International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 25065-25074

http://www.ripublication.com

Power Harvesting of Wind Energy Conversion System With Induction Generator Using Fuzzy Controller

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Abstract

Wind energy conversion system (WECS) is generally connected to the electric power grid which supplies electric power to supplement the base power from other generation systems using fossil fuel or nuclear energy. Induction generators are mechanically and electrically simpler than other generator types used in WECS. These are particularly suitable for wind generating stations as in this case speed is always a variable factor. To extract maximum power from wind energy, ANFIS control technique is used. The main goal of ANFIS controller is to continuously adapt to the rotational speed of the generator with the wind speed in a way that the turbine operates at its optimum level of aerodynamic efficiency. To compute the crisp values from the fuzzy values, weighted average method is used for defuzzification. The direct and quadrature voltage components are calculated using ANFIS controller and are applied to the generator. The desired rotor voltage in the rotor reference frame generates switching signals for the rotor side using space vector.

Keywords: ANFIS, fuzzy Controller, PWM converters, Wind Energy conversion system

Introduction

Wind energy conversion system is generally connected to the electric power grid and supplies electric power to supplement the base power from other generation systems using fossil fuel or nuclear energy. Induction generators are mechanically and electrically simpler than other generator types. Induction generators are particularly suitable for wind generating stations as in this case speed is always a variable factor. Unlike synchronous motors, induction generators are load dependent and cannot be used above for grid frequency control.

Therefore, from the existing wind energy potential, the electrical energy extracted from the WECS is increased and expansion of the exploitable wind speed region toward the lower speeds can be achieved. Furthermore, the undesirable start up and shutdown of the wind turbine, which are mainly attained at low wind speed range, are confined. The proposed MOL controller is easily implemented, since only the knowledge of induction generator parameters is required that are already known from the implementation of space vector control. Hence, neither the wind speed measurement nor the knowledge of the generator loss model is required, compared to loss minimization control techniques.

Block Diagram of Proposed Controller

Three phase squirrel cage induction motors can also be used as generators which work as the motor must either be connected to a grid supply or an arrangement of capacitors to provide excitation current.

Three-phase induction machines have three windings in the stator and three winding in the rotor. As it is known, all electrical machines can be described as motor and generator as well, consequently, they can be described with the same set of equations. It is appropriate to remember that these equations govern the operation of the electrical machines. These equations are divided in two groups, Voltage equations and Torque equations in machine variables and other which are expressed in the axis of the reference variables.

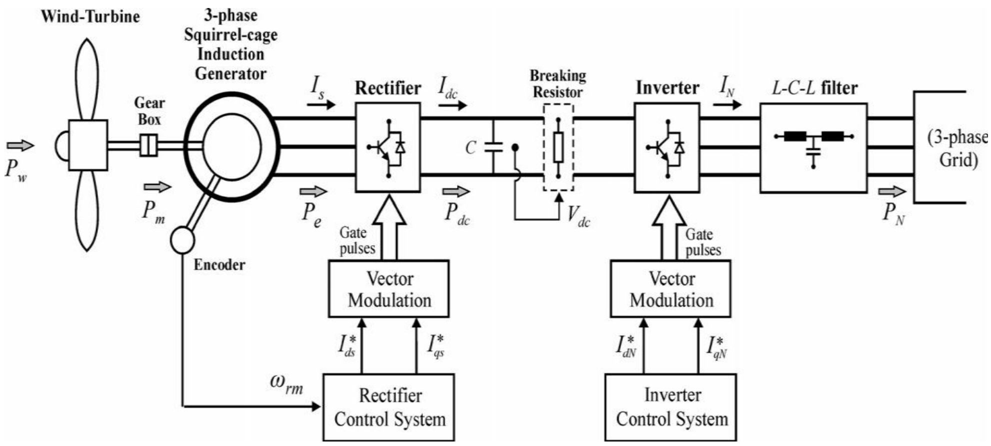

Figure 1.1: Single line diagram of proposed method

Symmetric and balanced three-phase induction machine, with a single winding rotor (Squirrel cage simple) and constant air gap is taken into consideration. In this proposed work the following assumptions are taken into consideration.

- Material is assumed to be linear, that is to say, the iron saturation is discarded.
- The iron magnetic permeability is assumed to be infinite in front of the air permeability, which means that the magnetic flux density is radial to the gap.
- All kind of losses in the iron are neglected.
- Both the stator windings as the rotor windings represent distributed windings which always generate a sinusoidal magnetic field distribution in the gap.

