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A Hybrid Honey Badger-Anfis Approach For Statcom-Based Reactive Power Compensation In Microgrids

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Abstract
Maintaining voltage stability and power quality in microgrids powered by hybrid renewable energy sources (HRES) continues to pose a great challenge due to the intermittency and finger-like action of solar/wind energies. This paper proposed a hybrid control structure to optimize a Static Synchronous Compensator (STATCOM) for reactive power compensation using an Adaptive Neuro-Fuzzy Inference System (ANFIS) and the Honey Badger Algorithm (HBA). The hybrid HBA-ANFIS controller has the capacity to adjust the nonlinear parameters of ANFIS while improving the STATCOM's dynamic response to enable faster voltage regulation at the point of common coupling (PCC). MATLAB/Simulink was used to develop an extensive simulation model of a microgrid including solar PV, a wind-based doubly-fed induction generator (DFIG), and a diesel generator to test the proposed method. Performance comparisons were made with standard PI based controllers and other optimization-based adaptive controllers including PID-GA, PI-ACO, and MPA-PIDA based controllers to measure settling time, voltage overshoot, as well as overall efficiency of the system. The results showed that the HBA-ANFIS controller had the best performance with an overall efficiency of 99.1% and a settling time of 0.4671 s with a voltage overshoot of only 11% meaning it is viable for voltage regulation in intelligent microgrid applications of the future.
Keywords : *Honey Badger Algorithm, ANFIS, STATCOM, Reactive Power Compensation, Hybrid Renewable Energy System, Microgrid, Voltage Stability, DFIG, Solar PV, MATLAB/Simulink..*

I. INTRODUCTION

The universal demand for clean and sustainable energy has generated an enormous swing towards the use of renewable energy sources (RES) [1], “including, solar photovoltaic (PV) [2] and wind energy”. These are potential solutions to fossil fuel reliance and are environmentally sustainable; however, their uncontrollable variability yield challenges for reliable power generation and delivery systems. With RES [3], various complications, such as voltage fluctuations, frequency instability, and power quality disturbances, emerge, particularly in microgrids. As microgrids are recognized for their decentralized nature to correctly deliver electricity, there is a need for reliable control methods to operate the microgrid in a stable fashion even with the fluctuating nature of RES. Hybrid Renewable Energy Systems (HRES) [4], which consist of combinations of sources “(such as solar, wind, and diesel generators)”, will help eliminate the indecisiveness of one of the sources. HRES can help maximize reliable and uninterrupted fluid electricity supply by allowing generation from the RES be complemented through dispatchable back-up generation when RES generation is insufficient.

The integration of disparate energy sources, especially intermittent ones such as PV and wind, presents distinct dynamic and control challenges and issues. A primary way to quantify some of these challenges is through maintaining PCC voltage stability, which is imperative to run microgrids efficiently. Flexibly AC Transmission System (FACTS) [5] devices have been successfully instantiated to meet these challenges, as in the case of the Static Synchronous Compensator (STATCOM) [6]. The STATCOM is particularly effective in terms of “dynamic reactive power compensation and voltage regulation in power systems with fluctuating loads or variable sourcing”. Performance or functionality in terms of STATCOM and its ability to react to microgrid dynamics is significantly affected, though, by its control. In clean-energy microgrids, gain sensitivity, such as would occur with traditional controllers like PI or PID [7], limits a control scheme's ability to react or maintain performance in regard to time-varying and nonlinear systems. To improve the dynamic performance of STATCOM, researchers and practitioners have paid following thematic concepts related to intelligent control. Among these concepts, the “Adaptive Neuro-Fuzzy Inference System (ANFIS)” [8] has been shown to be an outstanding approach for combining the learning ability of neural networks, and applicative aspects of fuzzy logic [9] reasoning. ANFIS is too, capable of modeling complex, nonlinear systems and adapt behavior through data. However, the performance of ANFIS[10] is very much dependent on effective tuning of the membership functions and static parameters of the network, as this requires a weight of challenge and computation. Metaheuristic optimization algorithms [11] with nature-inspired techniques have begun to mobilize researchers in achievements of upper dimensional, nonlinear optimization problems in a unique manner. The Honey Badger Algorithm (HBA)[12] is a comparatively newer "nature-inspired algorithm, one that is based on the foraging behavior of honey badgers" [13]. HBA certainly exhibits some level of exploitation and exploration capabilities and very fast convergence in objectives as well. Using the HBA in concert with ANFIS [14], fuzzy rules [15] and membership functions could then in fact be optimized dynamically, enhancing the overall performance of the STATCOM Controller [16].

