

A Novel Control Technique For Power Quality Mitigation Of Renewable Energy Based Microgrid System

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Abstract. The evolution of microgrids in power systems plays a significant part due to its lower pollution; diminished losses also provide flexible power to the customers. However, various technical issues arise due to the integration of microgrids with the variability of renewable energy systems. The power quality issues, such as voltage regulation and Total Harmonic Distortion (THD) are the foremost problems in microgrid coordination. For this reason, an innovative Hybrid Evolutionary Elephant Herd Fuzzy (HEEHF) optimization-based control algorithm has been developed for improving the quality of power in a microgrid. It combines the best features of Elephant Herd Optimization and fuzzy logic Controllers both for better system performance. The frequency and voltage of the system are regulated using this control method. The execution of this research was conducted using MATLAB/Simulink. The efficiency of the method has been tested under different power quality cases. The outcome from the simulation is compared with the conventional methods for validating the efficiency of the projected control technique.

Keywords: Microgrid, renewable resources, THD, EHO, Solar, Power Quality

1 Introduction

In recent times, the advanced power system network has played the main role in providing the required electricity to the customers. The generation of power can come from renewable as well as non-renewable resources [1]. However, due to the environmental pollution and global warming problem caused by fossil fuel burning, proper green energies have been developed. Therefore, sustainable and fresh energy from resources such as solar photovoltaic, wind, geothermal, biomass, water, and so on has been utilized [2]. Consequently, a minor power system has been developed to satisfy the electricity usage while there is no power in the grid, using various renewable energy resources. A microgrid is a less voltage-based power distribution network that is arranged depending upon the regulation abilities, rather than the major system, which creates power from the distributed generators, and also has supported loads [3]. Generally, the microgrid has been operated either in the grid-coupled model or the islanded model. Moreover, based on the system management, the reactive and active power can be transferred among grids in cooperation with grids in a grid-coupled model [4].

The grid with a distribution generation system provides significant enhancement in terms of reduced power loss in the distribution network, diminished carbon emission, improved efficiency, etc. [5]. Nevertheless, this has some crucial challenging tasks, such as fault range increases, regulation of voltage, and bi-directional power flow between the utility grid and microgrid. Consequently, the power quality problem in microgrid is a major challenge, including problems such as deviation of frequency and voltage, power changes, voltage swell/sag, pitiable power factor, and THD due to dynamic unbalanced nonlinear loads [6]. In electrical power arrangements, harmonics are a major problem, and this can increase the losses in transformers, also heating the neutral and panels, etc. [7]. Furthermore, voltage flicker is one of the problems associated with the quality of power

in a microgrid. This has been developed due to the sudden load current changes in the grid system [10].

Previously, various techniques have been proposed for mitigating the power quality problems, such as active, passive, and hybrid power filters [8], Transformer Integrated Filtering System (TIFS) [9], Unified Power Flow Conditioner (UPFC) [11], and Dynamic Voltage Restorer (DVR) [12]. However, the conventional methods are not optimally achieving the finest power quality improvement in microgrid systems in terms of stability, error, and so on [13]. This work developed an integrated method for the integration estimation of the finest power management operation in a microgrid coupled with the finest power quality solution. The hybrid evolutionary herd fuzzy (HEEHF) optimisation-based control method is developed for the distribution generation finest improvement. Simultaneously, the quality of power is monitored to maintain it within the IEEE range for distribution systems. The initial motivation for this work is the current improvement in modern technologies, like innovative automated methods that can improve the microgrid control method and operation to attain enhanced economic and operational objectives.

2 *Microgrid with Renewable Sources*

Solar photovoltaic (PV) (PV) and wind-based power generation are in high demand due to environmental conditions. However, fluctuations of power can be caused by the seasonal plant in the transmission of power and the distribution network. Therefore, Bakir, Hale, and Ahmet Afsin Kulaksiz [14] projected a new model of STATCOM integration in a hybrid form of wind with Solar PV with microgrid connection for a stable working limit. Moreover, the Bacteria Foraging Algorithm (BFA) and genetic algorithms (GA) are interconnected in STATCOM for PI controller parameters.

