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Design of Adaptive Network Based Fuzzy Controller and its Performance Analysis for Maximization of Energy in Variable Speed Wind Energy Conversion System

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Abstract: Variable speed wind energy conversion system (WECS) exhibits non linear nature due to number of variables associate which can produce disturbances in the system. Conventional controllers are not always able to provide significant result. To achieve the objective of maximum power from available wind, controller can be play crucial role. In WECS this controller can be implemented with the help of fuzzy logic and ANFIS logic. In this paper we perform comparative analysis which is based on two different controllers result. The application used for comparative analysis is Wind Turbine (WT) and software used is MATLAB/SIMULINK.

Keywords: Wind Energy Conversion system, Synchronous Control Induction Generator, Adaptive Network Based Fuzzy Inference System.

I. INTRODUCTION

Wind energy has attracted much attention from research and industrial communities. One of growth areas is thought to be in the offshore wind turbine market. The ongoing effort to develop advanced wind turbine generator technologies has already leaded to increased production, reliability, maintainability and cost-effectiveness [1]. Variable-speed wind turbines has advantages over fixed speed wind turbine, achieve maximum energy conversion efficiency over a wide range of wind speeds. The turbine can continuously adjust its rotational speed according to the wind speed.

SCIG based variable speed wind energy conversion system (WECS) is better because of cost-effectiveness and easily to design feature. But SCIG cannot optimally control the maximum available wind power and gives power problem in obtaining excitation current from the stator terminal. In general fuzzy logic controller is commonly used in WECS, but fuzzy logic controller can take decision on the basis of predefined rules which are constructed by the knowledge of experts. ANFIS logic controller has advantages of both neural network and fuzzy logic. An ANFIS adapts its structure based on the information coming to it which can offer better result. These are the main challenges which can affect the system (WECS) performance.

1. Low Efficiency
Primary problem with wind turbine is to efficiently generate power and faithfully transmit into grid.

To extract maximum amount of energy that could be converted to useful mechanical power, system need some adjustment like the generator speed should be controlled and position of machine flux have to be optimize, so that loss in the generated power can be minimized. Dynamic parameters that can affect the system efficiency has been found are

- Generator Speed.
- Rotor Flux.
- Generator Torque.

2. Better stability
Cage induction generators have serious issue that due to the coupling effect in between active and reactive power, SCIG always draws reactive power from the grid so reactive power compensation is required. Problem with obtaining excitation current from the stator terminal also causes power loss.

3. Parameter Tuning Search Method
For optimization of wind turbine variable parameter like wind speeds, turbine torques, rotor speed have to be control. This variable parameter can be adjusted by controller according with continuous search and average testing error. Because of continuous testing and optimum search technique, system needs human reasoning and artificial intelligence based algorithms. These algorithms allow the synthesis of various aspects based on human intelligence. So choice of logic for development of controller is totally based on best search method.

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A perfect control system is needed in wind turbine for gratefully power extraction, so that controller is very useful to improve the system performance from wind as well as for safety of the turbine itself. For extraction of the maximum power from available wind, actual challenges that affect the system efficiency are generator speed and another one is rotor flux, with proper tunning this variable, performance of the WECS can be improved [2].

II. SYSTEM MODELLING

The main objective of this work is to develop a MATLAB/SIMULINK wind energy conversion model with controller to extract maximum amount of energy that could be converted to useful mechanical power for the wind energy conversion system. Controllers are useful to avoid the non-linearity in the system.

Generator speed and rated rotor flux should be control with synchronous current control technique, so that loss in the generated power can be minimized. This work can be done with use of fuzzy logic controller and ANFIS controller technique. With the help of these two different controllers logic, generated power and performance analysis of system from maximum efficiency point of view is easily obtained.

1. Fuzzy Logic Controller

Fuzzy logic controller is rule based controller where a set of rules represents a control decision mechanism to correct the effect of certain cause used for generation systems. The design of fuzzy controller is knowledge base works on the area in which control error (ACE) and change in area control error (ΔACE) is considered as input [3].

