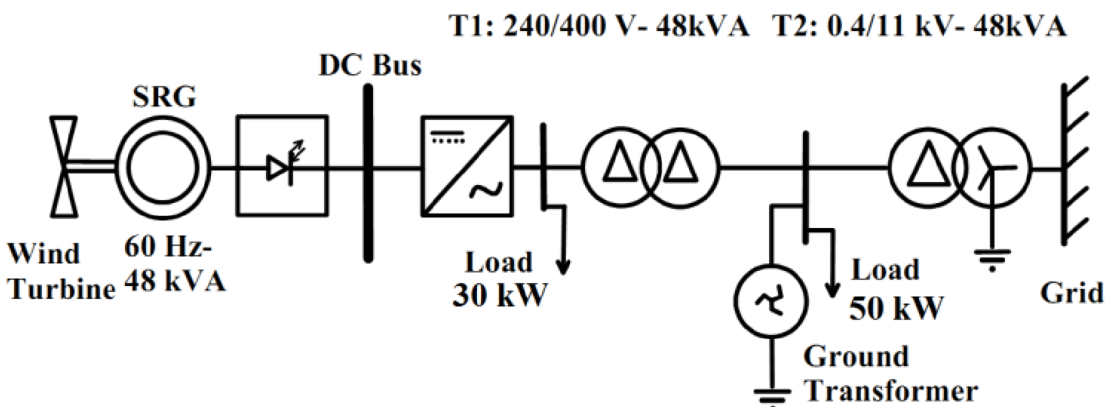

Fig. 5. Single line diagram of simulated system

Table no. 2: Design specification of model

Items	Values
Base wind speed	14 m/s
Nominal power	48 kW
Base rotational speed	3000 r.p.m
Base torque	152.87 N.m
Nominal AC voltage at generator side (ph-ph)	240 V
Nominal AC voltage at grid side (ph-ph)	11 kV
No. of phases	3

IV. Resultand Discussion

The speed of wind is not constant, it changes with the rate of change of time and wind flows. So waveform in fig.6. is taken as reference speed waveform which shows wind speed characteristics. The MPPT eventuate at desirable rotational speed for different wind speed. After manipulation of ANN controller, the parameters value set in the simulation model and analyzed.

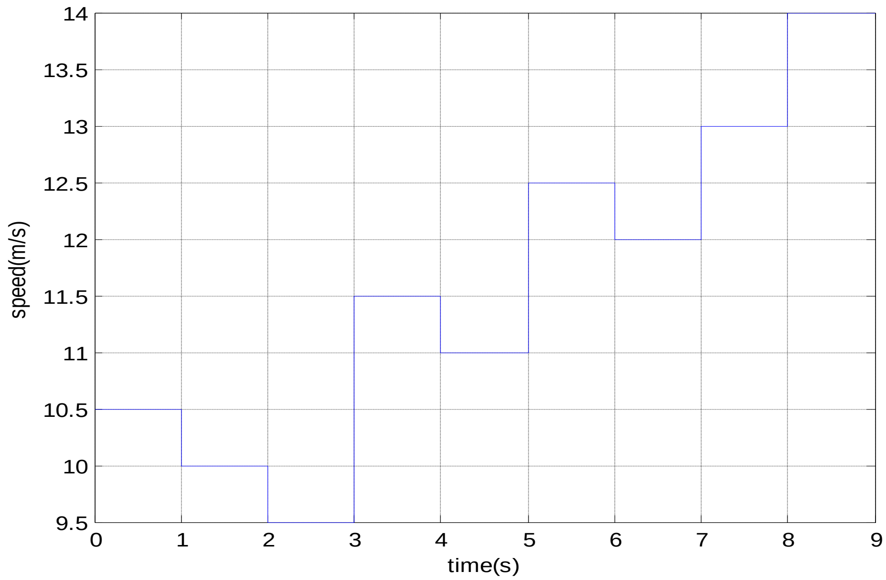

Fig.6 Input wind speed characteristics (Reference speed)

In fig. 11 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.