Bernardi, Emanuel, et al. [15] developed an optimization along with the control technique for sugarcane-based power plant industrial microgrid fault-tolerant power management. Furthermore, renewable energy systems are connected to this grid system under different load conditions and working constraints. Here, Moving Horizon Estimation (MHE) is developed to determine the fault, and Model Predictive Control (MPC) is created for fault-tolerant regulation objectives. However, the predictive control part is only applicable to the linear time-varying system.

The reliability and power regulation of renewable energy systems (RES) have been improved by the incorporation of Energy storage systems (ESSs). For this reason, Al-Ghussain, Loiy, et al. [16] projected a new model of investigation for the RES elements with different ESS conditions in grid systems via the estimation of the feasibility technique. Consequently, the electricity cost to the domestic tariff is estimated for the finest configuration of RES.

Benlahbib, Boualam, et al. [17] presented a new hybrid standalone-based microgrid system for remote area purposes. Consequently, the utmost power and speed from solar as well as wind are tracked by the Single Input Fuzzy Logic (SIFL) based control techniques. The State Of Charge (SOC) in the battery-based energy management method is proposed for the hybrid energy balance approach. Furthermore, a Proportional Integral (PI) based controller is applied for the voltage regulation in the AC system.

The renewable source with the distributed generation, power grid stability, and operation charges of the microgrid are the major challenges due to the fast increase of huge-scale renewable sources. For this reason, Jin et al. [18] developed a multi-agent system (MAS) along with game theory optimization for a microgrid. Moreover, the PSO algorithm is applied in the game theory Nash equilibrium. The profits of PV are increased up to 19%, wind turbine of 6% and micro gas turbine of 18% over the other methods.

The main contribution of this research is summarised below:

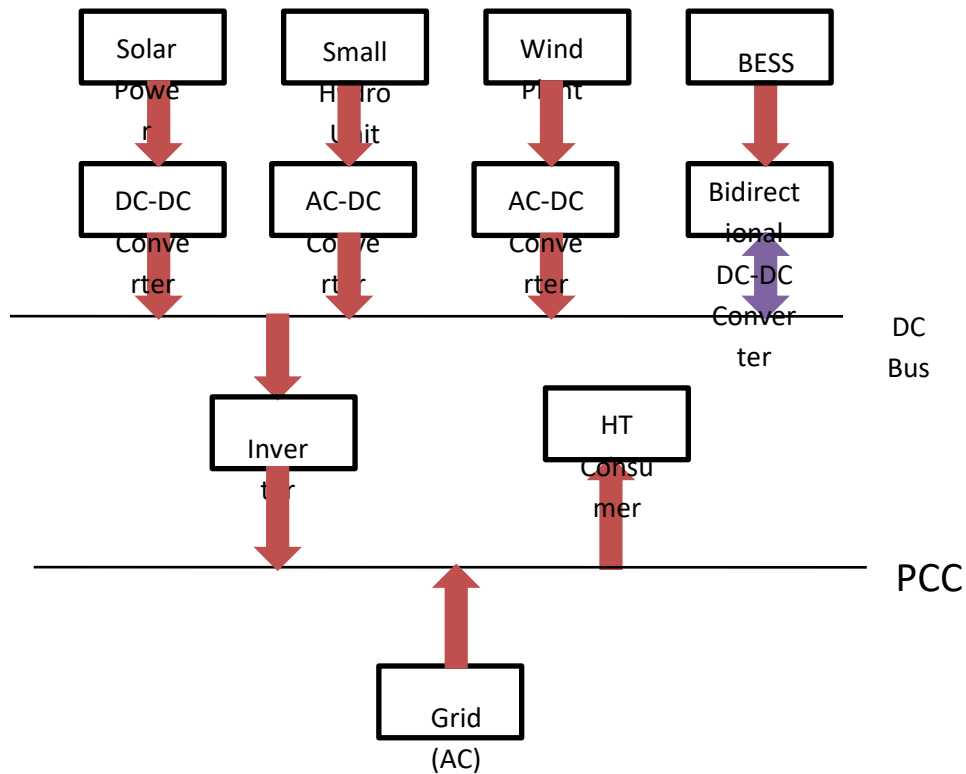
- Initially, the model of solar PV-based renewable sources for the microgrid is designed.

