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Artificial Intelligence Approach for the Control of SPMSG Based Grid Connected WECS

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ABSTRACT
In India, power plant requirement is rapidly increasing as non-conventional sources are in current need. Government financial aid plays important role for generator plant execution because of its tedious procedure. If the utilization of wind power production has to be doubled, then machines, turbines and converters are essential in two numbers. The research work includes parallel connection of two machines using star-delta-star transformer fashion resulting in six-phase permanent synchronous machine. This arrangement is more economical as the number of converters are reduced thereby increasing the efficiency by minimizing the switching losses. Initially rectifier setup is used wherein high frequency AC is converted to low frequency and maximum power point tracking is done with the aid of a converter. It is DC-DC conversion by decoupled DQ strategy. Later, it is again converted back to three phase AC so as to synchronize it to the grid. The system response is analysed by conventional PI controller by reducing the noise in the real & reactive power generation. Further, ANFIS-PI controller is implemented to improve the response of PI controller which is much essential for wind power generation. The MATLAB simulated results of PI controller system response and ANFIS-PI controller is presented in this paper.

Keywords: *decoupled direct & quadrature (dq) technique, incremental conductance (ic) algorithm, proportional integral pi) controller, six phase permanent magnet synchronous generator (spmsg)*

I. INTRODUCTION

Multi-Phase machines delivers a number of benefits like: amplitude minimization of pulsating torque, amplified pulsating frequency; decrease in phase current for similar voltage rating; harmonics elimination in dc-link current; lessening of copper losses of the stator and boosting its dependability with added variable quantity [1]-[3]. The Permanent magnet synchronous generators are preferred because of its greater efficiency, greater power density, stability and secure in standard operations. Costal wind energy systems are required to be lighter and consistent than inland wind energy systems. Hence, SPMSG has gained desired choice in offshore windfarms. Multiple phase machine drives and motors are also being utilized in aerospace, Electric automobiles, ship casting, hybrid EV, and higher-power usage systems that are cost effective in comparison to the overall system requirements [1]-[4]. The thorough survey associated with Multiphase drives in different sectors including its application for electricity generation was presented by Parsa [1]. Parallel connection of converters in integrated way were studied for its use in classical converters also [5]. The use of multiphase PMSG for wind machines shows that the two 3 phase windings are controlled individually [6].

Schiferl R F detailed a comprehensive schematic diagram of a six phase synchronous machines. This circuitry incorporates the coupling of mutual leakage between the considered two sets of 3 phase stator windings. Different modes of power transfer were being examined with sinusoidal inputs. Pitch for a number of practical 6-phase winding configuration and winding displacement angle relationship along with mutual leakage inductances in an Uninterruptible power supply scheme were described. [7]-[8]. A detailed study and investigation are carried out for the proposed intelligent controller of SPMSG [9]-[11].

Artificial Neural Network (ANN) has extremely high learning and computational capabilities. Fuzzy Logic (FL) has a good interpretability along with integrating the expert's knowledge. Hybridizing both the paradigms will yield the proficiency

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of investigation, perception and incorporation of foresight. Hybridized ANN technique training applied for fuzzy logic systems develops its decision ability. The accurate organization of the two models forms hybridized neuro-fuzzy system. The research work carried out presents the hybridized ANFIS controller for WECS. These expert systems increase the rate of learning along with estimation perfection. In the recent smart grid (SG) technology, the real time parameters of the operating system are controlled using fuzzy logic applications. Literature study indicates the efficacy of the power systems can be drastically improved by the application of neural network hybridized with the fuzzy logic. These adaptive neuro-fuzzy interface system with unique feature learning and parameter extraction techniques has led to revolution in the SG [12]-[15].

This paper focuses on conventional PI & hybridized ANFIS-PI controller of SPMSG based grid connected wind power generation system. Hence, the simulated results of both the methods are compared and it can be concluded that the ANFIS-PI performs better than the conventional PI controller.

II. MODELLING OF SPMSG WITH THE BRIDGE RECTIFIER

Over the years it is observed that WECS are frequently exposed to instability which leads to severe problems in power system operations. Recent advanced adaptive control is playing vital role in the designing of controller of the generator.