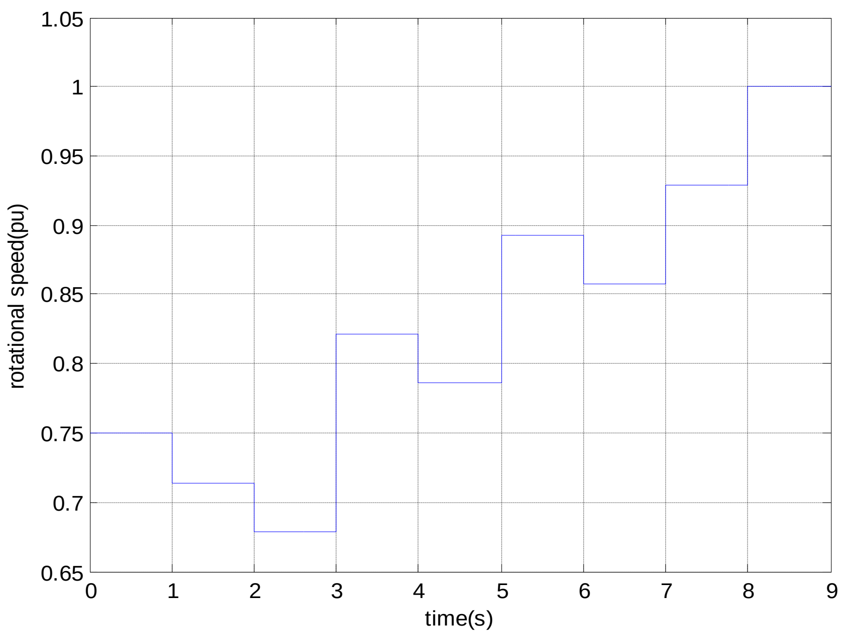

Fig. 7. The turbine optimum rotational speed for the wind speed (optimum speed)

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 ANN controller shown in fig 8.The ANNC can track MPPT effectively.

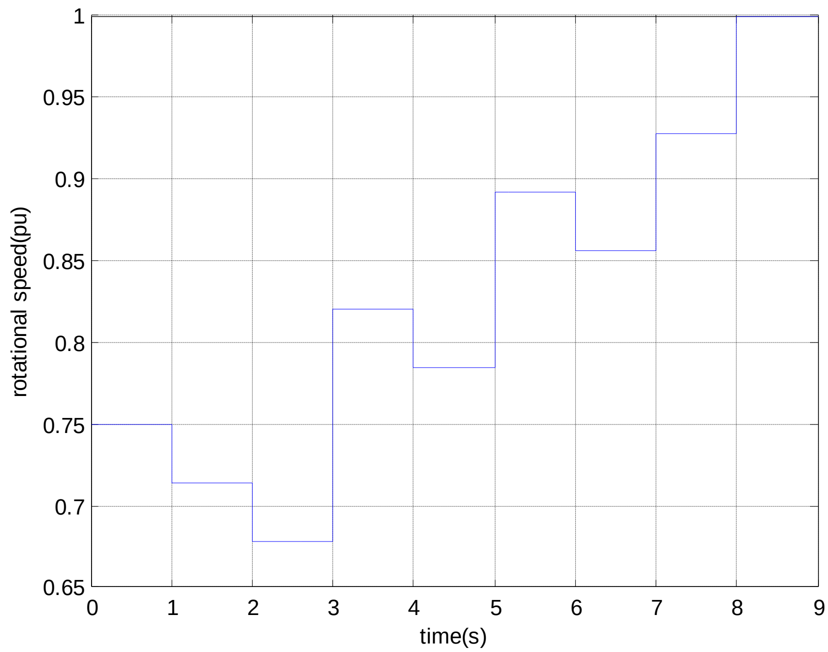

Fig.8. Turbine optimum speed for ANNC controller

Turbine output torque for ANN controller is shown in fig.9.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.

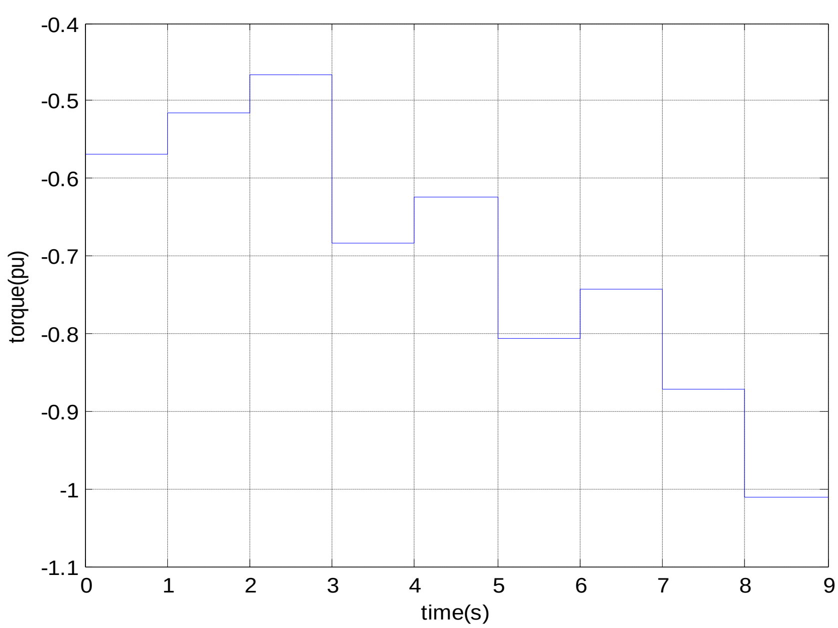

Fig. 9. The turbine output torque for ANN controller

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. 10.

