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RESEARCH ARTICLE

Adaptive Control-Based Technique for Enhancing Energy Efficiency of a Wind Energy Generator

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ABSTRACT

The need for wind energy conversion machines (WECMs) rises in tandem with the overall increase in demand for wind energy. One of them is the Doubly Fed Induction Machine, often known as the induction wind turbine generator. The best option is the doubly-fed induction generator (DFIG), however because it is such a delicate device, it might malfunction due to grid failures and changes in speed while in use. This work presents an adaptive control strategy to adjust the operating speed of the machine in order to overcome these undesired qualities. The steps in this process are to first assess the induction machine's performance, then create an adaptive control rule foundation to boost the wind turbine's driving efficiency. The creation of a traditional proportional integral control (PIC) system for energy efficiency is the next step. The results demonstrated that the efficiency of the conventional generator remains constant between 4 and 10 seconds at 59.7%. In contrast, generator one provides 60.77% efficiency across a steady time range of 4 to 10 seconds when an adaptive controller is applied. Using an adaptive controller improves the system's energy efficiency by 1.07% over the standard approach. Based on the final results, generator two has the highest efficiency of both conventional generators (76.5%) and adaptive controller generators (77.87%). When an adaptive controller is added to the system, the findings indicate a 1.3% improvement over the conventional approach.

***Keywords**: Energy Efficiency; Adaptive Control-Based Technique; Wind Energy Generator; Doubly Fed Induction Machine; Artificial Neutral Network*

Introduction

The added characteristics that allow the induction wind turbine generator to work at speeds that are either slightly higher or lower than its current rated synchronous speed are the sole distinction between them and AC electricity generators. Large variable speed wind turbines employ this technology because of the sudden variations in wind speed. When the wind suddenly picks up more speed, the blades of a wind turbine want to pick up more speed, but synchronous generators can't since they are linked to the national grid, which acts as the power grid. Therefore, significant pressures are produced in the hub, gearbox, and generator as the power grid pulls back to preserve balance (Tanko, 2018) Consequently, the machinery malfunctions due to wear and tear on the mechanism. When the turbine generator is allowed to accelerate right away after being impacted by a wind gust, the strains are reduced while the energy of the gust is still transformed into useful power (Akbari, 2011). A wind turbine's speed may be tactically adjusted by enabling the generator to produce any frequency, converting it to DC, and then using an inverter to return the DC signal to AC at the optimal output frequency. Wind turbines for tiny houses and farms usually employ this technique. To generate high power in megawatts, costly inverters must be purchased, installed, and maintained (Ugwu, 2021).

Double fed generators are employed to overcome the problem; in this case, the conventional field winding supplied with DC, where the armature winding generates energy, would have two three-phase windings, one revolving and one fixed. These kinds of devices are referred to be "doubly fed" when both of them are independently connected to external equipment (Ude, 2021). When one winding is directly linked to the output (grid frequency), it generates three-phase AC power at the synchronous speed frequency. Given that they are linked to 3-phase AC power at a variable frequency, both of the windings in this instance might be outputs. The term "field" usually refers to the

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second winding. In order to accommodate fluctuations or shifts in the turbine's velocity, this input power is is modified in both phase and frequency (Bakare, 2021). To alter the phase and frequency, a converter is required for both DC to AC and AC to DC. The structure makes use of very huge IGBT semiconductors. The converter is bidirectional as opposed to unidirectional as it permits electricity to go in both directions. Power can be supplied via this winding as well as the output winding (Akaninyenene, 2021). This study uses adaptive control in conjunction with a doubly fed induction generator to lessen sub-synchronous oscillations in the network (DFIG). The control techniques for a doubly fed induction generating machine would be examined, with an emphasis on adaptive strategies. This will help overcome other methods' shortcomings in addition to the appropriate construction of a doubly fed induction generator control.

The goal of the study is to use adaptive control to increase the energy efficiency of an Induction Wind Turbine Machine.