SPMSG connected with rectifier bridge develops the output DC voltage [10] that is depicted in Fig. 1. The MATLAB-based Simulink diagram of SPMSG with two identical PMSG is rigged up and these two identical PMSG is connected to the transformer. ANFIS model learning is described in Section III and the machine and circuit diagram parameters along with the obtained results are detailed in Section IV.

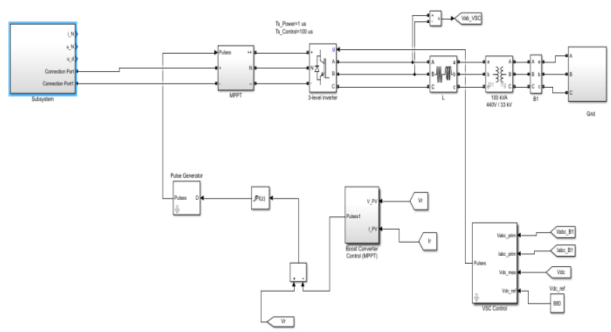

Figure 1: Six phase permanent magnet (SPMSG) connected to the rectifier bridge

III. ANFIS MODEL LEARNING

The goal is to employ the ANFIS approach, which is a hybridized method. This is being done as a continuation of those previous studies. It is determined whether the NN and fuzzy perform better than the ANFIS estimator when compared to its performance. These are categorised into five different layers. The layer 1 is the input layer for assigning of membership function called as fuzzification. The layer 2 identifies the input firing robustness known as the rule layer. Layer 3 normalises the layer 2 output in accordance with the total input firing robustness. The normalized firing robustness of layer 3 is given as input to layer 4 that determines the model parameters and defuzzified value. The layer 5 is fed to the output.

The Back Propagation (BP) algorithm is employed to edify the network. The fixed shape and its parameters are assigned to every membership function (μA_i). This algorithm tries to tune in the shape parameters with the aid of a trial set proportion to N (x_t, y_t). The membership functions play a major role in case of efficacy of non-linear modeling. The equation (1) & (2) gives the widely used TSK fuzzy rules:

Ri: IF x is Ai, THEN

$$y = \text{fi}(x) = \hat{y}i = \sum_{i=1}^{k} \frac{\mu Aixifi(x)}{\mu Aixi} \qquad (1)$$

$$y = E_t = \frac{1}{2}(y_t^{*} - y_t)^{\wedge}\square\square \qquad (2)$$

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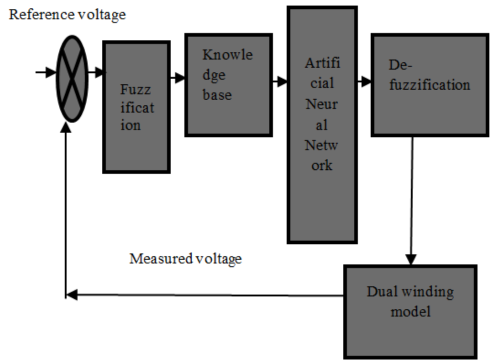

Figure 2: Learning of ANFIS model

Once the rule base is decided, the ANFIS will adjust the MFs of the predecessor and the resultant parameters. The BP algorithm is used to train the presumption and resultant parameters. The linear parameters A_i is learned by the RLS (Recursive Least Square) method. The heuristic method improves the learning rate η. The block representation of learning of ANFIS structure is as shown in Fig. 2.

ANFIS is a tool that can be utilized in control applications to help address the issues that were discussed earlier. By utilizing the ANFIS architecture, it is possible to create a Neuro-Fuzzy controller that is adaptable and contains a limited number of weights. Because it has such a small number of weights, the ANFIS structure is able to circumvent the issue of having an excessive number of tuning parameters and the requirement of modeling involves the process using an independent network model. One of the ways that Neural and Fuzzy hybridized controllers can be designed is through the process of inverse learning. It consists of two stages: the learning stage, and the application stage. During the knowledge gathering stage, the data to be trained is acquired by randomly created inputs in addition to watching the matching results obtained.

