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POWER QUALITY IMPROVEMENT USING A CUSTOM POWER DEVICE, INTELLIGENT CONTROLLER IN WECS

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Abstract

The increasing use of wind energy in power systems creates new problems with power quality, especially when trying to connect wind farms to the grid. This paper describes a simple way to improve the power quality in Wind Energy Conversion Systems using a custom power device called a Static Synchronous Compensator, which is controlled by a smart system. The proposed control system brings together an Adaptive Neuro-Fuzzy Inference System that works better because it's tuned using the Kookaburra Optimization Algorithm (KOA), which is an optimization technique that helps improve how well the STATCOM handles changes in voltage and reduces harmonic distortion more quickly. The MATLAB/Simulink environment is used to create a model of the WECS connected to the STATCOM-ANFIS-KOA controller while the system changes or reacts to different situations. Simulation results show that the suggested system works well in cutting down Total Harmonic Distortion (THD), keeping the voltage steady, and making the power usable even when there are different loads or problems with the system. This integrated solution helps make sure there is steady and safe electricity from renewable energy sources.

Keywords: Power Quality, Wind Energy, STATCOM, ANFIS, Kookaburra Optimization Algorithm (KOA), Harmonics, Grid Integration.

I.INTRODUCTION

Wind plants do not produce air pollution or give off gases that can make the climate change. Winds happen because the sun gets the atmosphere warm in different places and because the Earth is not flat. Compared to other types of renewable energy, wind power needs less equipment to turn it into usable energy, doesn't take up as much land, and generally needs less maintenance. Power quality means how steady, reliable, and strong the electricity is coming from your electrical system. Maintaining high power quality is important because even small deviations can cause things like broken equipment, mistakes in how systems

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work, sudden system shutdowns, and lost data. Additionally, having bad power can make machines work worse and cost more to fix. Power electronic technology is very important for making sure that new kinds of energy like solar and wind can be easily connected to the electrical grid and used by the public. Its use is common and these applications keep growing by using gird-based systems. In the wind energy sector, India's total wind power capacity grew to 47.96 GW by November 2024. Wind turbines can be built on farms and ranches, which lets the land owners earn extra money by renting out the land to companies in rural areas. Meanwhile, the land can still be used for other activities or things. The paper is set up as follows: The first part of the book, in Section I, takes a look at the positive sides of wind power, plus some of the issues that come up when connecting them to the electricity grid. The next few sections go over different kinds of generators and explain why both ANFIS and KOA are useful. In section V, I explained what the model's main ideas are and showed the basic results, then talked about them, and finally gave my conclusion in section VI.

II.WIND ENERGY CONVERSION SYSTEMS

The use of wind turbines with the grid creates some technical problems, like making sure there is enough support for the power response, keeping the voltage steady, and making sure everything stays steady. Two types of generators people can use are: Induction generators and synchronous generators are the main kinds of electric generators. Wind turbines can make power by using the wind to turn a set of blades, and the spinning blades make the turbine spin a generator to create electricity. either traveling at the same steady speed or at different speeds depending on the situation. The maximum possible amount of energy can be used from variable-speed winds by using a power electronic converter[4][8]. A gearbox helps the rotor and generator turn at the same speed, and then the power generator goes to a device that changes the electricity, before it goes to a big machine that steps up the voltage. This setup helps the energy not get lost as much and makes the power bills lower. There is complete control over both the big fan and the generator part. However, some problems come up when putting together a bike with an electric motor, like it can be tricky if something is wrong with the wiring, and you also need to pedal all the time because there is no easy way to shift gears. These type of washing machines can change the speed they run, which keeps the parts from wearing out and helps them get the most power out of the spin cycle. DFIG[20] is important in wind power generation because it runs well and can be used in many ways.

By using variable speed wind turbines that are controlled by electronic equipment, it helps increase the amount of energy the turbines can gather. With lower mechanical stress and the ability to extract as much power as possible, DFIGs[7] help make wind turbines work better, even though they do have some issues to deal with in operation. Fig.1 shows the basic

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diagram for a WECS using a DFIG.