Study Objectives

To increase performance under operating conditions, nonlinear functions that show up in tracking errors are performed using the Adaptive Control Technique. The study work's goals are expressed in quantifiable behavioural terms prior to proceeding to the next phase, completion, and validation. Thus, this work's objectives are to describe the features of the induction wind turbine machine. To increase the induction generator's energy efficiency, use an adaptive control system based on rules. Provide an Artificial Neural Network (ANN) with an adaptable rule foundation to enhance energy and its control system. Construct a proportional integral PI control system that uses less energy. To improve the doubly fed induction generator machine's energy efficiency, create a Simulink model by utilising the adaptive control approach. To verify and bolster the system's energy efficiency both with and without adaptive control.

Literature

The wound rotor induction machine is typically constructed with a three-phase winding that has the same number of poles as the stator (Anthony, 2021; Aneke, 2021). The rotor current can be regulated using three-phase slip rings and brushes. This type of machine is used in variable speed systems, such as variable speed turbines. For variable speed operation, it is necessary to separate the electrical frequency of the grid from the mechanical rotor speed. This is achieved by using back-to-back voltage source power converters to feed the three-phase rotor windings (Bakare, 2021). This separation allows the mechanical and electrical rotor frequencies to be matched independently of the mechanical rotor speed. Adaptive fuzzy systems are used to minimize errors and enhance efficiency, compared to simplified linear dynamics or conventional control algorithms (Bakare, 2021; Ngang, 2021).

The doubly fed induction generator (DFIG) offers advantages over other types of wind generators (Okedu, 2015). DFIG can maintain a nearly constant power output from the stator by keeping the rotor current frequency constant and can produce maximum power at different wind speeds by maintaining the desired tip-speed ratio (Ngang, 2020). When equipped with DFIG, a wind power production system only requires a converter that handles one-third of its rated power, making the system cost-effective and reducing power loss (Ngang & Aneke, 2021). DFIG can also generate controlled reactive power to maintain a constant power network voltage, thus enhancing the voltage profile and overall power factor (Uhunmwangho, 2015). By modifying the frame, DFIG can independently control reactive and actual power.

To minimize instability issues in the power system, power supply companies have recommended various techniques, protocols, and standards for connecting wind generators to the system (Aneke & Ngang, 2021). Consequently, research on reactive power regulation in DFIG for wind turbines has intensified, leading to numerous technical publications (Ajihilesh, 2012). Optimization techniques are considered one of the best ways to meet the rapidly increasing demand for energy (Bakare, 2021; Bazzi, 2008; Ngang, 2021).

Efforts to stabilize frequency fluctuations using fuzzy controllers have been made. Fuzzy controllers were employed to address disturbances in the Nigerian 330kV transmission line. Although artificial intelligence techniques, such as artificial neural networks, have been used to identify transient instability in power systems, they are not highly effective due to the stochastic nature of renewable energy sources.

Methodology

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Characterizing the Induction Machine

The methodology used in this work is the adherence to the study's goals, which have to do with measuring the data that have been collected with respect to the mechanical output and electrical output of two generators. Equations 3.1 and 3.2 depict how the data obtained were used to solve the generators' efficiency. The mechanical output was divided by the electrical input power to obtain the motor's efficiency. The mechanical output power was measured using a torque metre. Based on the motor's speed and load, a torque metre and tachometer were inserted and used and helped to calculate the mechanical power. Induction motors are less effective than large industrial synchronous motors. They are employed in situations where a steady speed is required, and due of their leading power factor, they may make up for an AC line's trailing power factor.

A three phase 15hp, 460V, 4pole, 60Hz, 17228 RPM induction generator delivers full output power in a load connected to the shaft. The windage and friction loss of the motor is 750w and full load shaft power or $P_s = 11190W$. The electrical output power = 20000w.

The mechanical power developed becomes

Full load shaft power = 11190W

Pm= Ps+ change in Pm

Pm = 11190+ 750 = 11840W.

Table1: Generators Mechanical and Electrical Powers

	Pm(W)	*Pe(W)*
Generator 1	11940	20000
Generator 2	15300	20000

To calculate the energy efficiency of generator!