The input and output variable transformed into linguistic variables as NVL: Negative Very Large, NL: Negative Large, NM: Negative Medium, NS: Negative Small, ZE: Zero equivalent, PS: Positive Small, PM: Positive Medium, PL: Positive Large, PVL: Positive Very large, respectively the squirrel cage induction generator have variation in parameter that depend on wind speed. As wind speed changes, the generator speed also varies, and corresponding output power changed [4]

i. Fuzzy Logic Controller for Generator Speed

As the wind velocity changes, generator speed has to track in order to extract maximum power. Control function done by first fuzzy logic controller FLC-1 based on real time search.

For fuzzy controller-1 design purpose these variable with mamdani fuzzy inference method is used in the linguistic logic to make the logical rule for controller and Block diagram of FLC-1 with Triangular Membership Function shown in figure 1 and figure 2 respectively [5].

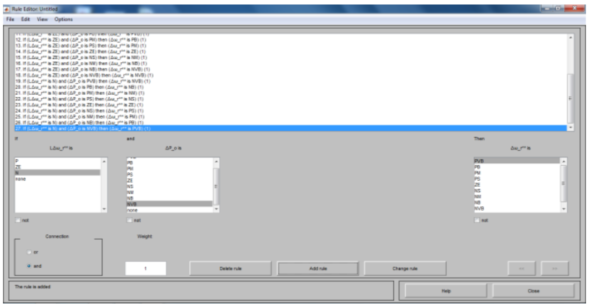

Fig.1- Fuzzy M.F. rule editor for FLC-1

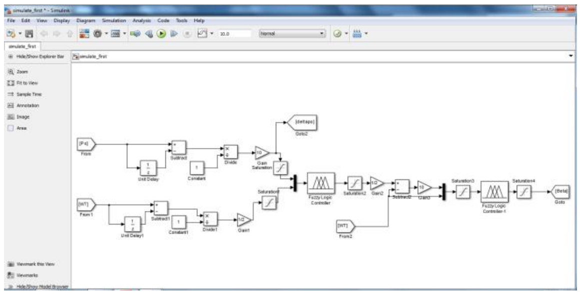

Fig. 2- Generator speed tracking controller with FLC-1

ii. Fuzzy Logic Controller for Generator Flux

Efficiency of WECS can be optimized on the basis of online search of rotor flux and it is implemented here by fuzzy controller-2. Principle of FLC-2 is quit much similar to FLC-1. FLC-2 starts when FLC-1 has completed its search at the rated flux condition. At certain velocity (V_{ω}) and corresponding generator speed (ω_r^*) established by FLC-1, rated rotor flux is adjusted by reducing excitation current(i_{ds}). With light load it decreases hence total generated power P_o increases. Logical rule for FLC-2 and Block diagram is shown in figure 3 and figure 4 respectively [6].

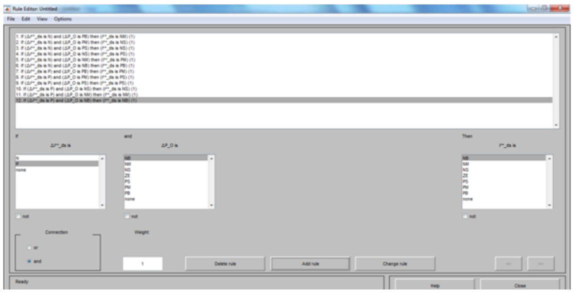

Fig. 3- Fuzzy M.F. rule editor for FLC-2

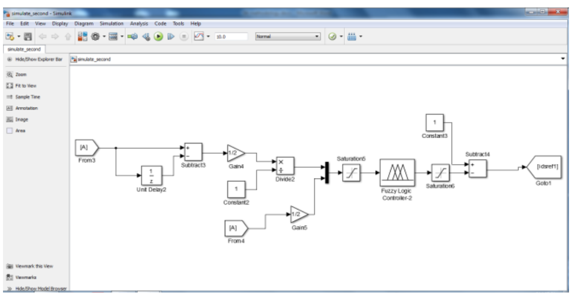

Fig. 4- Generator flux programming controller with FLC-2

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2. ANFIS Controller

The adaptive network based fuzzy inference system (ANFIS) is a data driven procedure representing a neural network approach for the solution of function approximation problems. Data driven procedures for the synthesis of ANFIS networks are generally based on clustering a training set of numerical samples of the unknown function to be approximated. Neuro fuzzy technique called adaptive network based fuzzy inference system (ANFIS) has been used as a prime tool in the present work [7, 8].

