



Energy Efficiency Improvement of Doubly-fed Induction Generator Using Self-Tuning Adaptive Control Technique

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Industries suffer from an inconsistent power supply which has led to low production capacity in these industries. To overcome this ugly situation of inconsistent power supply in the industrial layout that has led to low production capacity, there is a need to introduce a new system which has an improvement as compared to the existing system. This project work, therefore, designed a doubly-fed induction generator using a self-tuning adaptive control technique for energy efficiency improvement. The following objectives guided the design of the system; characterizing the doubly-fed 50KVA induction generator, developing an adaptive control rule base for increasing energy efficiency in doubly-fed induction generator, training an intelligent artificial neural network in an adaptive rule base to enhance the energy and its control mechanism, designing a SIMULINK model of doubly-fed induction generator and finally, developing self-tuning adaptive control in SIMULINK. The results obtained showed that the conventional generator efficiency is stable at 4s through 10s at 65.5%. While the efficiency of the generator when the adaptive controller is incorporated in the system is 66.67% at a stable time of 4s through 10s. The percentage energy improvement when an adaptive controller is incorporated in the system when compared to the conventional method is 1.17%.

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ABSTRACT

Keywords: Energy, Efficiency, Improvement, Doubly-fed Induction, Generator, Intelligent, Self-Tuning, Adaptive Control Technique

1. Introduction

A synchronous machine usually employed in direct-drive turbines consists of a stator holding a set of three-phase windings, which supplies the external load, and a rotor that provides a source of magnetic field. This may be supplied either from permanent magnets or from direct current flowing in a wound field. In the direct-drive synchronous generator, the generator is completely decoupled from the grid by a power electronics converter based on (Theodore, 2017). The grid-side of the converter is a voltage source converter. The generator side of the converter can be a voltage source converter or a diode rectifier. Hu, et al (2016) expressed that when the diode rectifier option is considered, the stator current and the stator voltage are always in phase, and this leads to large voltage drops and to a decreasing DC-link voltage when the stator current increases. The generator feeds power to the network as long as the DC-link has a constant voltage higher than the peak voltage of the network. The generator is not capable of generating a constant high voltage at low speed, as it is the case of direct-drive wind turbines, and therefore in the case of a diode rectifier configuration a boost converter (known also as DC-DC step-up converter), must be used to raise the voltage of the diode rectifier shows a three-phase diode rectifier as the generator-side converter in a grid-connected variable speed wind turbine employing a direct drive synchronous machine as the electrical generator. The diode rectifier is, therefore, not the best solution in a scheme employing a permanent magnet synchronous generator (PMSG) in wind turbine configuration.

2. Methodology

To Characterize Doubly-Fed Induction Machine

A torque meter is used to find the mechanical power based on the motor's speed and load.

Large industrial synchronous motors are more efficient than induction motors. They are used when constant speed is required. Having a leading power factor, they can correct the AC line for a lagging power factor.

Table 2.1: System Speed Parameters

Synchronous speed rpm	1500
Rotor speed	1400

$$\text{Synchronize speed} = \frac{120f}{\text{No of poles}}$$

$$\text{Synchronize speed} = \frac{120 \times 50}{4}$$

$$\text{Synchronize speed} = 1500\text{rpm}$$

AC induction motor slips calculation - step by step

$$\text{Slip} = \frac{N_s - n_r}{N_s} \times 100\%$$

$$\text{Slip} = \frac{1500 - 1350}{1500} \times \frac{100}{1}\%$$

$$\text{Slip} = 10\%$$

Slip speed is the speed difference between the Synchronous speed and Rotor speed. Slip speed = Synchronous speed – Rotor speed = $N_s - N$. Slip, $s = (N_s - N) / N_s$.

A three-phase 15hp, 415v, 4pole, 50Hz, 1350rpm induction generator delivers full output power in a load connected to the shaft. The windage and friction loss of the motor is 5900w and full load shaft power or $P_g = 11190W$ the electrical output power.