- Improve the quality of power in the microgrid, its THD reduction, and voltage regulation using the proposed novel HEEHF optimisation.
- Regulate the quality of power enhancement by the proposed controller to confirm the frequency and voltage regulation, even during rapid load changes and noise infusion.
- Finally, the proposed simulation outcomes are compared with different conventional methods for validating the efficiency of the proposed approach in a microgrid.

3 System Model and Problem Statement

The main significant components in the grid connection unit include hybrid RES such as solar and wind BESS, DC-DC converters, and bidirectional converters. The system model of grid-coordinated renewable energy is illustrated in Fig.1. The solar energy conversion is formed via PV panels, and the energy for the PV cells depends upon the temperature and solar irradiance. The PV array can deliver 10 kW in 1000 W/m² of solar radiation. Furthermore, the output power from the PV system is used to boost the PV array from a low output voltage to a high one using a DC chopper. Then the inverter converts the DC voltage into the AC voltage to the grid. The wind plant is coordinated with the grid system using an AC/DC converter. Moreover, the bidirectional converter is utilised to couple the energy storage system to the grid, which is AC in nature.

Fig. 1. System model of AC grid-coordinated renewable energy

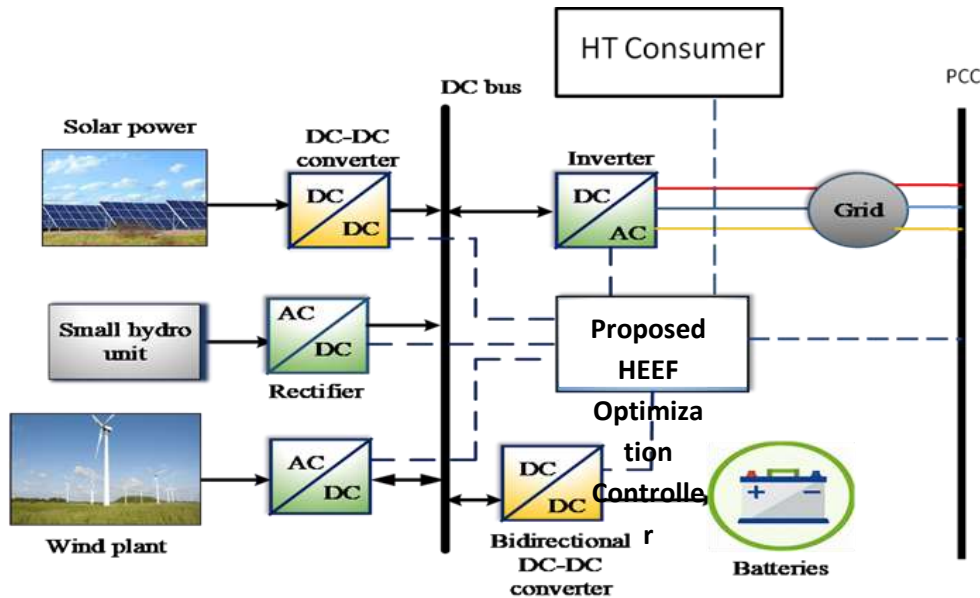


In recent times, the electricity demand has been increasing. So, the load demand must be satisfied to balance the system performance. Due to the over fluctuation of power demand in the distribution system, it produces problems in the quality of power, such as power loss, harmonic distortion, etc. This causes major problems for the grid system. Hence, this must be regulated in accordance with the standard level.