All hypotheses that we have explained before, using the induction motor's illustration, guide us to the following system of equations which describe the dynamic behavior of the induction machine.

$$\begin{Bmatrix} v_s^{abc} \\ v_r^{abc} \end{Bmatrix} = \begin{bmatrix} r_s^{abc} & 0 \\ 0 & r_r^{abc} \end{bmatrix} \begin{Bmatrix} i_s^{abc} \\ i_r^{abc} \end{Bmatrix} + \frac{d}{dt} \begin{Bmatrix} \lambda_s^{abc} \\ \lambda_r^{abc} \end{Bmatrix} \quad (1.1)$$

with
v_s^{abc} stator winding's voltage vector
v_r^{abc} rotor winding's voltage vector
i_s^{abc} stator winding's current vector
i_r^{abc} rotor winding's current vector
λ_s^{abc} stator winding's concatenated flows vector
λ_r^{abc} rotor winding's concatenated flows vector

The relationship between concatenated flows, rotor and stator's current is given by

$$\begin{Bmatrix} \lambda_s^{abc} \\ \lambda_r^{abc} \end{Bmatrix} = \begin{bmatrix} L_{ss}^{abc} & L_{sr}^{abc} \\ L_{rs}^{abc} & L_{rr} \end{bmatrix} \begin{Bmatrix} i_s^{abc} \\ i_r^{abc} \end{Bmatrix} \quad (1.2)$$

where each term represents a 3-dimensional matrix or a three-dimensional vector. Then, the vectors can be written as

$$v_s = \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix}, v_r = \begin{pmatrix} v_{ra} \\ v_{rb} \\ v_{rc} \end{pmatrix}, i_s = \begin{pmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{pmatrix}, i_r = \begin{pmatrix} i_{ra} \\ i_{rb} \\ i_{rc} \end{pmatrix} \quad (1.3)$$

Introduction about MPPT Controllers

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic modules. Photovoltaic solar cells have a complex relationship between solar irradiance (W/square meter), temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

- Solar inverters convert the DC power to AC power and may incorporate MPPT: such inverters sample the output power (I-V curve) from the solar modules and apply the proper resistance (load) so as to obtain maximum power.
- MPP (Maximum power point) is the product of the MPP voltage(Vmpp) and MPP current(Impp).

In this proposed work, the MPPT controller maximizes the wind turbine mechanical power by maximizing the power output using the following equations

$$P'_m = T_e \omega_{rm} / c$$
$$c = (3/2)p(L_m / L_r),$$

Comparison of methods

Both perturb and observe, and incremental conductance, are examples of "hill climbing" methods that can find the local maximum of the power curve for the operating condition of the PV array, and so provide a true maximum power point. The perturb and observe method can produce oscillations of power output around the maximum power point even under steady state irradiance.

The incremental conductance method has the advantage over the perturb and observe (P&O) method that it can determine the maximum power point without oscillating around this value. It can perform maximum power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method.

In the constant voltage ratio (or "open voltage") method, the current from the photovoltaic array must be set to zero momentarily to measure the open circuit voltage and then afterwards set to a predetermined percentage of the measured voltage, usually around 75%

Energy may be wasted during the time the current is set to zero.

The approximation of 76% as the MPP/V_{OC} ratio is not necessarily accurate though. Although simple and low-cost to implement, the interruptions reduce array efficiency and do not ensure finding the actual maximum power point. However, efficiencies of some systems may reach above 95%.

MPPT placement

Traditional solar inverters perform MPPT for the entire PV array (module association) as a whole. In such systems the same current, dictated by the inverter, flows through all modules in the string (series). Because different modules have different I-V curves and different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some modules will be performing below their MPP, resulting in the loss of energy. Maximum power point tracker into individual modules, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

Data suggests having one inverter with one MPPT for a project that has east and west-facing modules presents no disadvantages when compared to having two inverters or one inverter with more than one MPPT."Efficient East-West Oriented PV Systems with One MPP Tracker,"

Proposed Adaptive Neuro Fuzzy Inference System (ANFIS)

The main advantages of the ANFIS scheme are: computationally efficient, well adaptable with optimization and adaptive techniques. The developed strategy is not only simple but also reliable and may be easy to implement in real time applications using some interfacing cards like the dSPACE, data acquisition cards, NI cards, etc.

for control of various parameters. This can also be combined with expert systems and rough sets for other applications. ANFIS can also be used with systems handling more complex parameters. Another advantage of ANFIS is its speed of operation, which is much faster than in other control strategies; the tedious task of training membership functions is done in ANFIS. One of the most important features of the proposed ANFIS network is identification and estimation of the optimal wind turbine power coefficient.