Recall 1horse power =0.746KW

15hp = 15 x 0,746KW

15hp =11.19KW

15hp = 11,190wTheelectrical output power

The mechanical input power developed becomes

Electrical output = 11190W

Friction loss of the motor is 5900 w

Pm input= electrical output power + Friction loss of the motor

Pm input = 11190+ 5900 = 17090W.

Table 2.2: System Parameters

Convention Generators	Mechanical Input Power	Electrical Output Power
5oKVA Generator	17090W	11190W

To calculate the energy efficiency of the generator.

$$Efficiency = \frac{Electrical\ output}{Mechanical\ input} \times \frac{100}{1} \quad (1)$$

$$Efficiency = \frac{11190}{17090} \times \frac{100\%}{1}$$

Energy efficiency of generator = 65.5%.

To Develop Model Predictive Rule Base that would Enhance the Efficiency of Doubly-Fed Induction Machine

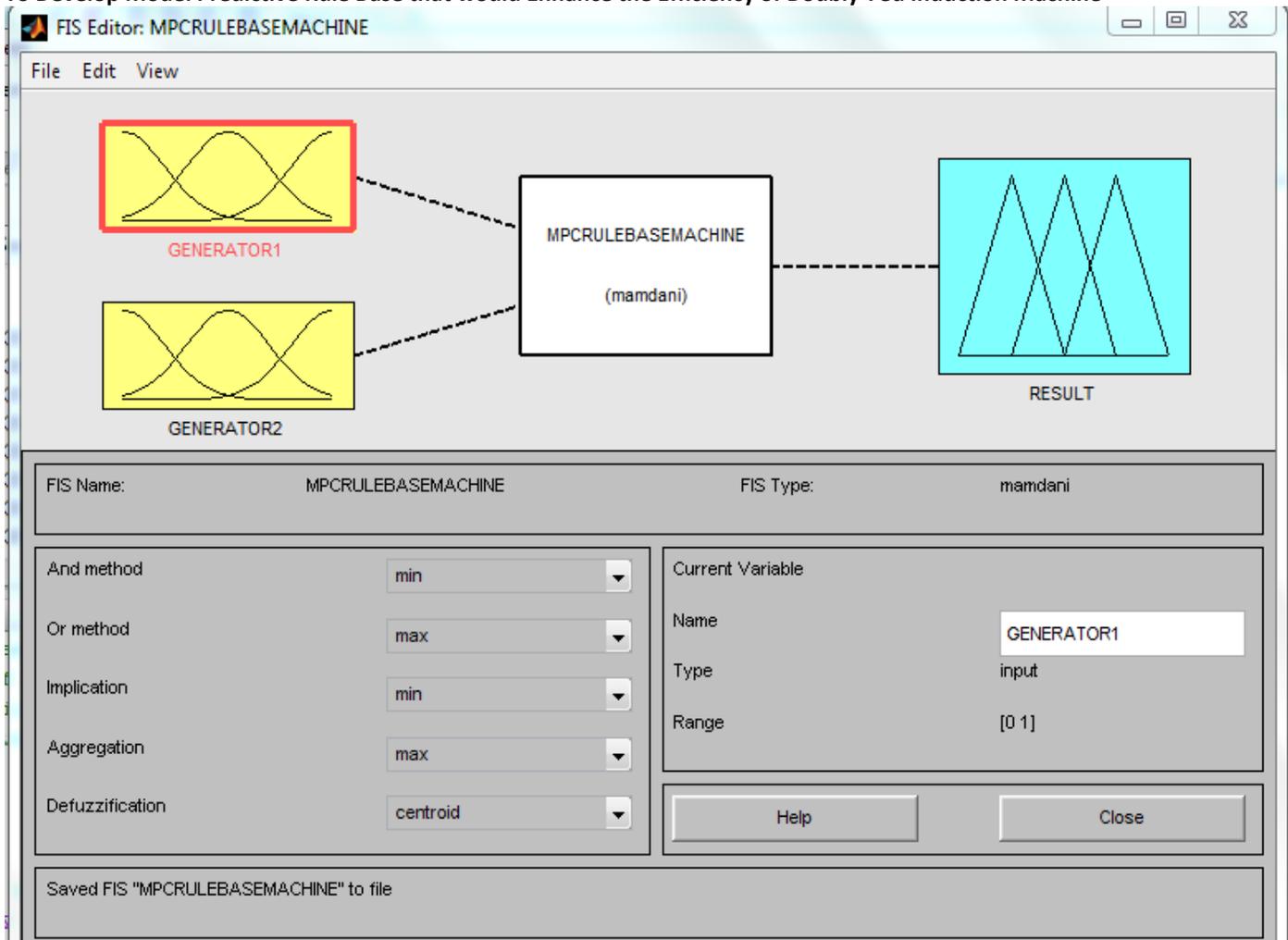


Figure 1: Developed Fuzzy Inference System Editor that would Enhance the Efficiency of Doubly-Fed Induction Machine

Fig 1 shows a developed fuzzy inference system editor that would enhance the efficiency of a doubly-fed induction machine. It has two inputs of generator 1 and generator 2. It also has an output of the result.