Energy efficiency = $\frac{\text{Mechanical output power x 100\%}}{\text{Electrical output power}}$

Energy efficiency = $\frac{\text{11940 xlOO\%}}{20000}$

Energy efficiency of generatorl = 59.7%

To calculate the energy efficiency of generator 2

Energy efficiency =$\frac{\text{Mechanical output power x 100\%}}{\text{Electrical output power}}$

Energy efficiency $\frac{\text{15300 x l00\%}}{20000}$

Energy efficiency of generator2 76.5%

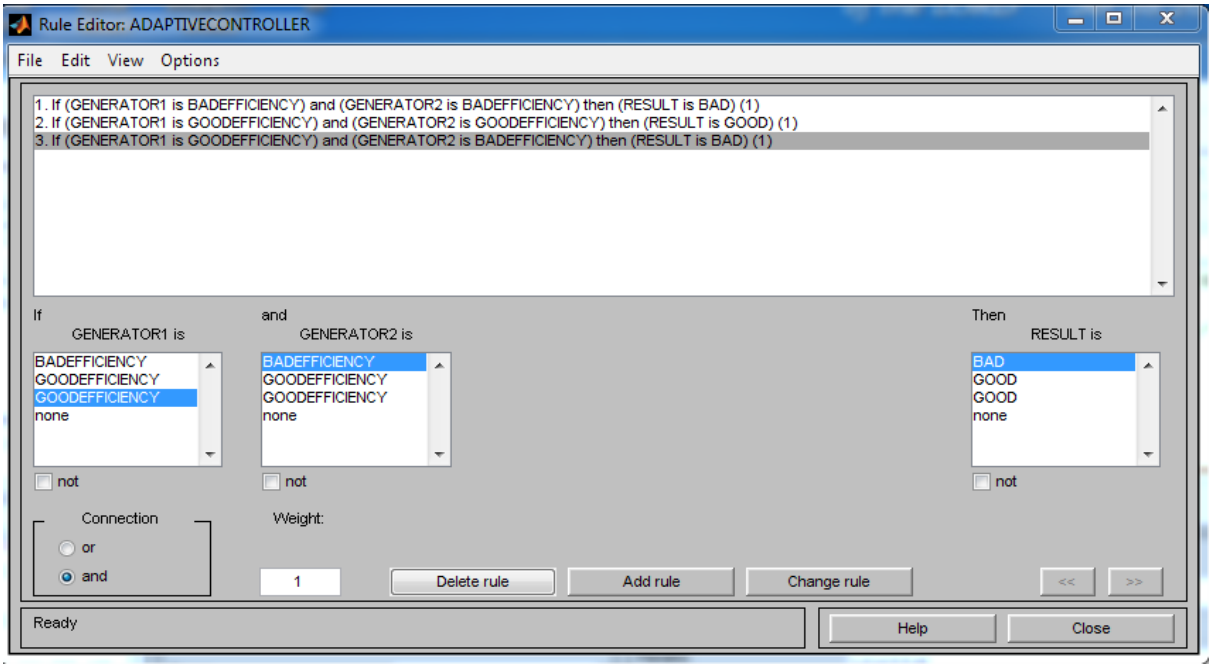

Fig. 1: Designed an Adaptive Control Rule Base for Increase Energy Efficiency in Doubly Fed Induction Generator

Designing an Adaptive Control Rule Base for Increase Energy Efficiency in Doubly Fed Induction Generator

Creating an adaptive control rule foundation to improve the doubly fed induction generator's energy efficiency. Fig. 1's adaptive control rule base is intended to improve an induction generator that is doubly fed in terms of energy efficiency. This rule specifies how to evaluate the generator's efficacy. The fuzzy toolbox is used in the MATLAB environment to monitor and enhance the induction generator's efficacy.

Training ANN in an adaptive rule base to enhance the energy and its control mechanism