The following points are relevant to ANFIS control over the Fuzzy control

- It is functionally equivalent to FIS
- It has minimum constraints so very popular
- ANFIS serve as a basis for constructing a set of fuzzy if-then rules with appropriate member ship functions to generate the stipulated input-output pairs
- The Adaptive network based fuzzy inference system (ANFIS) is a hybrid system.
- Fuzzy model is formed, based on the fuzzy rules extracted from the input output data set Tune the rules of the initial fuzzy model

ANFIS and Fuzzy Logic Controller:

The objective of a controller is that the output of a process remains in a given reference value, despite the disturbances that might occur in system variables, or to make the output follow a particular path.

The tuning of a controller based on fuzzy logic presents more difficulties than the tuning of conventional controllers. The reasons for this increased complexity are that the fuzzy controller is extremely flexible, and its performance depends on a wide range of parameters, from the membership functions to the inference mechanism; as it is a nonlinear controller. It there is not a unique method for tuning and adapting fuzzy controllers. Several approaches are possible, from the knowledge base built with experts' information about the controlled process to similarities between fuzzy controllers and conventional PID controllers. The main methods aimed at designing and analyzing the dynamics and the stability of adaptive fuzzy controllers are: the fuzzy self-organizing controller, the model reference and the neuro-fuzzy method.

Some benefits of fuzzy controllers are also presented: developing a fuzzy controller is cheaper than developing a model-based or other controller to do the same system, they are robust because they can cover a much wider range of operating conditions and they can operate with noise and disturbances of different natures, are customizable; indeed it is easier to understand and modify their rules, and easy to learn how fuzzy controllers operate and how to design and apply them to a real application. From the results presented in Table 3.1 it can be concluded that ANFIS controller performance is better than Fuzzy controllers in terms of lower peak time and settling time.

Performance Comparison of Proposed Controllers

Table 3.1: Comparison of Controllers

	Rise Time (Sec)	**Peak Time (Sec)**	**Settling Time (Sec)**
Fuzzy Controller	0.01	0.07	0.6
Anfis Controller	0.01	0.04	0.23

Table 3.1 represents the comparison of rise time, peak time, settling time between Fuzzy and ANFIS controllers.

Simulation Results and Discussions

Controller employed improves the efficiency of the whole wind energy conversion process is proposed. Thus, by making use of the existing wind energy potential, the electrical energy extracted from the Fuzzy is increased towards the wind speed region which can be achieved in lower speeds. The generator is connected to the power grid by means of two back-to-back PWM converters, both employing the space vector control technique. The minimum resistive loss of the generator is achieved by introducing a Fuzzy controller that adjusts the direct axis stator current according to the torque conditions. The proposed controller can be easily implemented because neither additional control signals nor the knowledge of generator loss model is required. The effectiveness of the Fuzzy controller and its successful cooperation with an ANFIS controller are verified through simulation.

Simulation Diagram:

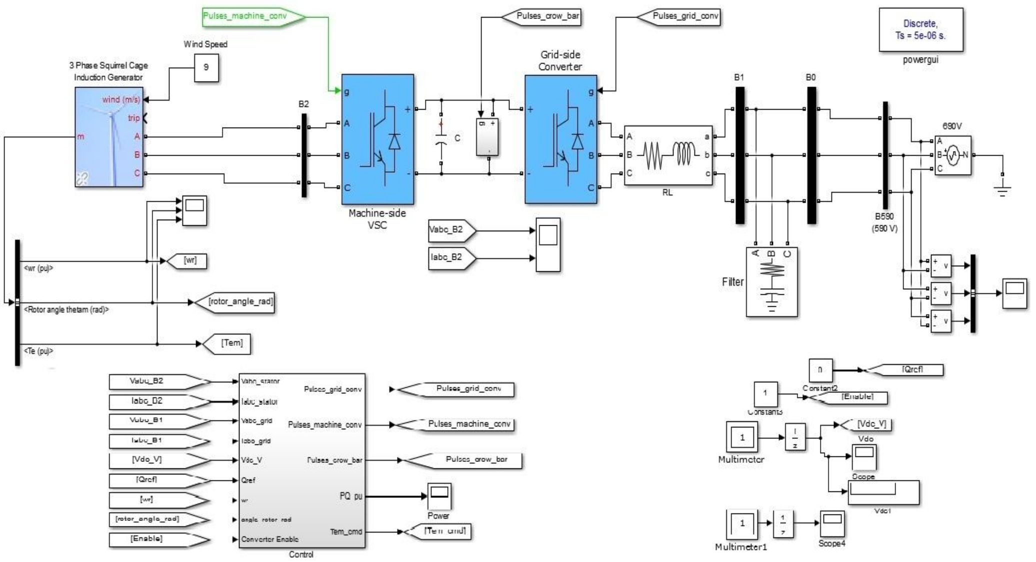

Figure 4.1: Simulation Diagram

The adaptive search control and alternatively the fuzzy-logic-based control techniques are employed for the implementation of the MPPT controller, as they are both independent of wind turbine characteristics. Thus, a high-efficiency ANFIS with induction generator is developed.