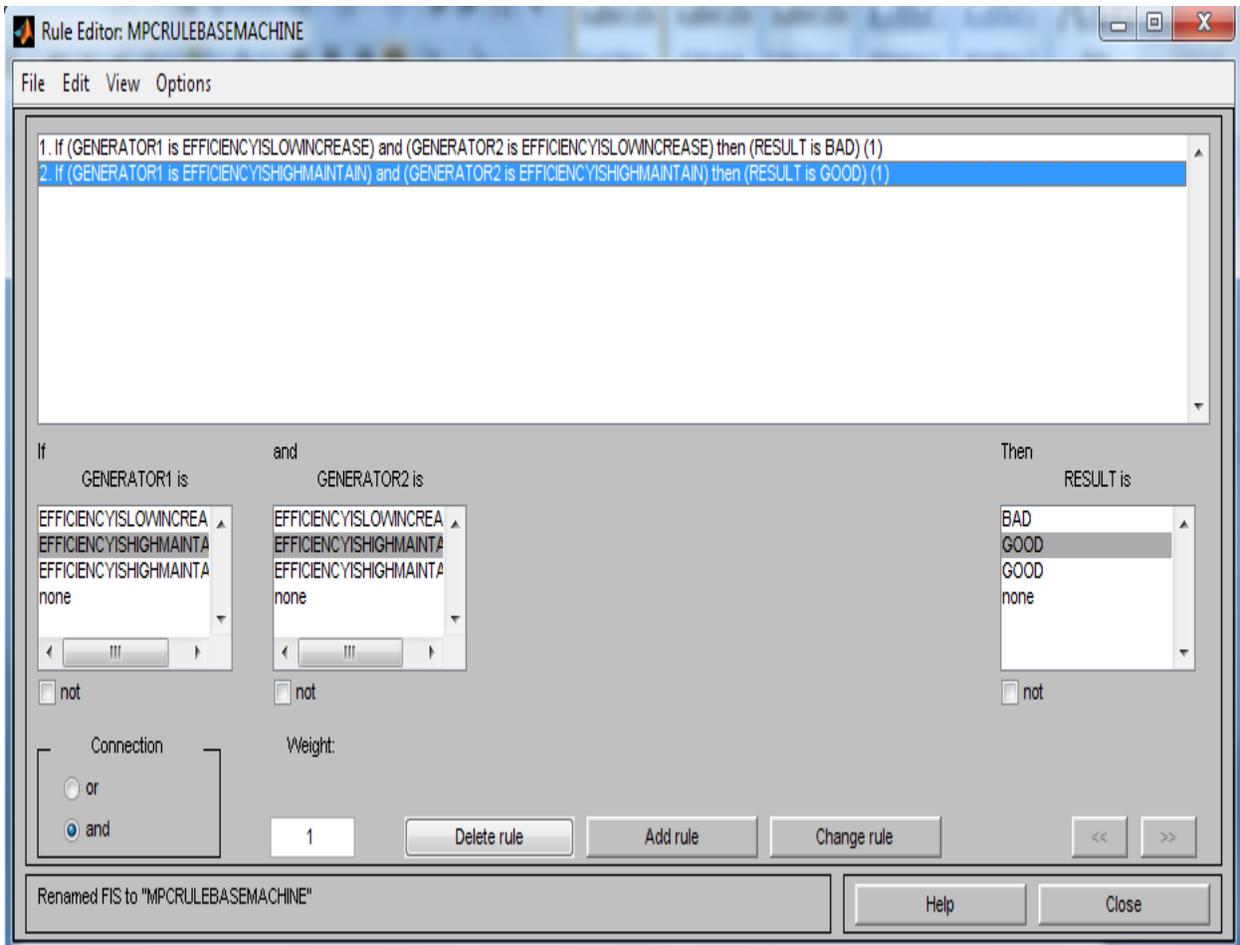


Figure 2: Developed Model Predictive Rule Base that would Enhance the Efficiency of Doubly-Fed Induction Machine

Figure 2 shows a developed model predictive rule base that would enhance the efficiency of a doubly-fed induction machine. The comprehensive detail of the rules is as shown in table 2.3

Table 2.3: Developed Model Predictive Rule Base that would Enhance the Efficiency of Doubly-Fed Induction Machine

1	If Generator1 Efficiency Is Low Increase	And Generator 2 Efficiency is Low Increase	Then the result is bad
2	If Generator1 Efficiency Is High Maintain	And Generator2 Efficiency Is High Maintain	Then the result is good