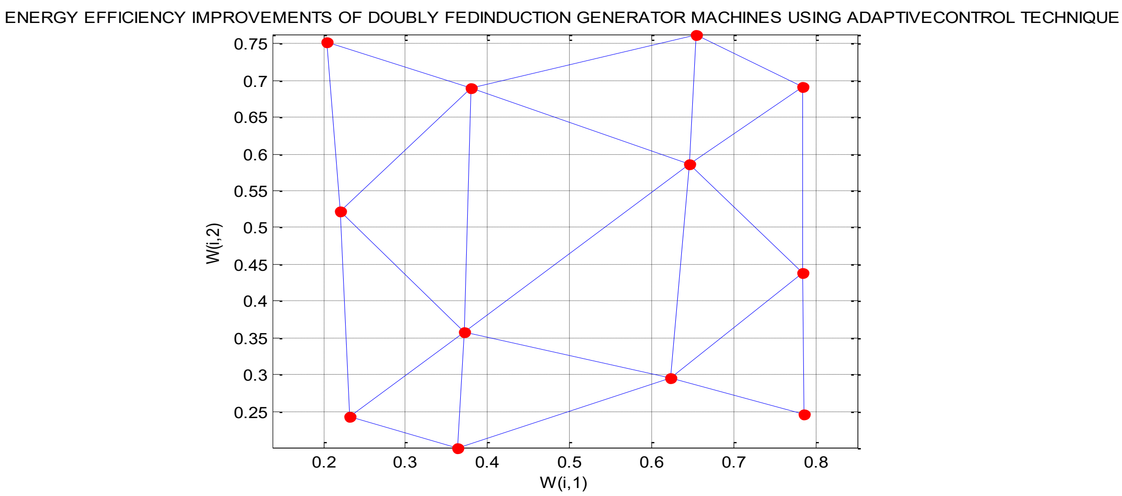

Fig. 2: Trained ANN in an adaptive rule base to enhance the energy and its control mechanism

Figure 2 displays a trained artificial neural network in an adaptive rule base to improve energy and its control mechanism. This is accomplished using the three-rule base. These three rules were trained four times, resulting in twelve neurons that mimic human intelligence and follow training instructions to the letter.

Developing a Conventional Proportional Integral P1 Control System for Energy Efficiency

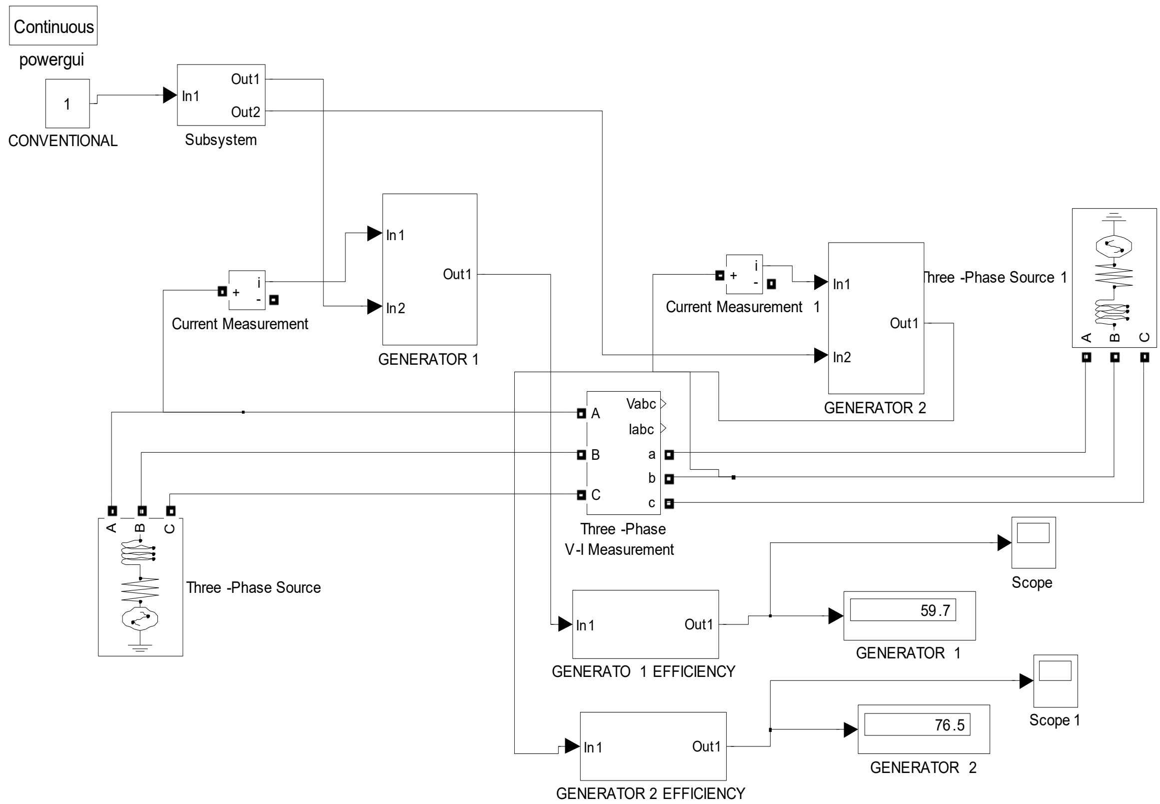

Fig. 3: Developed Conventional Proportional Integral P1 Control System for Energy Efficiency

Figure 3 shows developed conventional proportional integral PT control system for energy efficiency. This is designed in 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 figures 5 and 6 respectively.