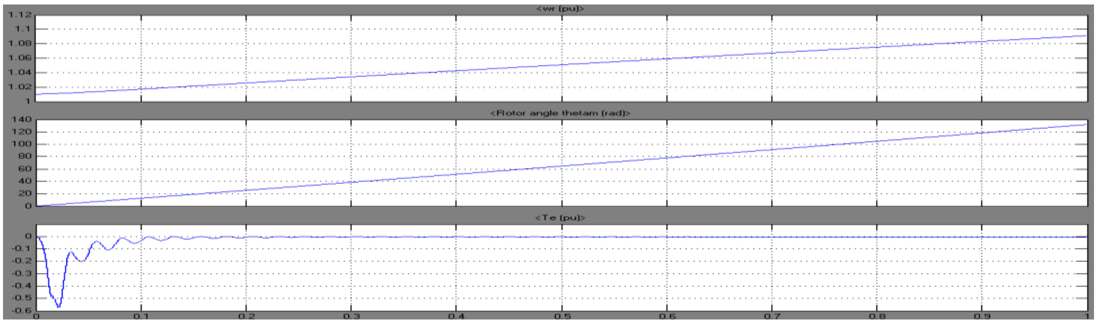

Figure 4.2: Speed, Rotor angle, Electromagnetic Torque

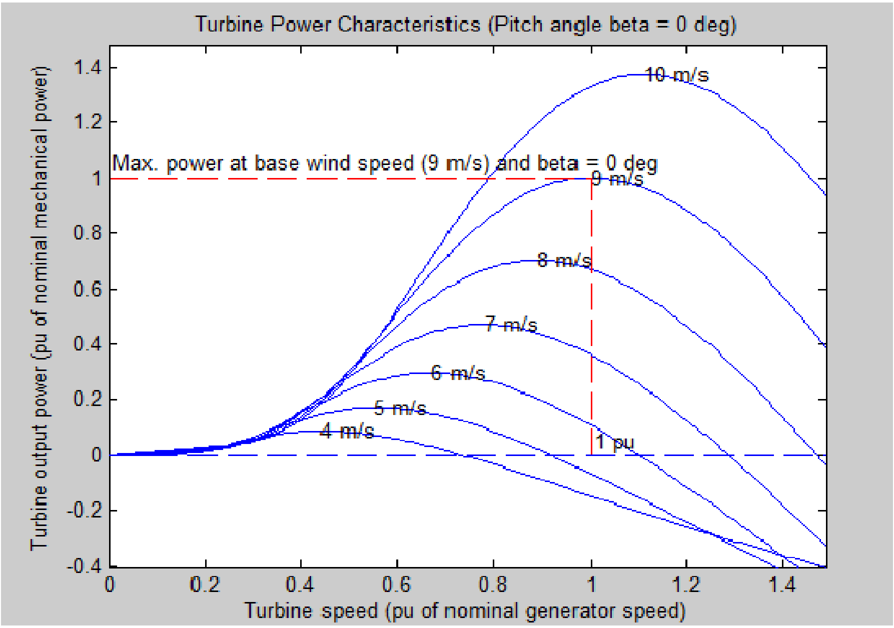

Figure 4.3: Turbine Characteristic Curve

ANFIS Dc Link Voltage

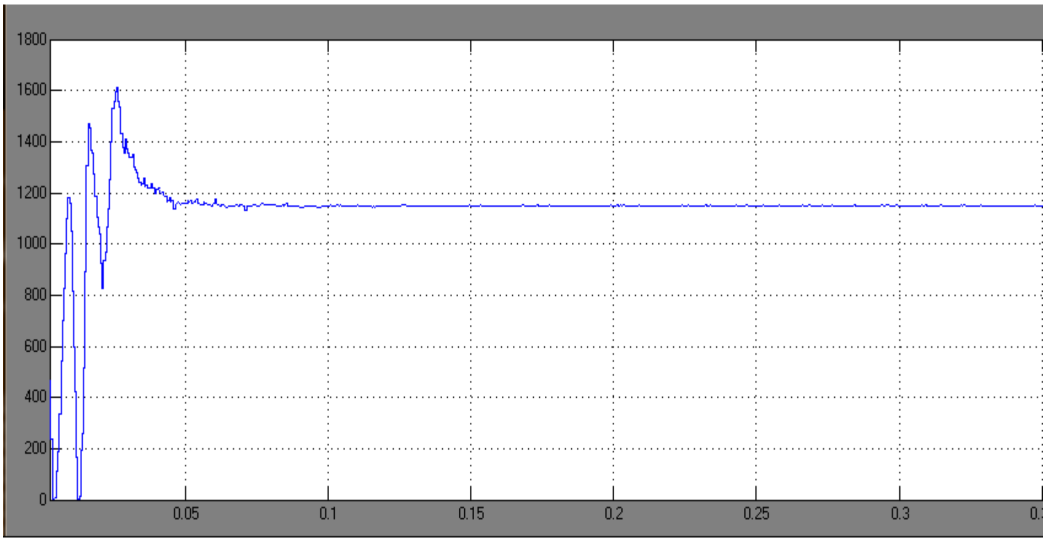

Figure 4.4: ANFIS Dc Link Voltage

Fuzzy Dc Link Voltage

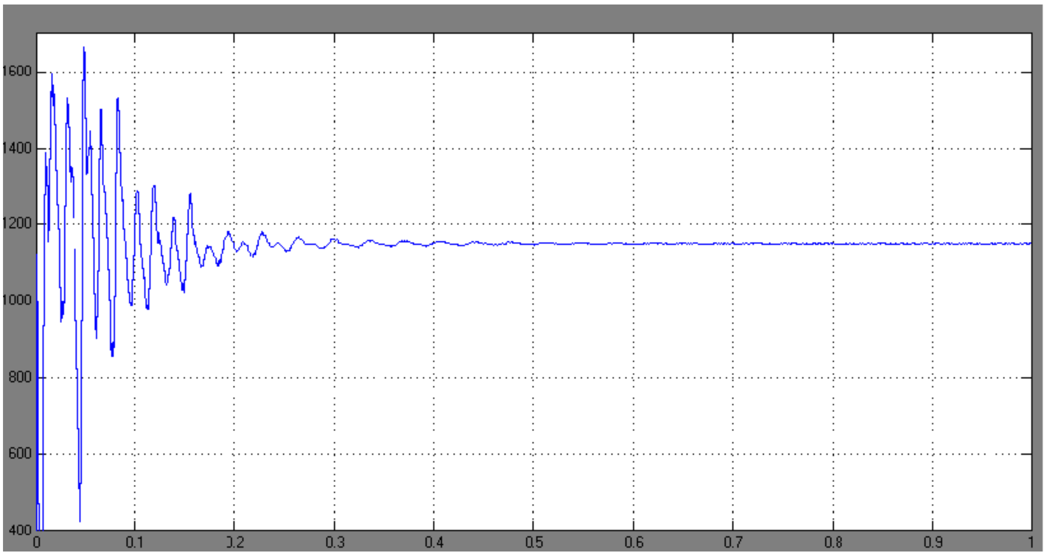

Figure 4.5: Fuzzy Dc Link Voltage

The above table shows the comparison DC link voltage between ANFIS and Fuzzy controller.