To Develop a Conventional Control System for Energy Efficiency

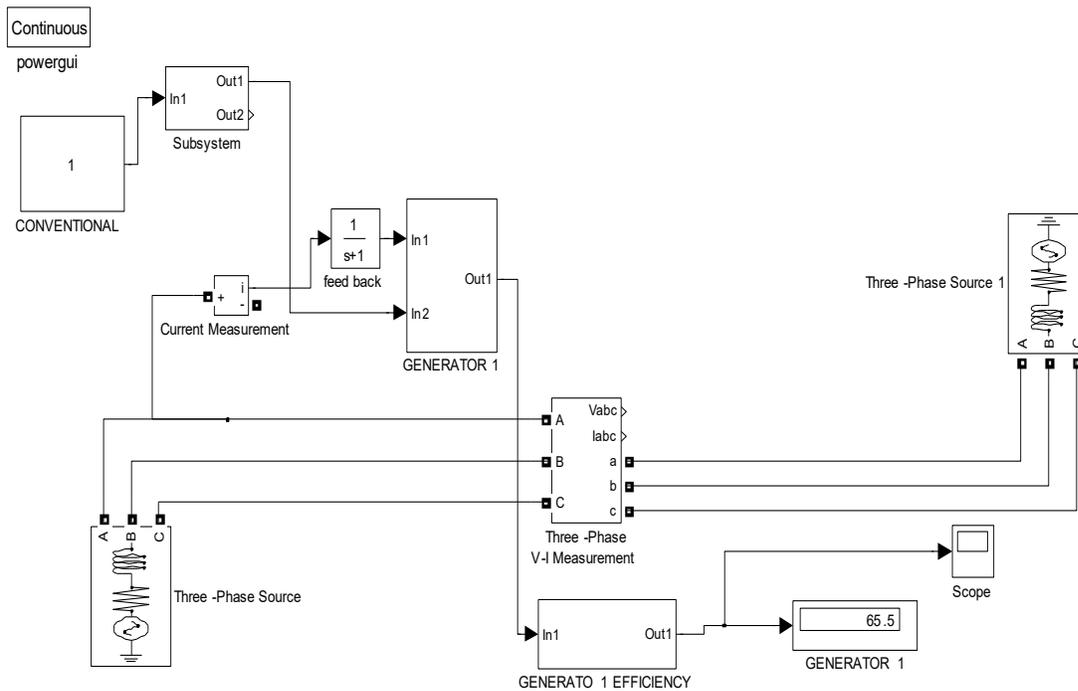


Figure 3: Developed Conventional Control System for Energy Efficiency

Figure 3 shows a developed conventional control system for energy efficiency. This is designed in a MATLAB environment with the following blocks induction generation, circuit breaker, efficiency subsystem, conventional proportional-integral. The computed generator efficiency was imbibed inside the efficiency subsystem. The results obtained were detailed in Figure 5.

To Develop Self-Tuning Adaptive Control in Simulink

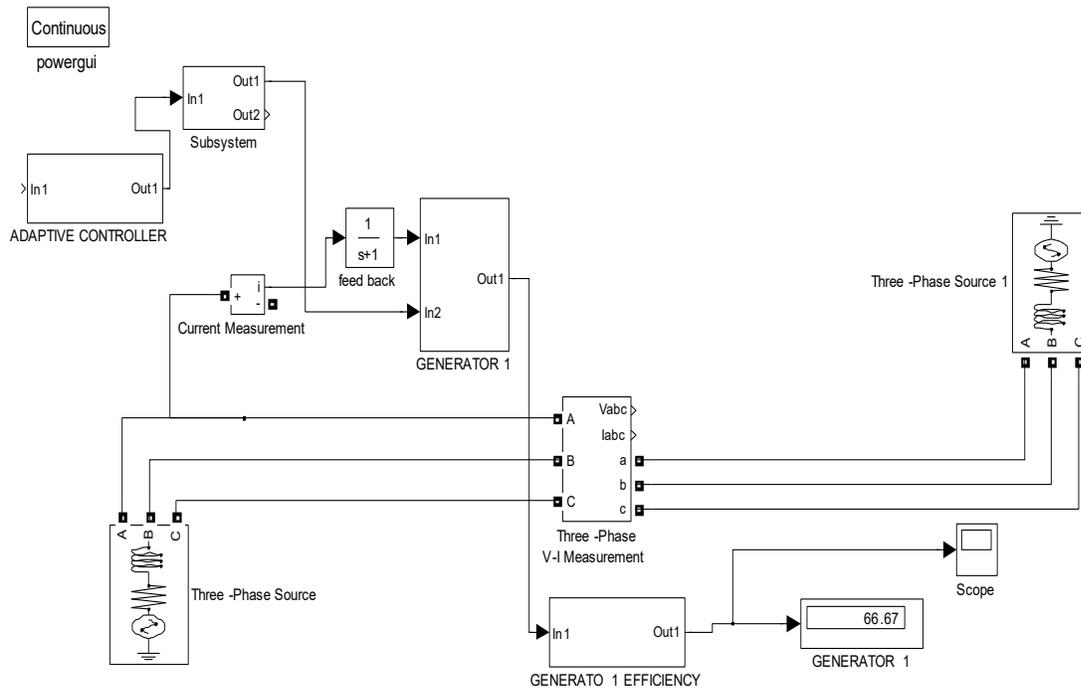


Figure 4: Designed Simulink Model for Energy Efficiency Improvements of Doubly-Fed Induction Generator Machine using Adaptive Control Technique

Fig 4 shows the designed SIMULINK model for energy efficiency improvements of a doubly-fed induction generator machine using adaptive control technique. The results obtained in equations 1 were imbibed in the designed model as shown in fig 3 and simulated it gave the exact analytical data as shown in equations 1 that depict conventional results obtained. The feedback transfer function was equally incorporated into the system. In fig 4 adaptive controllers were incorporated in the system to boost the energy efficiency of the double-fed induction machine as shown in figures 4 and 5 with a comprehensive analysis.