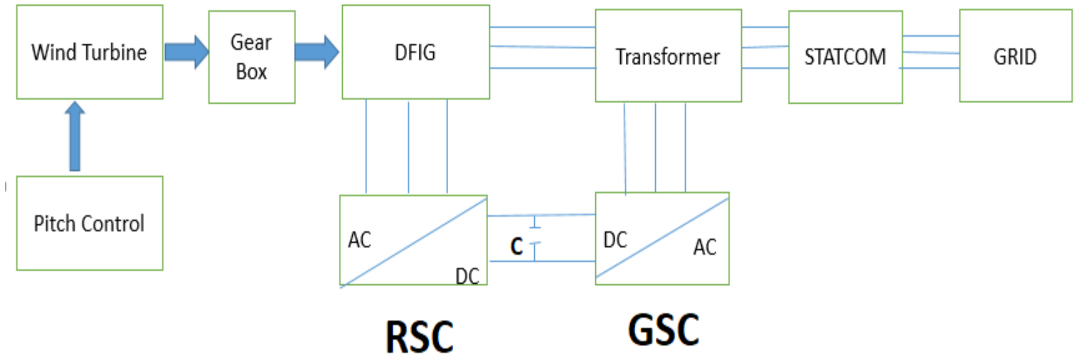

Fig. 1. Block diagram for WECS with DFIG

III STATCOM

STATCOM is part of the FACTS device family and helps control how power moves around the power grid, quickly responds to changes in power, and can be used to its full capacity as long as it doesn't get too hot. The innovation of using power electronics to help manage the flow of electricity in power systems for the good of customers or groups of customers is called custom power. Quality of power can get better when things like power electronics are used. Custom power brings together different solutions to help deal with the current problems that electricity companies and power operators are facing. In this paper, the Kookaburra Optimization Algorithm (KOA) together with ANFIS[15-16] is used to help improve the performance of STATCOM.

A STATCOM is a device that uses closed circuit loop components like switched capacitors and reactors, and then swaps these out with voltage source converters. As a FACTS device, STATCOM [10-12]. Offers several advantages: it gives a quicker reaction time and uses up less room because it doesn’t have big passive parts like a reactor. These devices can be broken down into separate parts, moved easily, and can connect to things like batteries, fuel cells, or superconducting magnets to store energy. They work well during low-voltage situations because they keep a regular amount of reactive power going. Additionally, if a FACTS device is rated for temporary overload, it can cause a bit more reactive current during those situations. A STATCOM is often thought of as working in a similar way to a Synchronous Condenser (or Compensator). The main goal of putting a STATCOM into a transmission network is to help keep the voltage up or down quickly at a spot where there is a lot of demand or where lines meet. This also makes it possible to send more power through the network, which means that total Available Transfer Capacity can go up.

ANFIS and KOA Algorithm

ANFIS is a clever controller that uses both neural networks and the idea of fuzzy logic together. The mix of these two approaches gives it the ability to learn, adapt to new situations, and use prior data. ANN can also be used to learn about what goes into creating

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net-like structures or making IF-THEN rules, or it can help get better at making choices [21-25].

The Kookaburra is a type of tree kingfisher that stays mostly on the ground, eats mostly meat, and is part of the Coraciiformes and Alcedininae bird families. Native to New Guinea and Australia, Kookaburras come in different colors, like blue, brown, and white. Behind the eyes of this bird, you can see a small dark spot, and because the feathers are shaped in a certain way, it looks like the bird is always ready to get angry. Kookaburras can grow to be between 28 and 47 cm long and usually weigh 300 grams. Among the everyday habits of these birds in the wild, the way they hunt is an important one. The bird hits the animal it gets against a tree to make sure it stops moving and is truly dead. These intelligent hunting behaviors are used to help make the KOA approach work better.

Fitness graph with different algorithms like PSO (Particle Swarm Optimization) , COA (Coati Optimization Algorithm), POA (Pelican Optimization Algorithm) was compared with the proposal of using KOA (Kookaburra Optimisation Algorithm) and it was found that KOA reached the optimal solution quicker than the others, as shown in fig.2. Table 1 shows how the THD changes when there are different loads, both with and without a STATCOM for supporting the grid.Fig 3 shows the steps of the Kookaburra algorithm in a flow chart.