IV. RESULTS & DISCUSSION

The results of WECS with SPMSG are obtained and analysed by using MATLAB-based Simulink. The application of MPPT algorithm to control the rectifier bridge DC output is observed to be beneficial thereby yielding better results. Converter is used in the next stage to convert the DC voltage to AC [10]. Each step simulated results are presented in detail in this section. The MATLAB-based simulated outputs are depicted in the Fig. 3–8. The output AC voltages of WECS with SPMSG is shown in Fig. 3.

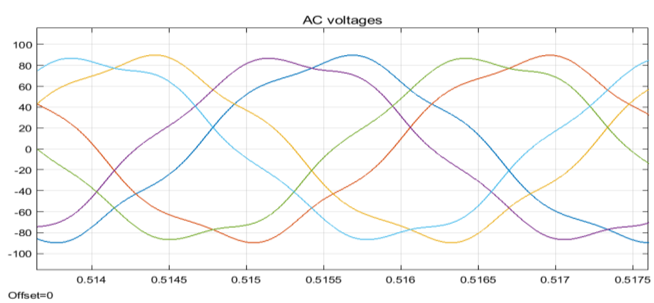

Figure 3: AC voltages output of WECS with SPMSG vs time in sec

These output AC voltages of WECS with SPMSG are given to the rectifier and the obtained DC output voltage of 300V is shown in Fig. 4.

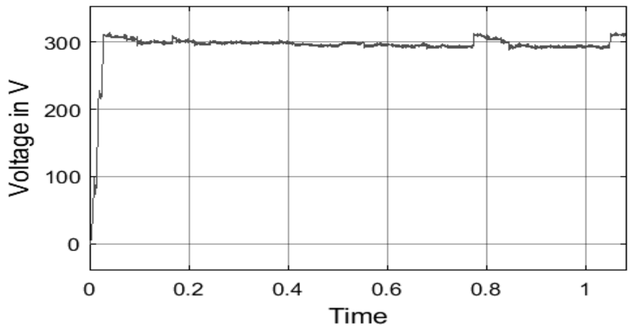

Figure 4: Rectifier output voltage vs time in sec

This rectifier output voltage is further boosted to 880V by using DC-DC converter as shown in Fig. 5 and the grid voltage and current waveform s are shown in Fig. 5.

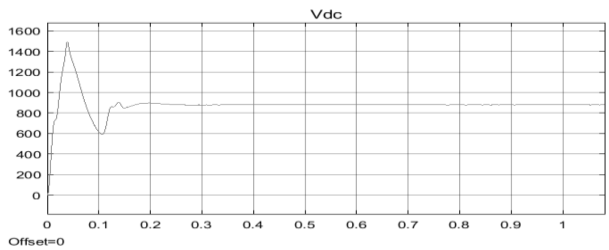

Figure 5: DC boosted voltage of DC-DC converter vs time in sec

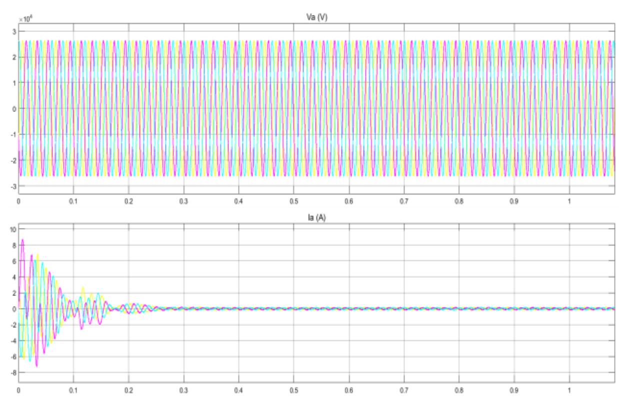

Figure 6: Grid voltage and current vs time in sec

Fig. 7 shows the grid real and reactive power. The enlarged figure of real and reactive power at the grid is as shown in Fig. 8. It is observed that real power is 5KW and reactive power is almost maintained to zero.