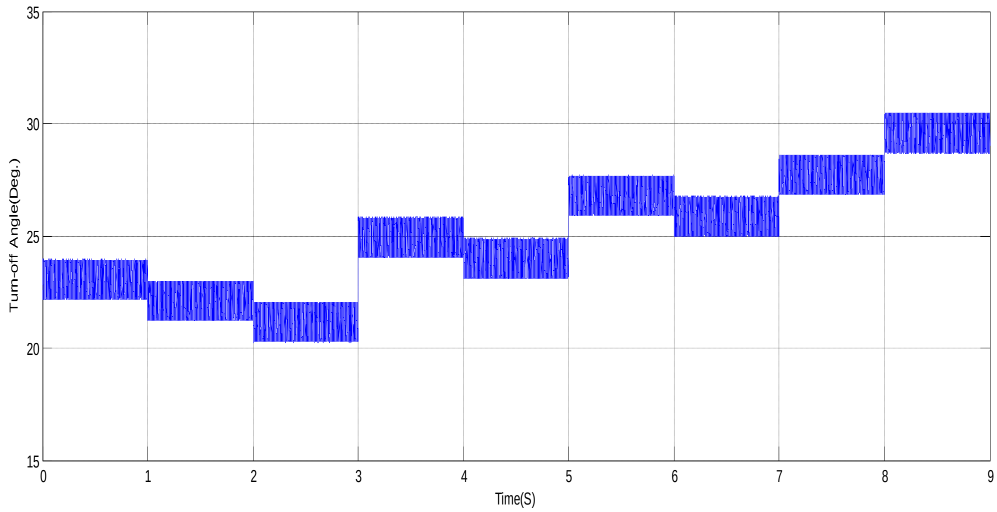

Fig. 10. The intelligent controller output

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.After getting turn off angle, SRG flux linkages of all three phases are obtained in fig. 12