i. ANFIS Logic Controller for Generator Speed

As the wind velocity changes, generator speed has to be tracked in order to extract maximum power. Control function of ANFIS-1 is same as FLC-1. Predicted logical rule for ANFIS-1 and block diagram of ANFIS-1 for generator speed tracking is shown in figure 5 and figure 6 respectively.

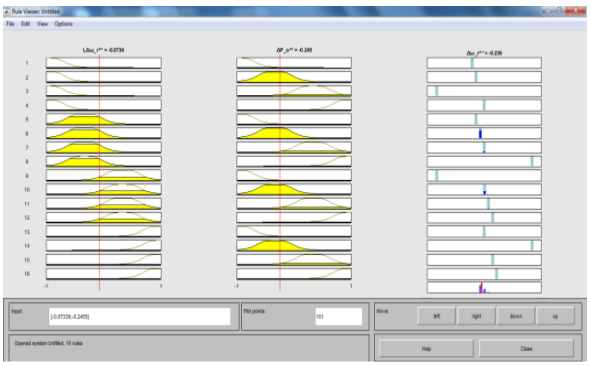

Fig. 5-ANFIS window for predicted logical rule

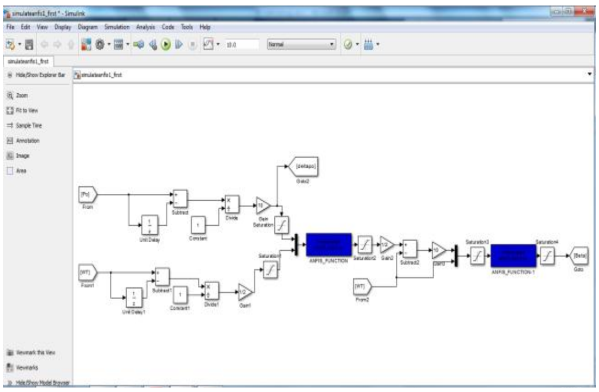

Fig.6- Generator speed tracking controller with ANFIS-1

ii. ANFIS Logic Controller for Generator Flux

Efficiency of WECS can be optimized on the basis of online search of rotor flux and it is implemented here by ANFIS-2. Principle of ANFIS-2 is quit much similar to ANFIS-1, ANFIS-2 starts when ANFIS-1 has completed its search at the rated flux condition. At certain velocity (V_ω) and corresponding generator speed (ω_r^*) establish by ANFIS-1, rated rotor flux is adjusted by reducing excitation current(i_{ds}). At light load machine excitation current goes low, so iron loss decreases hence total generated power P_o increases. Predicted logical rule for ANFIS-2 and block diagram of ANFIS-2 for Generator flux tracking is shown in figure 7 and figure 8 respectively [9].