This paper presents a hybrid control strategy that utilizes a "Honey Badger Algorithm-tuned ANFIS controller [17] for better performance of STATCOM operation in a microgrid which includes a hybrid renewable energy system" [18]. The hybrid system includes solar PV, a wind-based doubly-fed induction generator (DFIG), and a back up diesel generator. The aim of this work was to maintain voltage stability at the PCC [19] in light of varying loads and generation, thus achieving reliable and efficient microgrid operation and the proposed method is implemented and tested in MATLAB/Simulink and the results are compared with other traditional and optimization controllers.

So, the objectives of this research can be listed as ,

- To develop a hybrid renewable energy system (HRES) including solar photovoltaic (PV), wind (DFIG), and a diesel generator to generate reliable power.
- To evaluate voltage stability at the point of common coupling (PCC) in the microgrid, based on load and generation scenarios.
- To incorporate a STATCOM device to provide dynamic reactive power compensation in the hybrid microgrid.
- To develop an intelligent "Adaptive Neuro Fuzzy Inference System (ANFIS)" controller to optimally and efficiently control the opening of the STATCOM operation is stated as an objective.
- To utilize Honey Badger Algorithm (HBA) to optimize the ANFIS controller as a way to get a more accurate controller with a substantially faster response time.
- To compare "the efficiency and performance of the proposed HBA-ANFIS controller to other control methodologies" such as PI- ACO, PID-GA, and MPA-PIDA.
- To assess the performance of the system with respect to the settling time, overshoot of voltage, efficiency and computational time in MATLAB/Simulink simulations..

II. LITERATURE REVIEW

A three-phase reactive power compensation model of the power system networks is proposed with a technological combination of Static Synchronous Compensator (STATCOM) by A. M. Galadima (2025) [20]. The constructed STATCOM device with MATLAB/Simulink, is shown to use inverted signals based on the instantaneous reactive power theory and equalize exactly the load's capacitive currents in order always ameliorate to unity of power factor despite of variable loads. The system exhibits an excellent power quality improvement as the total harmonic distortion (THD) is reduced from 14.22% to 0.22%, lower than that required by IEEE 519 standards, respectively confirming STATCOM effectiveness for both improving PF and mitigating harmonics in present distribution systems. Dr. N. Dharani Kumar, et al. (2025) [21] objects to a new control strategy for improving the power quality at point of common connection (PCC) in isolated photovoltaic-wind microgrids with machine learning-based approach using ANFIS controllers. Superimposing supervised, deep and reinforcement learning in the control architecture allows our system for enhancing voltage stability, dynamic power dispatching efficiency as well as guarantee of good quality electric power. Simulation results indicate that the MLCC significantly surpasses conventional ANFIS approaches in terms of both THD reduction and dynamic response speed as well as operational efficiency, which corroborates a promising prospect toward smart microgrid control. Khaled Sh. Gaber (2025) [22] summarizes significant, recent approaches in HES design and integration with special attention to the contribution of high-end optimization algorithms toward renewable energy exploitation (Gaber 2025). The paper highlights the increasing role of artificial intelligence, ML and predictive resource management in driving flexibility and sustainability. Considering practical obstacles including scalability, integration complexity and costs, the review shows how HES can significantly enhance grid performance and efficiency when guided by advanced optimization approaches while contributing strongly to global sustainability related targets in an efficient way; thereby closing some emergent technical gaps within various decentralized multi-source renewable energy systems. E. Hosseini,et al. (2024) [23] present multi-level and multi-objective mathematical models for optimal design of the hybrid renewable energy system (HRES), including advanced hybrid heuristic algorithms to address not only nonlinear, but also mixed integer-linear complex arrangements among multiple RES technologies. The trade-offs between reliability, cost-efficiency and sustainability are modelled in a comprehensive manner. Through case studies, it is shown that the new hybrid algorithm has excellent flexibility and efficiency in practical renewable energy integration on a microgrid scale and thus has great potential to change modern generation management by reducing costs, emissions as well as enhancing reliability of power supply under the scenario of a mixed AC/DC grid. A. S. Satapathy, et al. (2024) [24] article presents a comprehensive literature on the vital importance of reactive power compensation in microgrids with focus on recent developments and unresolved issues related to voltage stability. The latter studies voltage regulation demands and overviews recent progresses for reliable/ high-quality microgrid operations, with a special emphasis on compensating techniques. X. Zhan et al. (2024)[25] coordinated control strategy of reactive power compensation for flexible distribution transformer is proposed to solve the problem of power quality in DG access network. The paper models the operation of flexible transformer and proposes a priority control method to provide maximum reactive power, verified by extensive simulations that show enhanced voltage stability and quality. A. Nigam (2024) [26] studies techniques of reactive power compensation under conditions at or close to convergence level in order to continue good quality and performance of distribution system. Different FACTS controllers are compared and the study emphasizes on the development of advanced compensation schemes in emerging grid scenarios. E. Alipour et al. (2024) [27] investigate enhanced frequency regulation in a PV-interfaced microgrid by employing higher order controllers. A new class of Recurrent Adaptive Neuro-Fuzzy Inference System (RANFIS) is proposed and dynamic simulations demonstrate that the RANFIS provides a significant improvement in frequency regulation under uncertain conditions, compared to traditional as well as deep learning-based control. M. Thiruveedula, et al. (2024) [28] An optimization algorithm for siting electric vehicle charging stations in radial distribution system based on the Honey Badger Algorithm (HBA). The proposed algorithm yield the optimal positions and capacities of charging stations, reducing power loss as well as voltage variation; also it was verified to be better than some existing or state-of-the-art algorithms. H. Bakir and A. A. Kulaksiz [29] devised four PI controllers, incorporated into the control circuit of the STATCOM, using optimization methods, GA and BFA. This hybrid approach substantially improved the voltage stability and dynamic response of a STATCOM subjected to the nonlinear operating conditions of a hybrid solar-wind energy system. S. Gandhar., et al. [30] “proposed a Unified Power Flow Controller (UPFC) to provide the flexibility of voltage regulation and mitigation of reactive power fluctuation in islanded microgrids”. H. Bakir and A. A. Kulaksiz [31] built on their work developing a more optimized STATCOM controller for a Renewable Energy System (RES) with wind and solar PV sources.