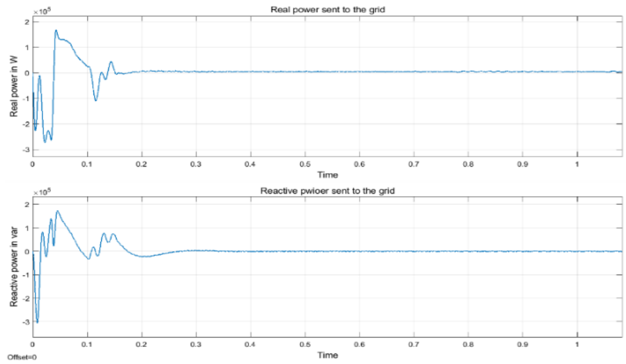

Figure 7: Real power & reactive power sent to the grid vs time in sec. at the grid

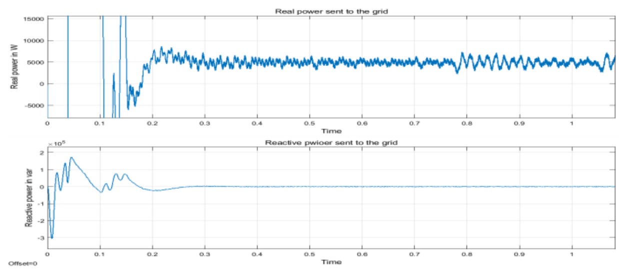

Figure 8: Magnified view of grid real & reactive power

Hence, the six phase AC voltages are generated by the WECS with SPMSG which is given to the rectifier bridge. The resulting DC voltage is obtained from the rectifier. Need arises to manifest the maximum power point. This is achieved by DC-DC converter. Hence, the obtained voltage is boosted and then given to the inverter. Here, DC is converted to AC by the inverter with the use of DQ technique. The obtained AC voltage can now be integrated with the grid. It is observed that 5kW of power is generated with the use of SPMSG [10]. Table I gives the simulation circuit details. The machine specifications are tabulated in Table II.

Table 1: Machine parameters [10]

Boost Converter	Inductor	5mH
	Capacitor	12000µF
	Frequency	50kHz
Transformer	kVA rating	100
	Low side voltage	415V
	High side voltage	11KV
	frequency	50Hz
Grid	MVA rating	100
	Voltage	11kV
	frequency	50Hz

Table II: Parameters of circuit diagram [10]

Torque	6 Nm
Vdc	300 Volts
Speed	4500 rpm
Rotor type	Salient pole
Back emf type	Sinusoidal

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In comparison to PI controller, Fig. 9 illustrates the grid real and reactive power using ANFIS model. The analysis of the obtained results of both the models shows that the ANFIS model performance is better compared to PI model with less settling time.