Designing a Simulink Model for Energy Efficiency Improvements of Doubly Fed Induction Generator Machine using Adaptive Control Technique

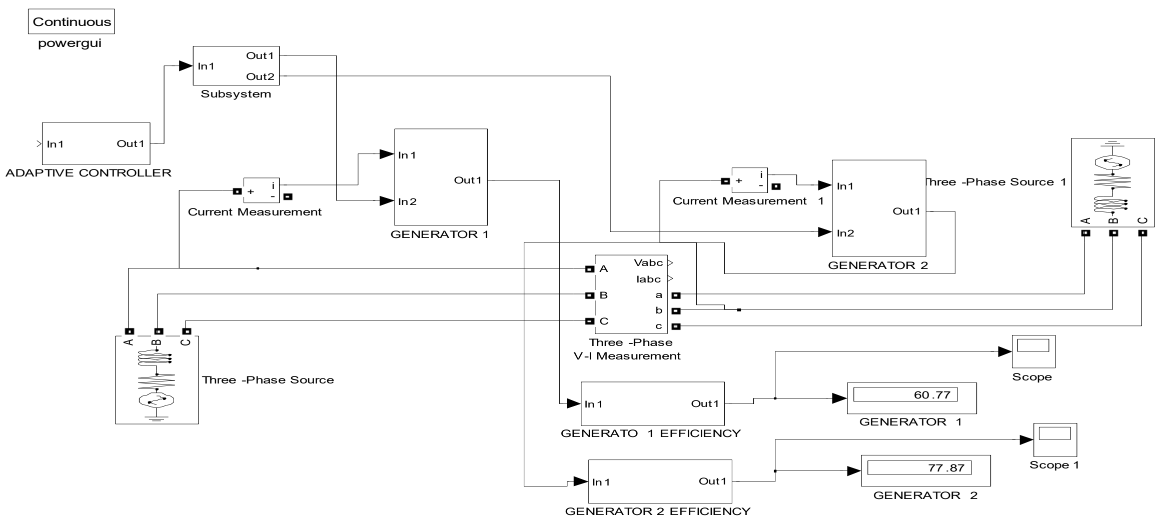

Fig. 4: Designed Simulink model for energy efficiency improvements of doubly fed induction generator machine using adaptive control technique

Figure 4 depicts a Simulink model that was created to improve the energy efficiency of a doubly fed induction generator using adaptive control. The simulated results were displayed in figures 5 and 6 in fig.4 along with a thorough analysis.