M. G. Yenealem., et al. [32] developed a STATCOM controller which combined Proportional-Integral (PI) and Fuzzy Logic (FL) controllers to improve flow in microgrids by reducing power losses. M. I. Mosaad., et al. [33] sought to optimize the operation and performance of hybrid systems that “included PV and wind energy systems with the use of a STATCOM.” S. Rajendran., et al. [34] provided a hybrid STATCOM controller using the combinations of Particle Swarm Optimization (PSO) controlling a Sliding Mode Controller (SMC) and LCL filter to overcome the issue of power quality through reduction of total harmonic distortion and optimization of the power factor. A. A. Nafeh., et al. [35] used intelligent fuzzy logic to implement fuzzy controllers in AC-DC Micro Grid systems to enhance the voltage stability and improve the power quality.

III. RESEARCH METHODOLOGY

System Design and Architecture

The proposed system consists of a “hybrid renewable energy system (HRES) as a combination of solar photovoltaic (PV) [36], wind-based doubly-fed induction generator (DFIG) [37], and a diesel generator (DG) connected as a Point of Common Coupling (PCC)”. The solar PV output is unidirectional current or DC output, which was then converted into three-phase AC output via a Voltage Source Inverter (VSI), and passed through a step-up transformer and connected to the PCC. The wind subsystem used a DFIG for its benefit of being able to maintain a constant output frequency while operating at a variety of wind speeds. The DFIG was interfaced into the PCC with use of back-to-back converters and a transformer.Because of variability and intermittency in the solar and wind energy sources, a diesel generator was added for backup power or continued supply [38]. The load on the system consisted of both balanced and non-linear components; where the non-linear loading simulated a common DC electric vehicle charging station.

Modeling of Solar PV System

The single diode model is chosen for the PV module modelling. "The current-voltage (I-V) characteristics of the PV cell are defined by:

$$I = I_{PH} - I_S\left[\exp\left(\frac{q(V + IR_S)}{AkT}\right) - 1\right] - \frac{V + IR_S}{R_{SH}}$$

where:

- I_{PH} is the photocurrent,
- I_S is the diode saturation current,
- q is the electron charge,
- A is the diode ideality factor,
- k is Boltzmann's constant,
- T is the temperature,
- R_S is the series resistance,
- R_{SH} is the shunt resistance."

Modeling of Wind-Based DFIG

The stator and rotor voltages in the synchronous d-q reference frame are given by:

$$V_s = R_s i_s + \frac{d\gamma_s}{dt} + j\omega_s \gamma_s$$

$$V_r = R_r i_r + \frac{d\gamma_r}{dt} + j(\omega_s - p\omega_r)\gamma_r$$

The flux linkages are:

$$\gamma_s = L_s i_s + M i_r$$

$$\gamma_r = L_r i_r + M i_s$$

where R_s, R_r are the resistances, i_s, i_r are currents, L_s, L_r are self-inductances, M is mutual inductance, ω_s is stator frequency, and ω_r is rotor speed.

Diesel Generator Modeling

The diesel generator operates when renewable sources are insufficient. Its power output is limited by:

$$0 \leq P_{BG} \leq P_{BG_{max}}$$

Its fuel consumption is modeled as:

$$F_{BG} = \alpha_0 P_{BGR} + \alpha_1 P_{BG}$$

where α_0 and α_1 are fuel coefficients, P_{BG} is the generated power, and P_{BGR} is rated capacity.