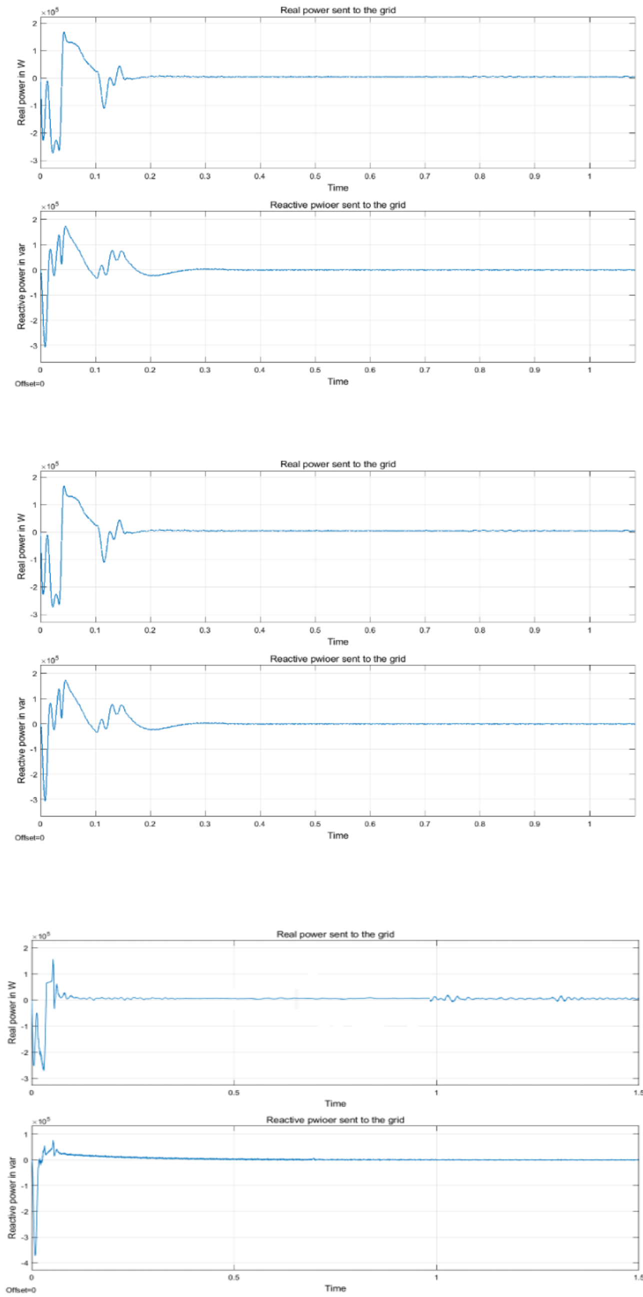

Figure 9: Grid real and reactive power vs time in sec

Fig. 10 & 11 gives the comparison of real and reactive power at the grid using PI & ANFIS Model. It is clear that the settling time of the PI controller is around 0.2 Seconds, ANFIS controller is 0.1 Seconds.

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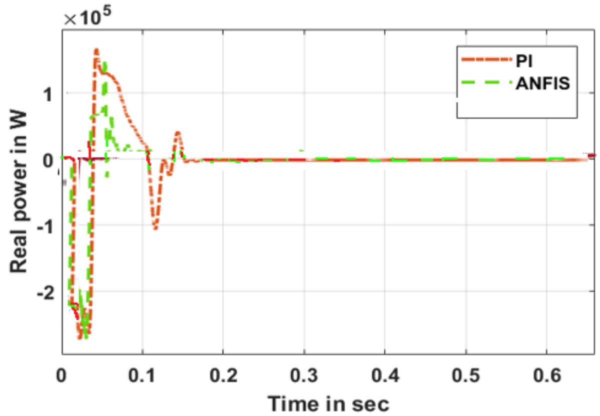

Figure 10: Real power comparison with PI & ANFIS

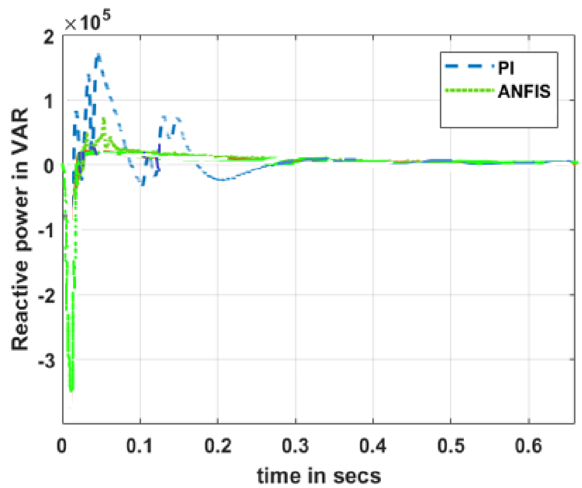

Figure 11: Reactive power comparison with PI & ANFIS

V. CONCLUSION

This research paper shows the implementation of controlling approach for wind power generation provided with SPMSG. The conventional PI controller is hybridized with advanced ANFIS controller resulting in PI-ANFIS controller. This combination has given the output power of 5kW for WECS with SPMSG, thereby increasing the maximum power operating point. The performance analysis of this system is investigated by analysing the real & reactive power produced at the grid. It is to be noted that the hybridized ANFIS controller performed better compared to conventional PI controller with less settling time. The grid real and reactive power comparative study with the aid of above-mentioned hybridized controller clearly indicates that the settling time of the PI controller is around 0.2 seconds and ANFIS controller is 0.1 seconds which improves the performance of the wind power generating system. However, the efficacy of the system can further be optimised by implementing modernized hybrid controllers like fractional order PID (FOPID) controller.

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