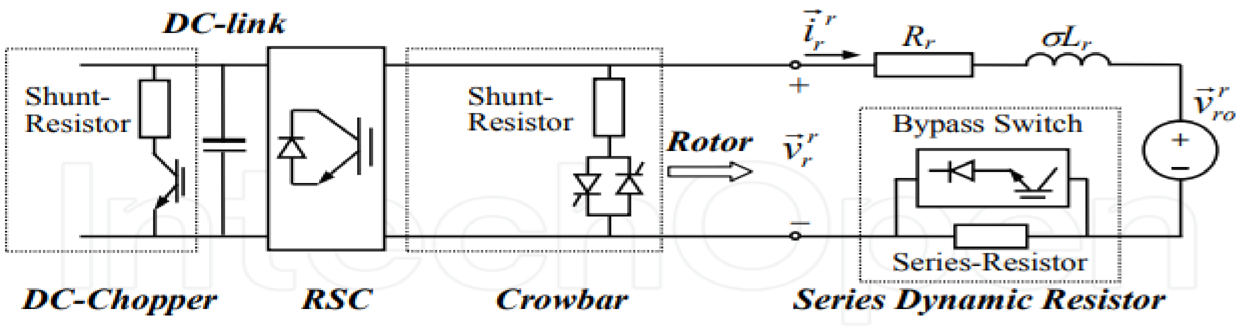

Fig. 5: DFIG rotor equivalent circuit with all protection schemes shown

Results and Discussion

Table 1 presents the estimated results of the first aim, which deals with characterizing the machines that are being studied. Fig. 1 illustrates the construction of an adaptive control rule basis for a doubly fed induction generator with the goal of improving energy efficiency. Figure 2 displays an Artificial Neural Network (ANN) that has been trained and has an adaptive rule foundation to enhance energy and its control mechanism. To do this, the three-rule basis is employed. After these three principles were taught four times, twelve neurons were created that, when trained, resemble human intellect and obey commands. Fig. 3 shows the creation of a conventional proportional integral PT control system for energy efficiency. Conventional proportional integral blocks, efficiency subsystem, circuit breaker, and induction generation were

used in the MATLAB environment for this design. The calculated generating efficiency was used by the efficiency subsystem. A Simulink model designed to improve the energy efficiency of a doubly fed induction generating machine using adaptive control is shown in Fig. 4. Figures 5 and 6 in Figure 4 displayed the simulation results in addition to a detailed analysis. The analogous circuit for a DFIG rotor, which incorporates all protective techniques, is depicted in Figure 5. The effectiveness of the adaptive controller generator 1 and the traditional controller generator are contrasted in Fig. 6. From 4 to 10 seconds, the conventional generator 1 in Fig. 6 maintains a constant efficiency of 59.7%. On the other hand, Generator 1's efficiency increases to 60.77% over a steady interval of four to ten seconds. Using an adaptive controller improves the system's energy efficiency by 1.07% over the standard approach. On the other hand, Fig. 7 contrasts the efficiency of generator 2's conventional and adaptive controllers. The maximum generator 2 efficiency in Fig. 7 is 77.87% when utilising an adaptive controller, compared to 76.5% when using a traditional controller. When an adaptive controller is added to the system, the findings indicate a 1.3% improvement over the conventional method. The generator 1 efficiency of conventional and adaptive controllers is contrasted in Table 2. The efficiency of generator 2's conventional and adaptive controllers were compared in Table 3.

From 4 to 10 seconds, the conventional generator 1 in Fig. 6 maintains a constant efficiency of 59.7%. However, Generator 1's efficiency is 60.77% throughout a steady time range of 4 to 10 seconds when an adaptive controller is applied.

Using an adaptive controller improves the system's energy efficiency by 1.07% over the standard approach.

The effectiveness of generator 2's conventional and adaptive controllers is contrasted in Figure 7. The maximum generator 2 efficiency in Fig. 4.2 is 77.87% for a system with an adaptive controller, compared to 76.5% for a traditional system. When an adaptive controller is added to the system, the findings indicate a 1.3% improvement over the conventional method.

Table 2: Comparing Conventional and Adaptive Controller Generator 1 Efficiency

Time(s)	*Conventional generator 1 efficiency (%)*	*Adaptive controller generator 1 efficiency (%)*
0	0	0
2	50	52
4	59.7	60.77
10	59.7	60.77

Table 3: Comparing Conventional and Adaptive Controller Generator 2 Efficiency

Time(s)	*Conventional generator 2 efficiency (%)*	*Adaptive controller generator 2 efficiency (%)*
0	0	0
2	62	64
4	76.5	77.87
10	76.5	77.87