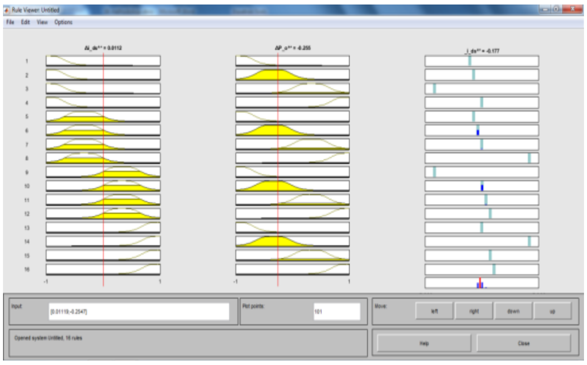

Fig. 7-ANFIS Window for Predicted logical rule

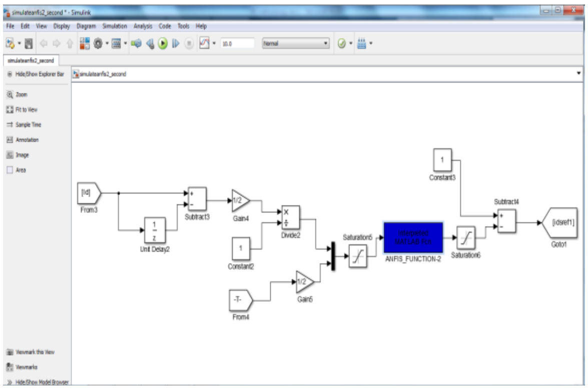

Fig. 8- Generator flux programming controller with ANFIS-2

For the maximum power generation in variable speed wind turbine, variable parameters are adjusted for optimum value, through two fuzzy logic controllers and after that with two ANFIS logic controllers. Here input, output variable which are evaluated with controllers are same in both fuzzy logic and ANFIS logic. First controller is used for the tracking generator speed and second controller for minimum value of rotor flux adjustment. This approach is basically giving idea about tuning parameters and rule set so that controller takes logical decision [10].

III. SIMULATION & RESULTS

Performance of WECS can be analysed with the help of two different logical Controller known as FLC-1 and ANFIS-1. Here both this two controller are used to track generator speed value until an optimum output power point. The response of the given controllers is observed in the front panel as shown in the below figures.

The FLC-1 and ANFIS-1 controllers were operated in sequence and corresponding boost of power was observed as shown in table-1.

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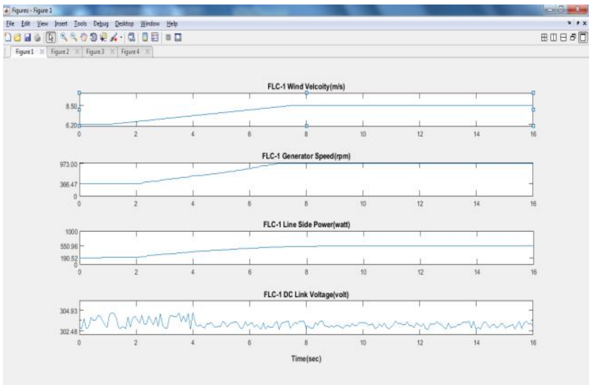

Fig 9 -Response from FLC-1

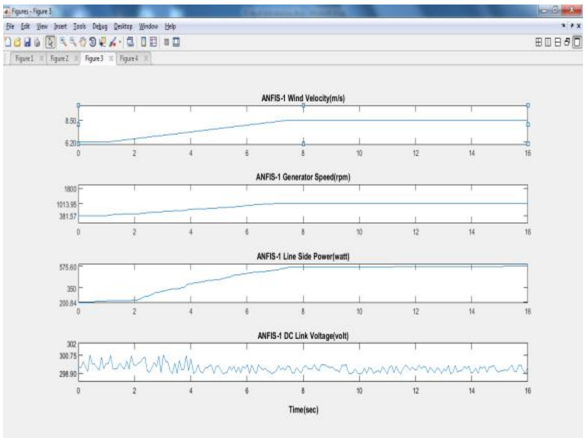

Fig 10 -Response from ANFIS-1

Table- 1: Experimental values for FLC-1 and the ANFIS-1 Model

Parameter	FLC-1	ANFIS-1
Wind Velocity (m/sec)	6.20-8.50	6.20-8.50
Generator Speed (rpm)	366.47-973.00	381.57-1013.95
Line side power (Watt)	190.52-550.96	200.84-575.60
DC link capacitor voltage (Volt)	302.48-304.93	298.90-300.75