STATCOM Modeling

"The d-axis and q-axis voltages of STATCOM are given by:"

$$V_{dst} = K_{mst} V_{dc} \sin(\theta_{pcc} + \alpha_{st})$$

$$V_{qst} = K_{mst} V_{dc} \cos(\theta_{pcc} + \alpha_{st})$$

The DC capacitor dynamics are:

$$C_{dc}\frac{dV_{dc}}{dt} = \omega\left(I_{dc} - \frac{V_{dc}}{R_m}\right)$$

ANFIS-HBA Controller for STATCOM

ANFIS combines fuzzy logic [39] and neural networks. Its inputs are:

- Error in PCC voltage ΔV_{PCC}
- Derivative of error $\Delta V_{PCC}'$

The Honey Badger Algorithm optimizes ANFIS parameters by simulating foraging behavior. The update rule is:

$$x_{new} = x_{prey} + F\beta I x_{prey} + F r_3 \alpha d_i \cos(2\pi r_4)[1 - \cos(2\pi r_5)]$$

Here, F is a flag, β tunes solution quality, I is fitness, and r_3, r_4, r_5 are random numbers for exploration and exploitation phases.

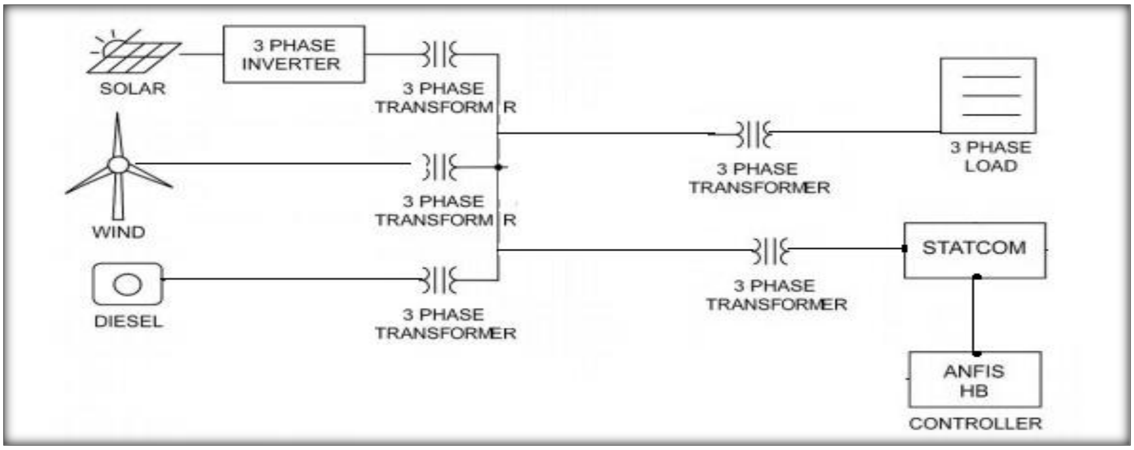

Figure 1. System Model Diagram

IV. Simulation Results and Discussion

The proposed hybrid power system was established "using MATLAB / Simulink to incorporate solar PV, wind generated via a Doubly Fed Induction Generator (DFIG), and a diesel generator system". These sources are physically located behind a common PCC through three phase transformers. The system adopts a Static Synchronous Compensator (STATCOM) device for voltage changes, and reactive power, and is governed by an Adaptive Neuro-Fuzzy Inference System (ANFIS) based on an optimization by the Honey Badger Algorithm (HBA) [40].

The solar PV system was modeled to operate under normal conditions at 1000 W/m² irradiance, and 25°C of temperature. The PV delivered an output voltage of approximately 950 V and an output power of roughly 1750 W. The various parameters of the PV module details can be seen in Table 1.

"Table 1: Photovoltaic (PV) Parameters

Parameter	Value
Open circuit voltage (VOC)	37.6 V
Short-circuit current (ISC)	8.55 A
Voltage at max power point (Vmp)	31 V
Current at max power point (Imp)	8.06 A
Maximum power	249.86 W
Temperature coefficient of VOC	-0.35°C
Temperature coefficient of ISC	0.06°C
Irradiance	250 W/m²
Temperature	25°C
Diode saturation current (IO)	2.0381e-10 A
Light-generated current (IL)	8.5795 A
Diode ideality factor	0.99766
Shunt resistance (Rsh)	301.81 Ω
Series resistance (Rs)	0.247 Ω