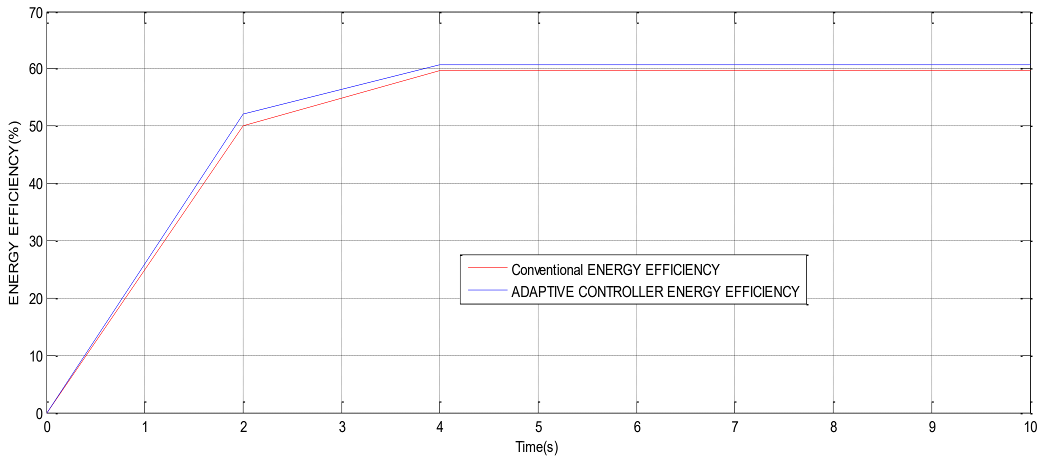

Fig 6: Comparing conventional and adaptive controller generator 1 efficiency

Fig. 6 depicts comparing the effectiveness of generator 1 for conventional and adaptive controllers.

The efficiency of the conventional generator 1 in Fig. 6 remains constant from 4 to 10 seconds at 59.7%. However, when an adaptive controller is used, Generator 1's efficiency is 60.77% over a stable time range of 4 to 10 seconds.

When compared to the conventional method, the system's energy efficiency increases by 1.07% when an adaptive controller is used.

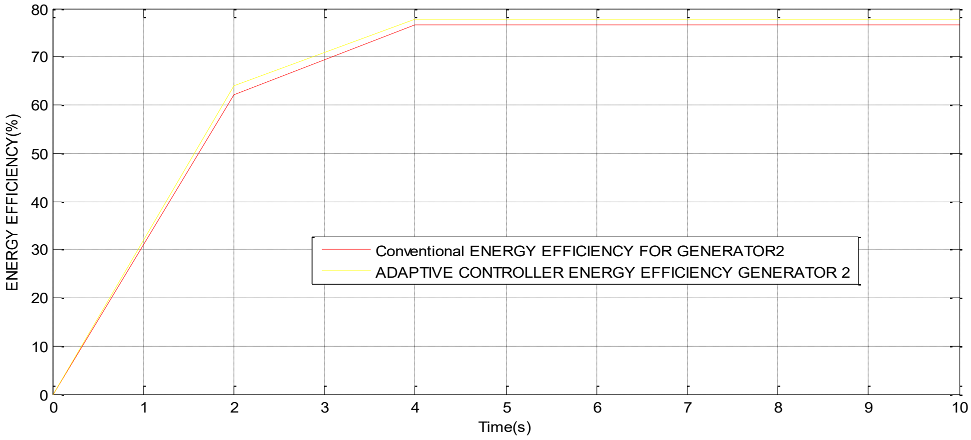

Fig. 7: Comparing conventional and adaptive controller generator 2 efficiency

Figure 7 compares the efficiency of the conventional and adaptive controller generator 2. In Fig. 4.2, the highest generator 2 efficiency for a conventional system is 76.5%, while the highest generator 2 efficiency for a system with an adaptive controller is 77.87%. The results show a 1.3% improvement when an adaptive controller is incorporated into the system compared to the traditional approach.

Conclusion

The decreasing efficiency of induction generators have led to a reduction in production capabilities in certain manufacturing businesses that depend on them for regular output. The risky issue of this generator's efficiency loss is addressed by energy efficiency enhancements of doubly fed induction generator machines using adaptive control technology. The manner in which it is operated defines the doubly-fed induction generator. To increase energy efficiency, a traditional proportional integral PI control system will be created. An ANN will be trained in an adaptive rule basis to enhance energy and its control mechanism. enhancing the energy efficiency of a doubly fed induction generator by designing an adaptive control rule basis. building a Simulink model to enhance a doubly fed induction generator's energy efficiency while verifying and supporting the energy efficiency when adaptive control is used as well as traditional control. The findings show that from 4 to 10 seconds, the efficiency of conventional generator 1 stays at 59.7%. In contrast, generator 1's efficiency is 60.77% throughout a steady time range of 4 to 10 seconds when an adaptive controller is applied. Compared to the conventional method, using an adaptive controller has resulted in a 1.07% increase in the system's energy efficiency. According to the final results, generator 2 has the best efficiency of any conventional generator (76.5%) and the highest efficiency of any adaptive controller (77.87%). The findings indicate that adding an adaptive controller to the system can enhance performance by 1.3%.

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