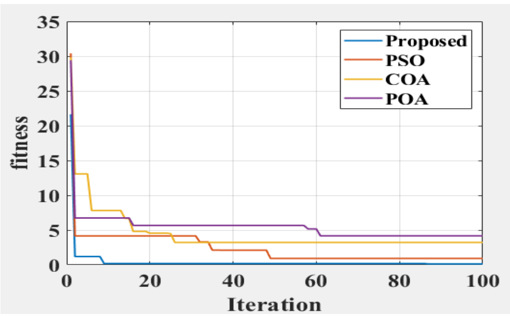

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Fig.3 Flowchart for Kookaburra Optimization Algorithm

Fig. 2. Comparison graphs of different controllers

IV SYSTEM MODELING

Both the speed of the rotor and the speed of the wind affect the power generated by a wind turbine [25]. The aerodynamic power from the wind can be calculated using the equation below.

$P = 0.5\rho A C_P(\lambda,\beta) V_w^3$ ---(1)

Here, P is the wattage of the power in kilowatts, ρ measures air density, A is the rotor swept area, Vw is the speed in the meter per second, and Cp stands for the power coefficient of the rotor. The power a turbine can handle and how it operates are affected by the rotor blades' area, the wind's speed, and the conditions at the rotor due to the wind. In this way, the

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turbine's output power changes with its area and also with adjustments at the rotor system, which is the main control method for wind energy conversion systems.

The tip speed ratio λ is equal to the linear velocity at the tip of the blade, divided by the wind speed far from the blade [2, 7].

$\lambda=(\omega_m R)/V_\omega$ ------------(2)

R is the radius of the turbine and ω_m is the speed of the rotor in radians per second.

$C_P(\lambda, \beta)=0.5176(116/\lambda_i-0.4\beta-5)\, e^{((-21)/\lambda 1)}$ ----(3)

Where $\lambda_i=[1/(\lambda+0.08\beta)-0.035/(\beta^3+1)]^{(-1)}$-----(4)

Power coefficient is affected by the turbine's TSR as well as the pitch angle of its blades. Fig.4 demonstrates the regular ways in which the power coefficient can vary depending on the TSR for different angles of attack.

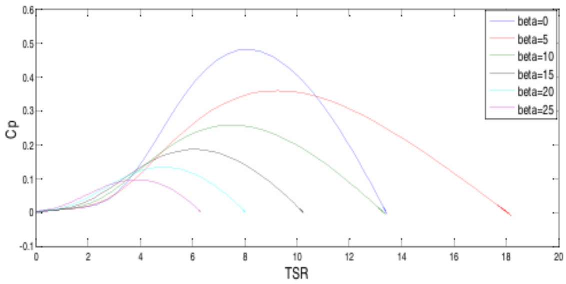

Fig. 4. CP vs. λ (TSR) for various pitch angles β

Control scheme for the Inverter:

Figure 5 shows how the grid-side converter is controlled. Setting up the PI controller to manage the two currents allows active and reactive power to be managed. The outer loop of voltage voltage is applied to the capacitor to create the current reference needed for the active-power flow in the d-axis. If you work with unity power factor, the q-axis reference current will be set to zero since it represents the intended reactive power the inverter is injecting to the grid. By using the PLL block, you can find the grid voltage phase angle, θg, to do Park conversion and set the timing of the inverter to match the grid.

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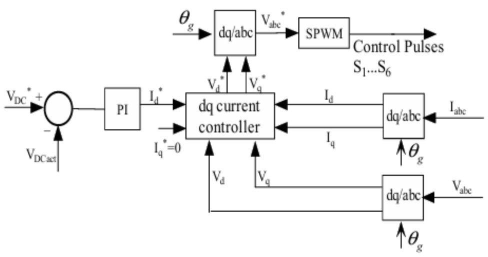

Fig.5 control scheme of the grid-side converter

V RESULTS AND DISCUSSIONS

All the systems are modeled with Matlab/Simulink using the discrete type of simulation. How the system is modeled in Matlab/Simulink is shown in Fig. 4. The simulation used these system parameters: DFIG Parameters: These are the numbers for Stator Phase Resistance=0.023Ω, Inertia = 0.685Kg-m2, Rotor Phase Resistance =0.016 Ω, Rotor Phase Inductance=0.16mH, Magnetizing inductance=2.9 H, Pole pairs = 3, Pout=1.667MW, Vwrated=12m/sec. Three examples and different loads will be used in the simulation study.