Figure 7 illustrates the MATLAB/Simulink model of the proposed hybrid renewable energy system, incorporating solar PV, a wind-based DFIG, and a diesel generator, providing the assets are combined together at the Point of Common Coupling (PCC) through three-phase transformers". The PV system extracts power from the sun to produce DC power (Ppv), then uses a voltage source inverter to convert the DC power to three-phase AC power to the PCC. The wind-energy system delivers regulated AC output using a DFIG that is interfaced via power electronics. The diesel generator, is standby in the renewable generation is limited. Where the combined generated power supplies 2 types of loads; a balanced three-phase linear load, and a non-linear load (i.e., electric vehicle charging). At the PCC, a STATCOM device provides reactive power compensation and voltage regulation to stabilize the system according to the voltage regulation demand. The STATCOM switching is controlled and coordinated by intelligent hybrid controller employing Adaptive Neuro-Fuzzy Inference System (ANFIS-HBA) which has been optimized incorporating the Honey Badger Algorithm (HBA) with PHI. ANFIS-HBA block utilizes voltage and currents signals received from electrical grid (from Grid, Ipv, ,Iwind, Idiesel), controlling the STATCOM device via pulse signals allowing for voltage stability maintaining quality power under variations of generation output and load require.The DFIG system was tested under variable wind speeds. It maintained a stable output frequency as speed varied from 15 rpm to 20 rpm. Table 2 provides the wind turbine parameters used in the simulation.

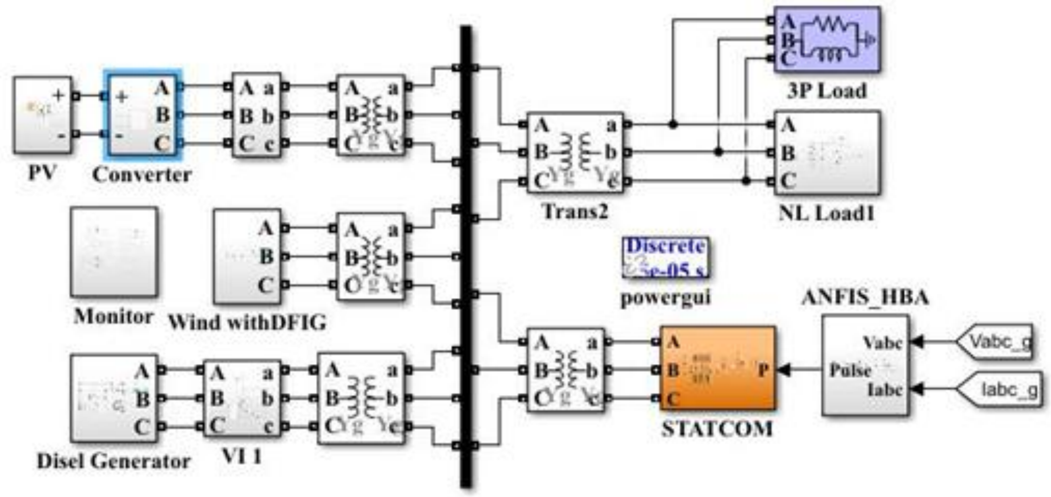

Figure 2. MATLAB / Simulink Model

The DFIG system was evaluated utilizing variable wind speeds. When speed varied from 15 rpm to 20 rpm, the output frequency remains stable. Wind turbine parameters used in the simulation are presented in Table 2.

"Table 2: Wind Turbine / DFIG Parameters

Parameter	Value
Inertia constant (H)	0.685 s
Friction Factor (F)	0.01 pu
Number of poles (P)	3
Magnetizing inductance (Lm)	2.9 pu
Stator resistance (Rs)	0.023 pu
Stator inductance (Ll_s)	0.18 pu
Rotor resistance (R'r)	0.016 pu
Rotor inductance (Llr)	0.16 pu

The diesel generator acts as a backup source and switches on when the supplied power from PV and DFIG is not sufficient". Its parameters are shown in "Table 3.

Table 3: Diesel Generator Parameters

Parameter	Value
Regulator gain	40 k
Engine time delay (Td)	0.024 s
Minimum torque (Tmin)	0 pu
Maximum torque (Tmax)	1.1 pu

Load conditions were modeled with a nominal phase-to-phase voltage of 25 kV, frequency of 60 Hz, active power of 30 MW, and reactive power of 2 MVAR (inductive). The system was then tested using three controller setups: basic STATCOM, STATCOM with ANFIS, and STATCOM with ANFIS-HBA".

Simulation plots confirmed that the ANFIS-HBA controller provided better control during voltage swell and load changes. Table 4 summarizes the performance comparison of the controllers based on Peak Overshoot Transient (POT), settling time, maximum voltage, and computation time.

"Table 4: STATCOM Controller Performance Comparison

Parameter	ANFIS-HB	PI-ACO	PID-GA	MPA-PIDA	IFOC
POT (%)	11	16.3	153	60.18	-
Settling time (sec)	0.4671	0.6373	1.6	-	1.2
Maximum voltage (V)	1.1	1.7	25	1.2	1.5
Computing time (min)	40	50	55	-	-

Also, the performance comparison of the various optimization methods was performed. The results displayed in Table 5 indicate that the ANFIS-HBA controller achieved not only the highest efficiency, but also the least CPU time to complete optimization.