In FLC-1 with variable wind speed from 6.20 m/sec to 8.50 m/sec and peak value of generator speed 973.00 rpm, corresponding optimum value of line side power is 550.96 watts. But ANFIS-1 has generator speed 1013.95 rpm and comparatively higher generated line side power is 575.60 watts. Comparison in between FLC-1 and ANFIS-1 experimental values shows that ANFIS-1 controller has improved generating power almost 4.48 %. With the use of ANFIS-1 DC link capacitor voltage fluctuations in the curve are greatly reduced. By comparing both the results regarding the control of DC link voltage variation, an observation is made, proving that the response of the system can be greatly improved by more précised use ANFIS-1 controllers.

Figure 11 and 12 shows the performance of FLC-2 and ANFIS-2 at constant wind velocity.

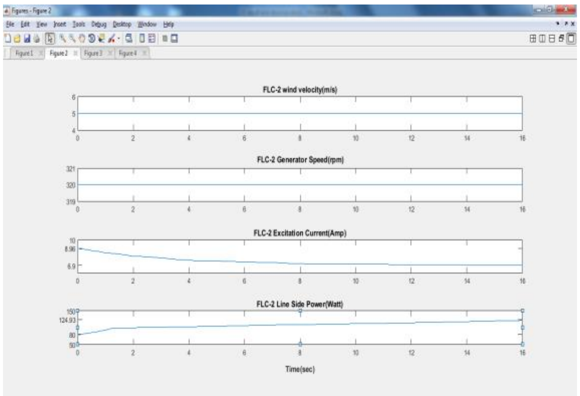

Fig 11- Response from FLC-2

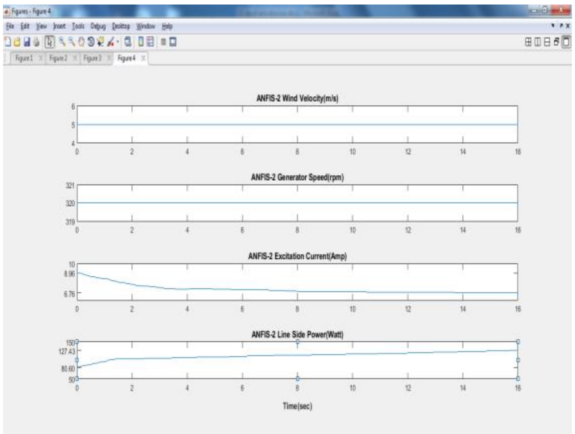

Fig 12- Response from ANFIS-2

The FLC-2 and ANFIS-2 controllers were operated in sequence and corresponding boost of power was observed from the data of table-2.

Table-2: Experimental values for FLC-2 and the ANFIS-2 Model

Parameter	FLC-2	ANFIS-2
Wind Velocity (m/sec)	5	5
Generator Speed (rpm)	320	320
Excitation current (i_{ds}) (Amp.)	Parameter	8.96-6.76
Line side power (Watt)	80.00-124.93	80.60-127.43

Excitation current gradually decreases from the initial rated value 8.96 ampere up to 6.90 Ampere and corresponding optimum values of line side power is 124.93 watts. But with the use of ANFIS-2 machine efficiency is improved because excitation current can fall down from 8.96 Ampere to 6.76, ANFIS-2 has lower excitation current value than FLC-2. By use of ANFIS-2 controller generated line side power is reaches up to 127.43 watts. It means that as machine excitation current goes low, iron loss decreases hence total generated power P_o increases. By comparing both the results at light load, ANFIS-2 improves generated power almost by 2 %.

IV.CONCLUSION

On the basis of fuzzy controller response and ANFIS controller response we conclude that, in variable wind energy conversion system for the maximum power generation, variable parameters are adjusted for optimum value through two different logic controllers. With response value analysis, we get ANFIS logic controllers have better performance as compare to the fuzzy logic controllers because ANFIS combines the advantages of adaptive neural network and fuzzy logic which has more generated power, better stability, and ANFIS logic has well continues search and low average testing error.

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