Case 1: A Simulink model from Chapter 9, Part II that does not include STATCOM, with just RLC load. IEEE Std. 1547-2003 states that the load in Fig. 6 is an RLC load with a THD less than 5%. As we see from Fig.7, the distortion is higher than what is allowed standards. With stronger winds, the rotation of the turbine is reduced. Consequently, the amount of power coming from the wind system and the inverter's current is reduced. To deal with the shortfall, a STATCOM is required to keep up with the demand.

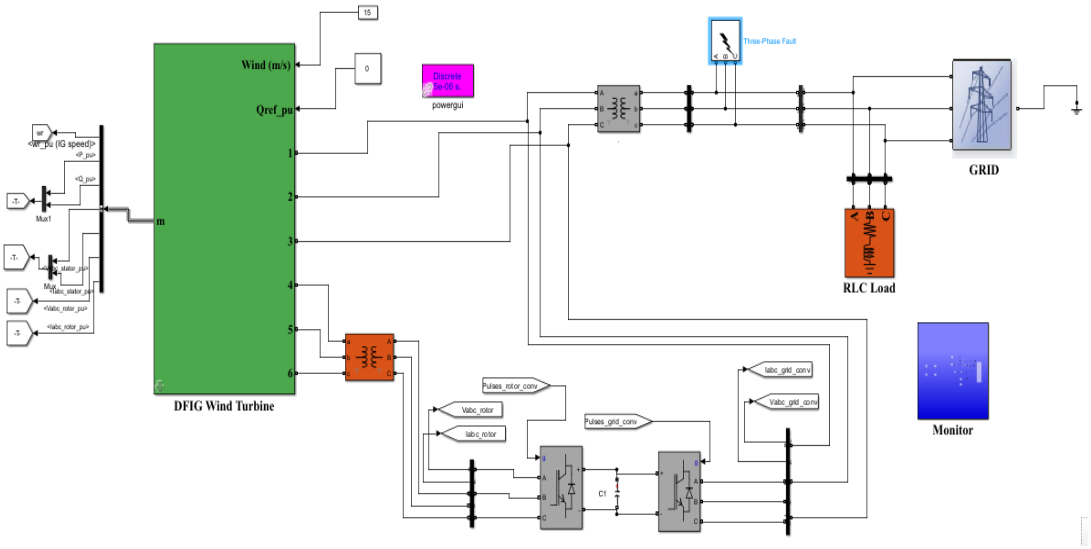

Fig. 6. Simulink model without STATCOM with RLC load

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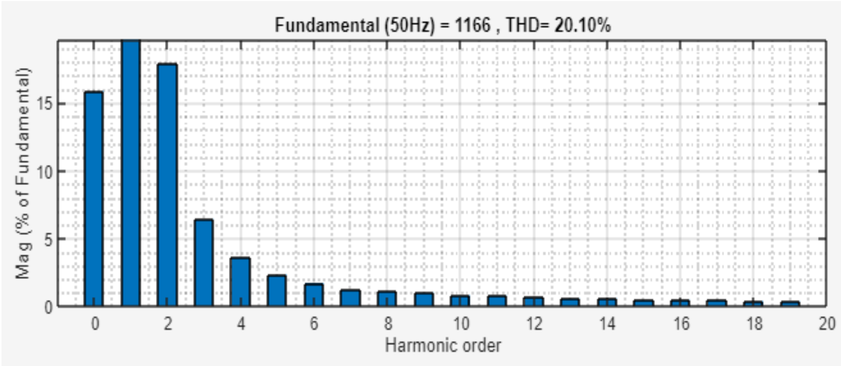

Fig.7 THD analysis of current without STATCOM

Case 2: Simulink model with STATCOM with RLC load

In Fig. 8, one can see the Simulink model of WECS paired with STATCOM supplying power to the connected grid and RLC load. The variation of stator voltage, inverter output voltage, active power, reactive power, wind speed, bus voltage, and output current's percent variation in time is depicted in Fig 9. As you can see from Fig. 10, the harmonic distortion of the model is at 2 %, which complies with the required standard.