Table 5: Optimization Techniques – CPU Time and Efficiency

Optimization Technique	CPU Time (min)	Efficiency (%)
ANFIS-HB	40	99.1
Pathfinder Optimization	58	87.0
Grey Wolf Optimization	53	89.3
Chicken Swarm Optimization	64	85.0

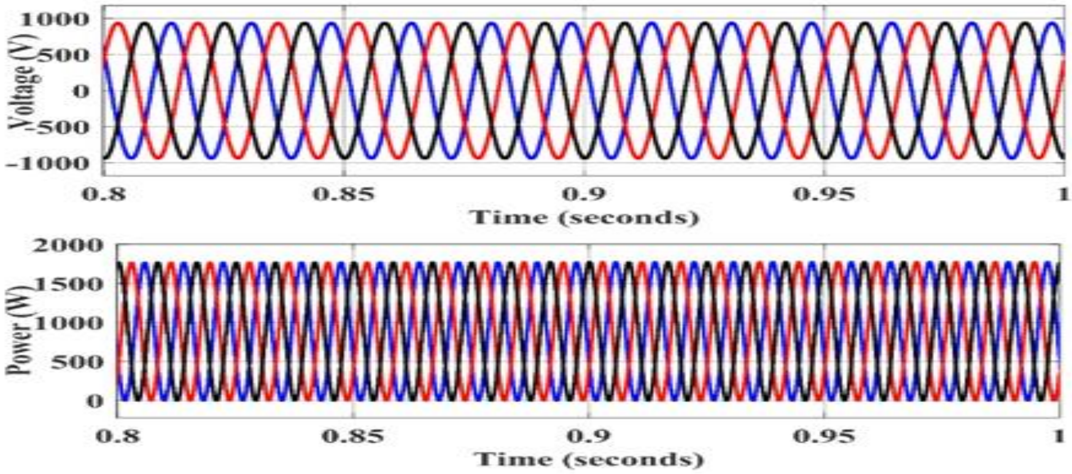

Figure 3: Voltage and Power Output from the Solar PV System”
Here, the Figure 3 , transient response of the solar photovoltaics (PV) system. The upper plot captures the three-phase AC voltage waveform after the DC-to-AC conversion with the voltage oscillating symmetrically between ±1000 V. This symmetrical oscillation shows that the inverter is operating under control; thus, the inverter is meeting demand. The lower plot shows instantaneous power output, where the waveforms osculate at double the system frequency that is likely related to the contributory reactive power component. The average power output of the solar PV system was about 1750 Watts, as a result, we are able to capture solar energy and successfully turn it into usable electrical power under standard irradiance conditions.

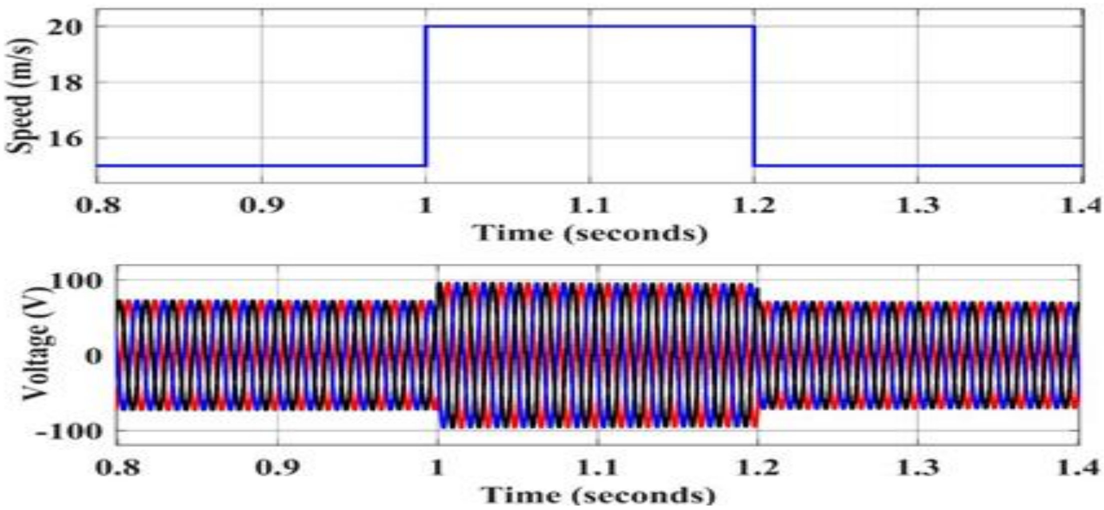

Figure 4: Voltage output from the DFIG under Variable Wind Speed Conditions
This figure 4 shows the output response from the wind based DFIG (doubly fed induction generator) under variable wind speeds. The upper plot captures the time based wind speed variations, starting at 15 m/s, rising to 20 m/s from 1-1.2 seconds, and declining back to 15 m/s. The lower plot showed different wind speeds, but the output provided by the DFIG was stable and the three phase voltages were constant and balanced. This outcome is significant because it indicates that the DFIG using wind energy is able to function under variable wind speeds while achieving consistent frequency and output stability.