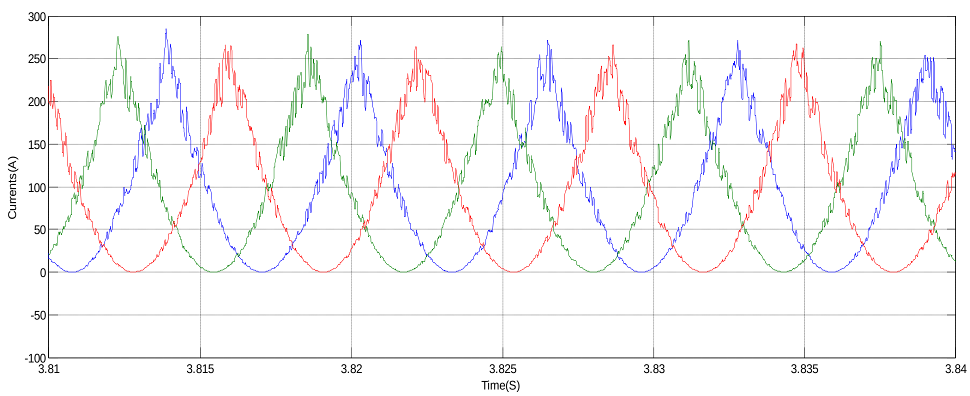

Fig.11. The SRG phase current

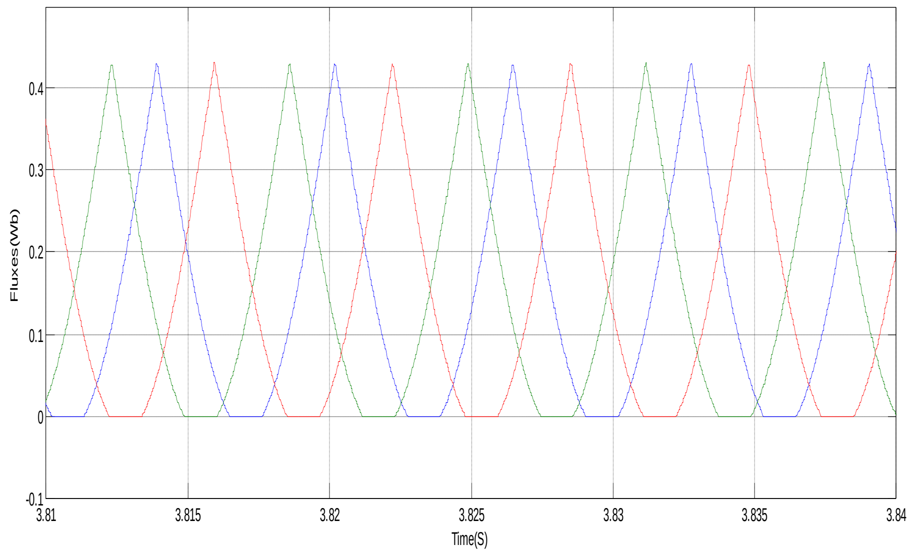

Fig. 12. The flux linkages in the SRG phases

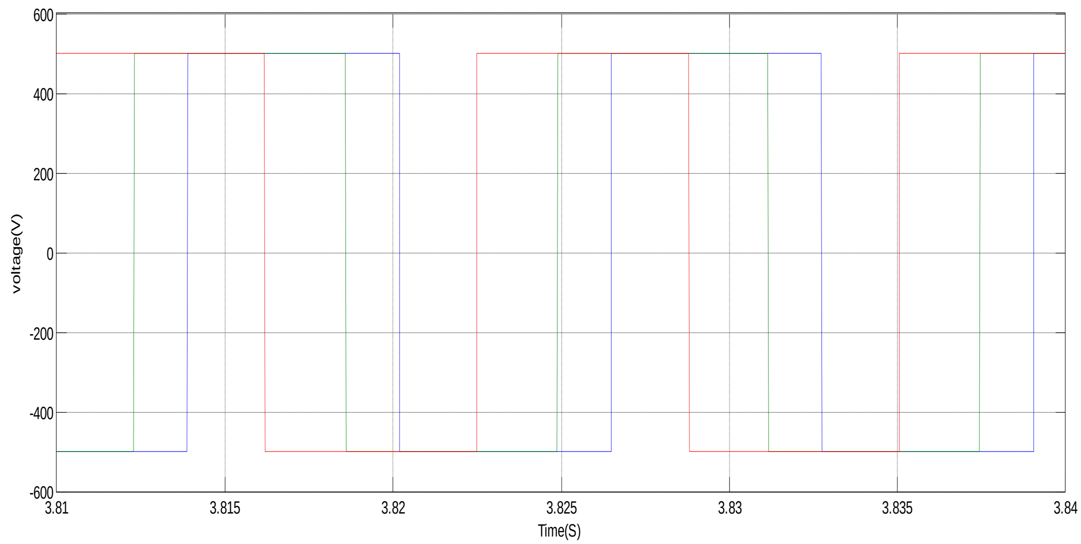

Fig. 13. The SRG phase voltages

Torque waveform of SRG changes with variation in speed as shown in fig. and voltage waveforms illustrated in fig. 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.

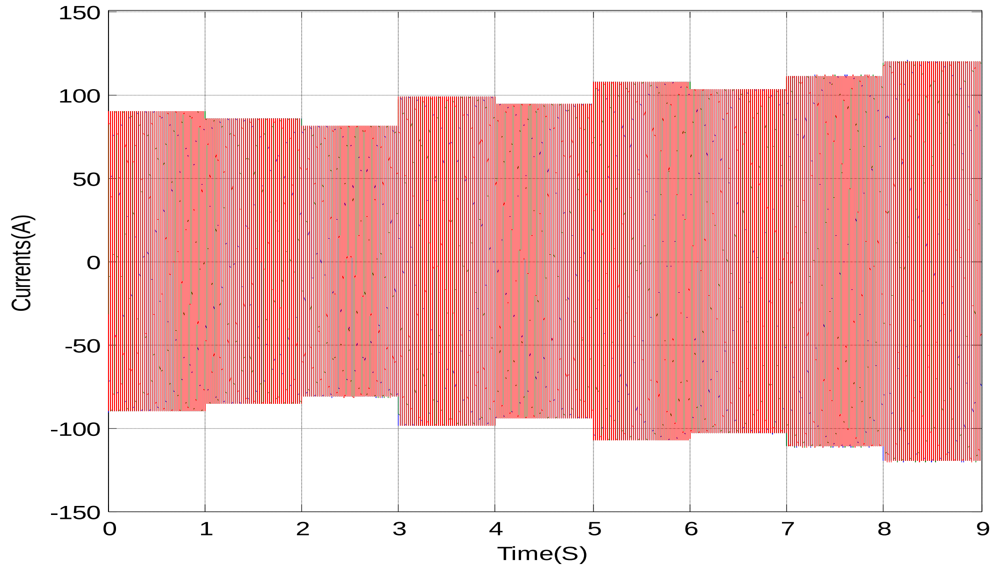

Fig. Inverter output current

V. Conclusions

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.

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