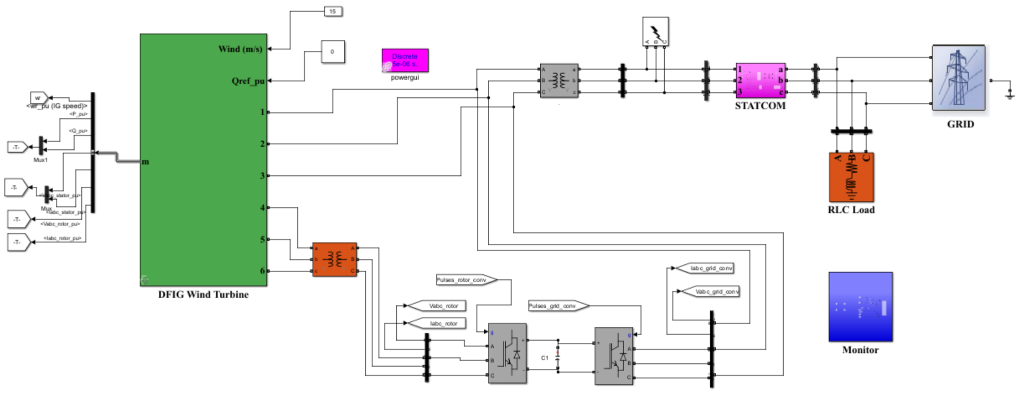

Fig.8.Simulink model with STATCOM with RLC load

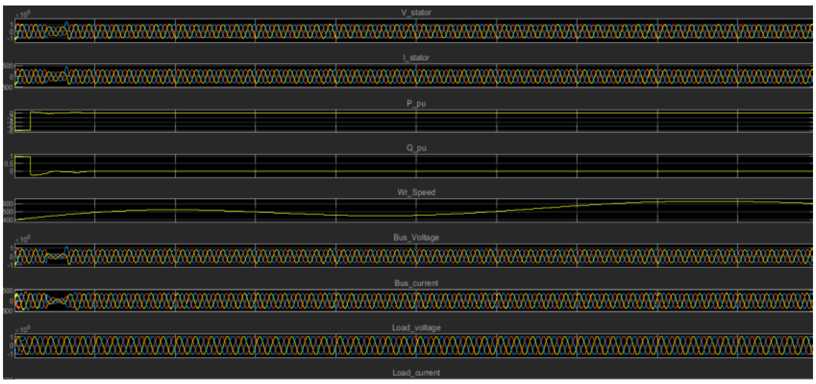

Fig.9.Output waveforms of P, Q, I, V with STATCOM

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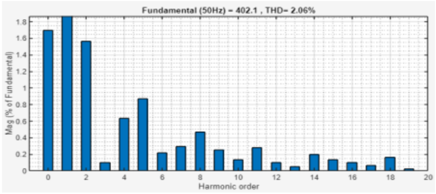

Fig. 10.THD analysis of current with STATCOM

Case 3: Simulink model without STATCOM with Inductive load

An inductive load is added to the model of WECS without STATCOM. In Fig 9, we see the computer simulated results for stator voltage, output voltage, active power, reactive power, wind speed,bus voltage and the change in the percentage of THD in the output current. The data in Fig. 12 clearly shows that harmonic distortion in the proposed model is as high as 28 %, so it exceeds the standard.

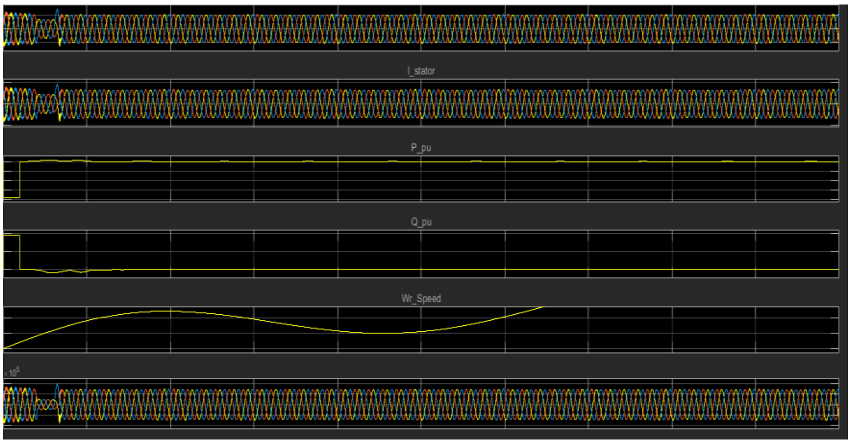

Fig.11 Output waveforms of P,Q,I,V without STATCOM with Inductive (Non-linear) load