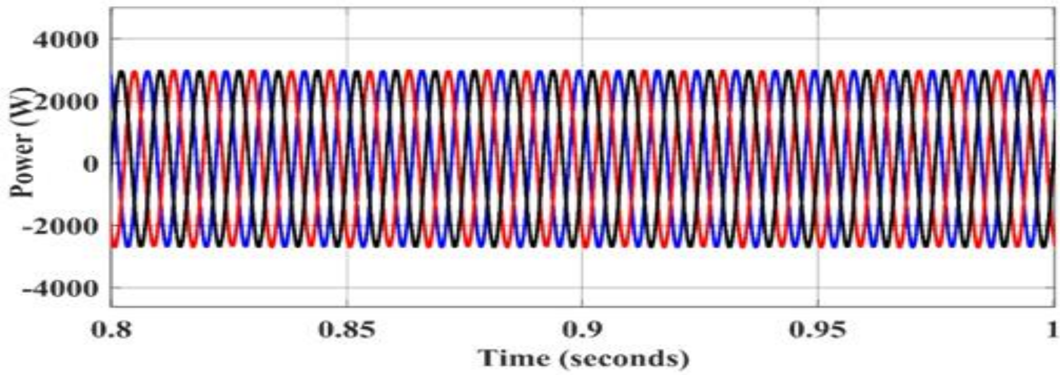

Figure 5: Output Power from Diesel Generator to Compensate Load Demand
Figure 5 illustrates the three-phase power output from the diesel generator in a situation where there is not enough renewable energy sources to fully compensate for the load. As shown, the waveform is fluctuating between ±4000 W, meaning we provide sinusoidal power to the PCC. The continuous and balanced waveform confirmed that the diesel generator provided adequate support to the hybrid system during struggling solar or wind energy. This backup generation allows the continuous flow of energy while providing a reliable alternative for the microgrid. In conclusion, the simulation results demonstrate that the proposed ANFIS-HBA controller offers superior performance in regulating STATCOM operation within a hybrid renewable microgrid. It reduces transiency, accelerates settling time, and optimizes voltage stabilization while maintaining computational efficiency. Compared to conventional methods and other metaheuristic approaches, the ANFIS-HBA method achieves better dynamic and steady-state behavior, making it a promising solution for intelligent reactive power control in microgrids.

"Table 6: Honey Badger Parameters

HB Parameter	Value
Population	50
Maximum iterations	100
Constant 'C' for getting density	2
Ability to get solution 'β'	6

Table 6 presents the main parameters adopted for the optimization of the Honey Badger Algorithm (HBA), being utilized in the proposed hybrid ANFIS-HBA-STATCOM controller". The parameters include a population size of 50 agents, a maximum of iteration (i.e., convergence) of 100 iterations, a constant C value of 2 for density calculations, and a solution-seeking ability factor β of 6. These initial parameters will help induce the searching behaviour of HBA during the search and subsequently help the ANFIS controller be tuned to maximize the performance of the STATCOM in regard to reactive power compensation.

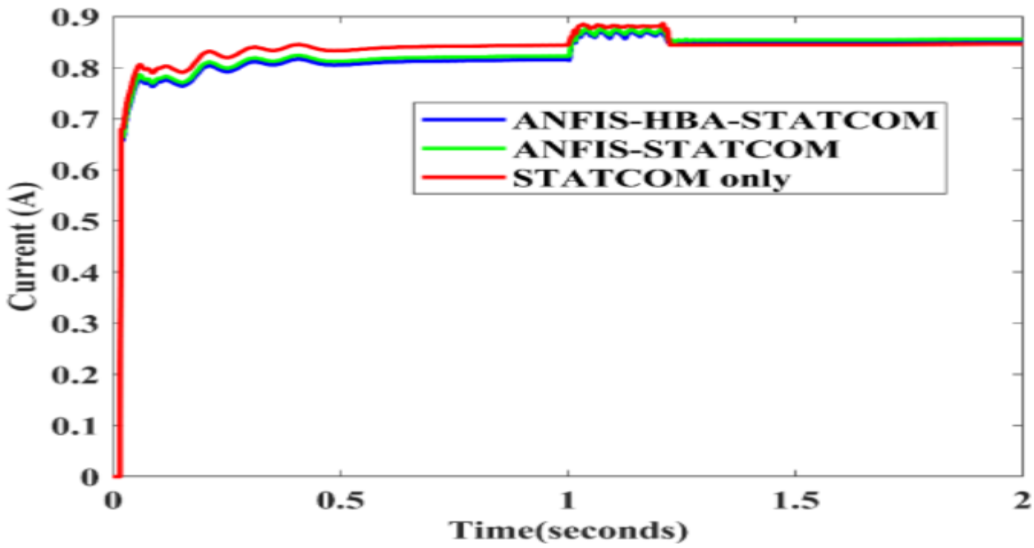

Figure 6: Current Response at PCC Using Different Controllers under Voltage Swell Conditions