3. Discussion of Result

Table 3.1: Comparing Conventional and Adaptive Controller Generator Efficiency

Time(s)	Conventional Generator Efficiency (%)	Adaptive Controller Generator Efficiency (%)
0	0	0
1	40	42
2	54	58
3	61	62
4	65.5	66.67
10	65.5	66.67

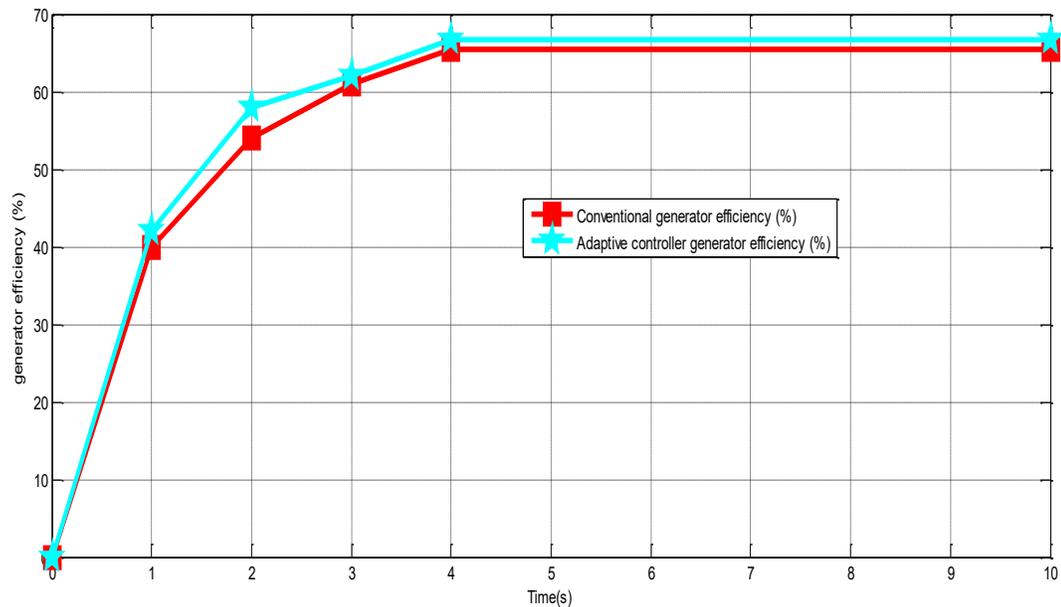


Figure 5: Comparing Conventional and Adaptive Controller Generator Efficiency

Fig 5 shows Comparing conventional and adaptive controller generator Efficiency. In fig 5 the conventional generator efficiency is stable at 4s through 10s at 65.5%. On the other hand, the efficiency of the generator when the adaptive controller is incorporated in the system is 66.67 % at a stable time of 4s through 10s. The percentage energy improvement when the adaptive controller is incorporated in the system when compared to the conventional method is 1.17%.

4. Conclusion

The reduction in efficiency of induction generators has led to the reduction of production capacity of some manufacturing industries that depend on this generator for their routine production.

This precarious situation of reduction in efficiency of this generator is addressed by energy efficiency improvements of a doubly-fed induction generator using adaptive control technique. It is done in this manner, characterizing the doubly-fed induction generator. Designing an adaptive control rule base for increased energy efficiency in a doubly-fed induction generator, training ANN in an adaptive rule base to enhance the energy and its control mechanism, developing a conventional proportional-integral PI control system for energy efficiency.

Designing a SIMULINK model for energy efficiency improvements of a doubly-fed induction generator machine using self-tuning adaptive control technique and validating and justifying the energy efficiency conventionally and when adaptive control is incorporated in the system. The results obtained were the conventional generator efficiency is stable at 4s through 10s at 65.5%. On the other hand, the efficiency of the generator when the adaptive controller is incorporated in the system is 66.67 % at a stable time of 4s through 10s. The percentage energy improvement when the adaptive controller is incorporated in the system when compared to the conventional method is 1.17%.

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