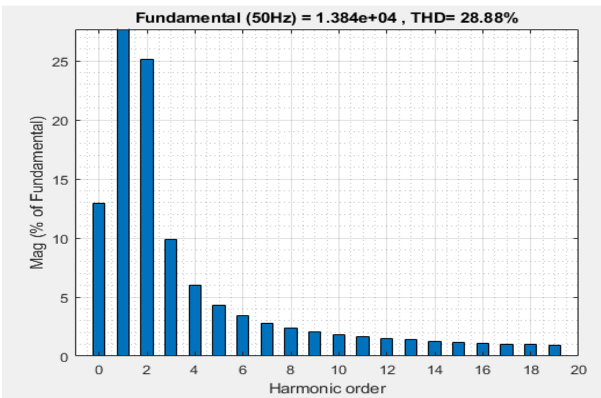

Fig. 12.THD analysis of current without STATCOM

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Case 4: Simulink model that features a STATCOM and an Inductive load

An inductive load is now hooked up to the grid, and a Simulink model of WECS with STATCOM is currently under development. Stator voltage, inverter output voltage, active power, reactive power, wind speed, bus voltage and percentage THD variation in output current can be seen in Fig13. The harmonic distortion plot in Fig. 14 shows that our proposed model is well below the allowed 4 % by standards..

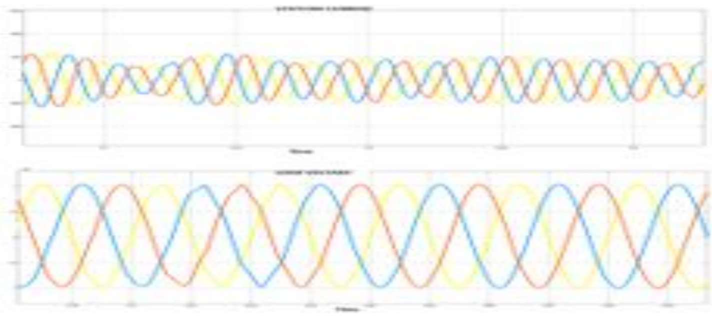

Fig. 13. Output waveforms of P, Q, I, V with STATCOM for Inductive (Non-linear) load

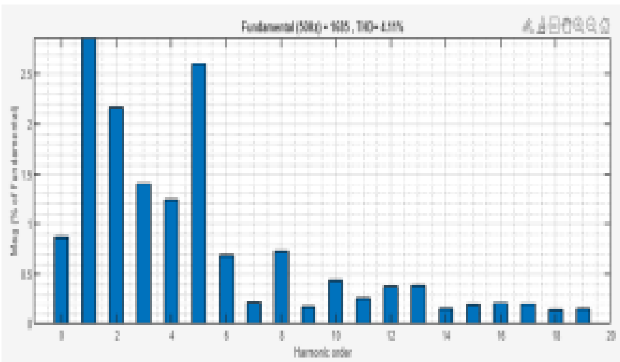

Fig. 14. THD analysis of current with STATCOM

TABLE I

THD analysis with different loads with and without STATCOM

Sl.No	Particulars (Current)	% THD
1	Without STATCOM with RLC load	20.102
2	With STATCOM with RLC load	2.06
3	Without STATCOM with Induction Motor load	28.89
4	With STATCOM with Induction Motor load	4.08

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VI. CONCLUSIONS

Analysis of various waveforms and testing THD with and without the presence of a STATCOM proves that the new system shows much better results. This technique works to solve power quality problems and also supports the world's efforts to adopt sustainable and eco-friendly energy solutions. It is stated in this paper that using an intelligent controller, ANFIS, along with a STATCOM and the KOA algorithm can improve power quality by increasing voltage stability and adjusting reactive power.

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