Figure 6 depicts the current response at the Point of Common Coupling (PCC) for voltage swell conditions and shows the results of three separate control strategies: the first was the STATCOM only controller to benchmark, the second was the ANFIS-STATCOM controller, and finally the proposed ANFIS-HBA-STATCOM controller. The results illustrate that the controller proposed in this study (represented by the blue curve) demonstrated both a faster response and more stable current than the other control strategies. The current does not significantly rise during the transient, due to controller action; even fluctuating considerably during the disturbance from around 1 to 1.2 seconds, not accurately representing an actual disturbance transient, illustrating transition prior to returning to stable operation with minimal fluctuations. From the previous analysis, it is demonstrated that the HBA is ideal for optimal tuning of the ANFIS structure, allowing for sufficient control of the reactive power compensation to the STATCOM. Overall it can be stated that the hybrid controller allows for enhanced performance of the overall system, enhanced disturbances and transient to improve current regulation and allow for minimal transients during voltage disturbances.

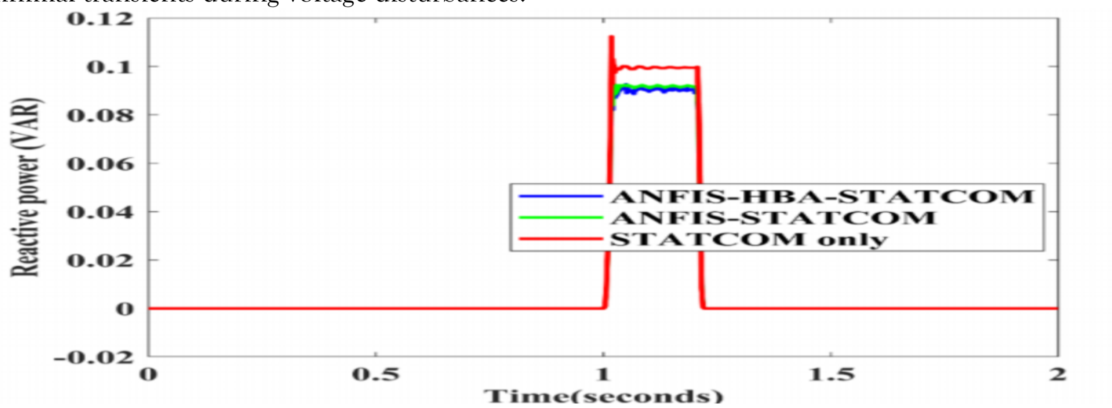

Figure 7: Reactive Power Absorbed by STATCOM with Different Controllers

Figure 7 shows the reactive power absorbed by STATCOM at the Point of Common Coupling (PCC) under a voltage swell condition with three different controllers (STATCOM alone, ANFIS-STATCOM, and proposed ANFIS-HBA-STATCOM). The graph clearly shows that the ANFIS-HBA-STATCOM controller absorbed the most amount of reactive power directly after the disturbance with improved voltage regulation. It shows a more immediate and stable response in reactive power as compared to the other two controllers. This performance leads to improved capacity to limit voltage overshoot, a reduced settler time, and better voltage stability. The graph depicts the benefit of a hybrid optimization-based controller regarding dynamic compensation and fast stabilization to the voltage disturbance.

V. CONCLUSION

This research proposed and realized a hybrid intelligent control strategy for reactive power compensation and voltage stability control of a hybrid renewable energy-based microgrid, comprised of "solar photovoltaic (PV) technology, wind-based Doubly Fed Induction Generator (DFIG) technology and a diesel generator connected to a common bus, where a STATCOM device was used to provide suitable voltage stability support". The STATCOM was controlled through Adaptive Neuro-Fuzzy Inference System (ANFIS) Control, while the parameters of the controller were optimized through "Honey Badger Algorithm (HBA), a metaheuristic optimization algorithm inspired by the foraging behaviour of honey badgers. Simulation studies carried out in (MATLAB/Simulink)" indicated that ANFIS-HBA controller provided far superior dynamic and steady state performance than traditional controllers (e.g., PI-ACO, PID-GA, MPA-PIDA, IFOC) in terms of reactive power compensation to provide voltage stability when there was load transients and time-varying generation. More specifically, ANFIS - HBA resulted in better peak overshoot, faster settling time and more voltage stability. Specifically, ANFIS-HBA exhibited system efficiency of 99.1% and settling time of 0.4671 seconds in comparison to all other compared approaches. Moreover, the inclusion of diesel backup allowed for no interruptions in power supply when the renewable sources experienced variability. Overall, the proposed technique has been successfully applied to implement intelligent reactive power control in smart microgrids and overall, improves the operational stability of hybrid-microgrid energy systems.

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