Fuzzy Grid Side Voltage:

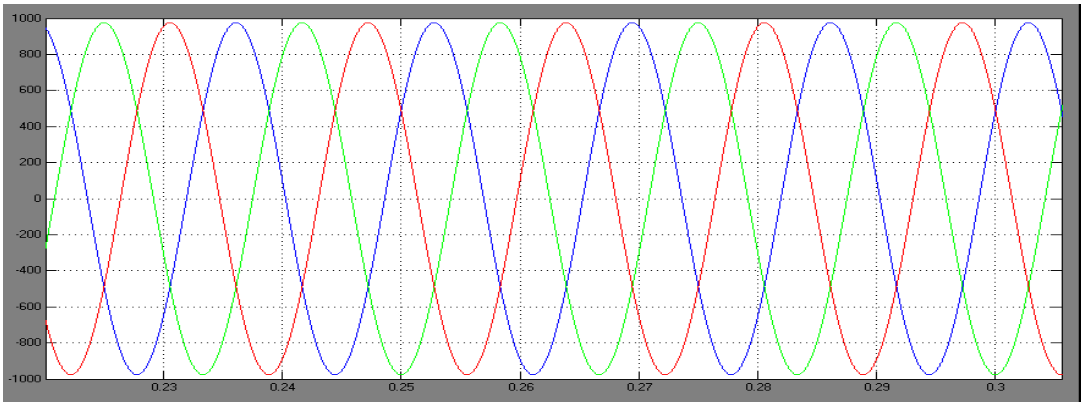

Figure 4.6: Fuzzy Grid Side Voltage

ANFIS Grid Side Voltage

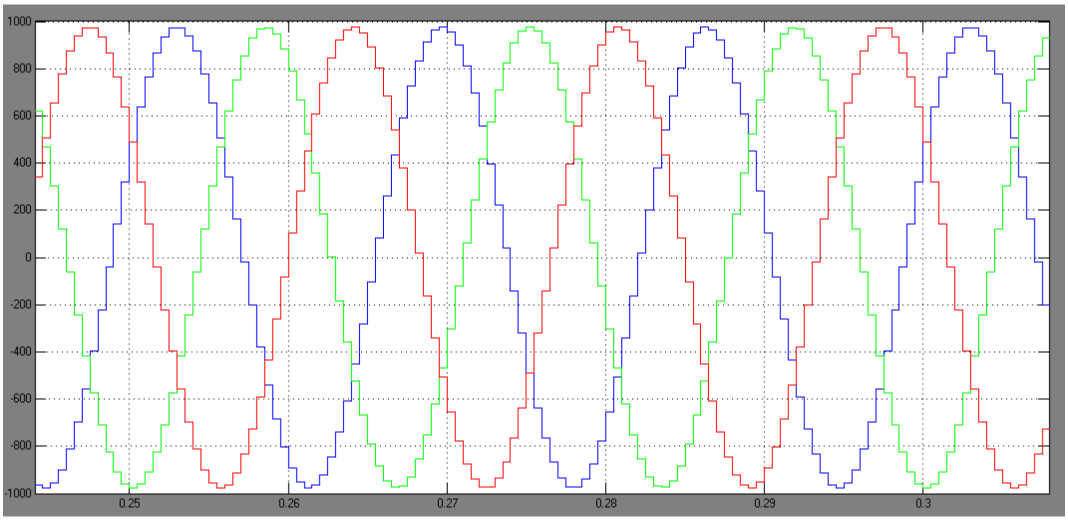

Figure 4.7: ANFIS Grid Side Voltge

Conclusion

Control system that improves the efficiency of the whole wind energy conversion process has been proposed. The control system provides minimum resistive power loss of the squirrel cage induction generator in combination with maximum power tracking of the wind turbine. Thus, by making use of the existing wind energy potential, the electrical energy extracted from the WECS is increased and expansion of the exploitable wind speed region toward the lower speeds can be achieved. The generator is connected to the power grid by means of two back-to-back PWM converters, both employing the space vector control technique.

The minimum resistive loss of the generator is achieved by introducing an MOL controller that adjusts the *d*-axis stator current according to torque conditions. The proposed controller can be easily implemented because neither additional control signals nor the knowledge of generator loss model is required. The effectiveness of the MOL controller and its successful cooperation with an MPPT controller are experimentally verified. The adaptive search control and alternatively the fuzzy-logic-based control techniques are employed for the implementation of the MPPT controller, as they are both independent of wind turbine characteristics. Thus, a high-efficiency WECS with induction generator is developed. In this proposed work the ANFIS controller response observed are, fast settling time, quicker rise time with less peak time compared to fuzzy logic controller.

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