4 Proposed Methodology

The proposed HEEHF control technique integrates a hybrid evolutionary-based herd algorithm with a fuzzy-based control approach. This control algorithm is designed to enhance the performance of the grid system by minimizing both power loss and Total Harmonic Distortion (THD), ensuring that THD remains compliant with the IEEE 519-2014 standard. The step-by-step process begins with the initialization of real and reactive power values obtained from the renewable resource-based grid system. Next, all relevant system input parameters are collected and prepared for processing. The algorithm then evaluates the current state against predefined conditions derived from the evolutionary optimization. The proposed control method in the grid-coordinated system is illustrated in Fig.2

Fig. 2. System model of HT Consumer with AC grid-coordinated renewable energy with proposed system



4.1 Proposed HEEHF control method

The proposed HEEHF control technique is a combination of a Hybrid Evolutionary-based Elephant Herd Optimization algorithm and a Fuzzy-based control approach. EHO eliminates the minimal values of the power available from renewable sources and Fuzzy logic improves unbalanced system, reduces THD and The significance of the control algorithm is to improve the performance of the grid system in terms of reducing power loss as well as reducing the THD values. The THD value is maintained within the IEEE 519-2014 standard. Initially, the real power and reactive power from the renewable resources-based grid system are initialized. Then the input parameter of this system includes all values. The condition has been given to the proposed algorithm based on the evolutionary approach. HT consumer is fed by the renewable sources and proposed system is model is connected to the Point of Common Coupling. The various quantities of all the resources and the HT consumer and grid are initiated in the coding

The output of solar Power is as follows:

$$P_{pvout} = P_{N-pv} \times \frac{G}{G_{ref}} \times [1 + ((T_{amb} + K_t(0,0256xG)) - T_{ref})]$$

Where, P_{pvout} is output power of PV (kW), P_{N-pv} is rated power under reference, G is Solar radiation (W/m^2), G_{ref} is $1000 W/m^2$, K_t is $-3.7 \times 10^{-3} (1/^\circ C)$, T_{amb} is ambient temperature, and T_{ref} is $25^\circ C$.

The output of wind power is as follows:

$$P_{w-out} = \frac{1}{2} \times \rho \times A \times V^3$$

Where, P_{w-out} is power output of wind plant (kW), ρ is air density (Kg/m^3), A is swept area of the turbine blades (m^2), V is wind speed (m/s)

The power output of small Hydro-Electric power plant is as follows:

$$P_{H-out} = Q \times H \times \eta \times 9.81/100$$

Where, P_{H-out} is the power output of small Hydro-Electric power plant (kW), Q is the flow rate (m^3/s), H is the net head (m), and η is the turbine efficiency.

The output from battery is taken as P_{B-out} in kW.

The mathematical representation of the clan updating operator is as follows:

The genetic operator function has been applied using the equation (1),

$$G = p_{m,n} \dots \dots \dots n \quad (1)$$

The fitness of each power value is expressed by the equation (2).

$$p_{new_m,n} = p_{old_m,n} + b \times (p_{best_m,n} - p_{m,n}) \times q \quad (2)$$

Where, $P_{new_m,n}$ is the new position of the power value is denoted as with the particular location to a bus, $P_{old_m,n}$ is the old position of the power value is denoted as with the particular location to a bus, the finest bus herd in the location is referred to as $P_{best_m,n}$, the scaling factor is represented as that belongs to also q belongs to $[0,1]$. The finest value is estimated by the equation (3).

$$p_{new_m,n} = \alpha \times p_{center_m,n} \quad (3)$$

The membership function for the current controller is expressed by the equation. (4)

$$\beta(C_i) = \begin{cases} 1 - |C_i - d|/e_h & a \in [d, d + e_h] \\ 1 - |C_i - d|/e_l & b \in [d - e_l, d] \\ 0 & otherwise \end{cases} \quad (4)$$

Where, e_l and e_h are the low error and high error of the key values, respectively. Then the weights of the error values are updated. The fitness function of the system is applied based on the threshold estimation.

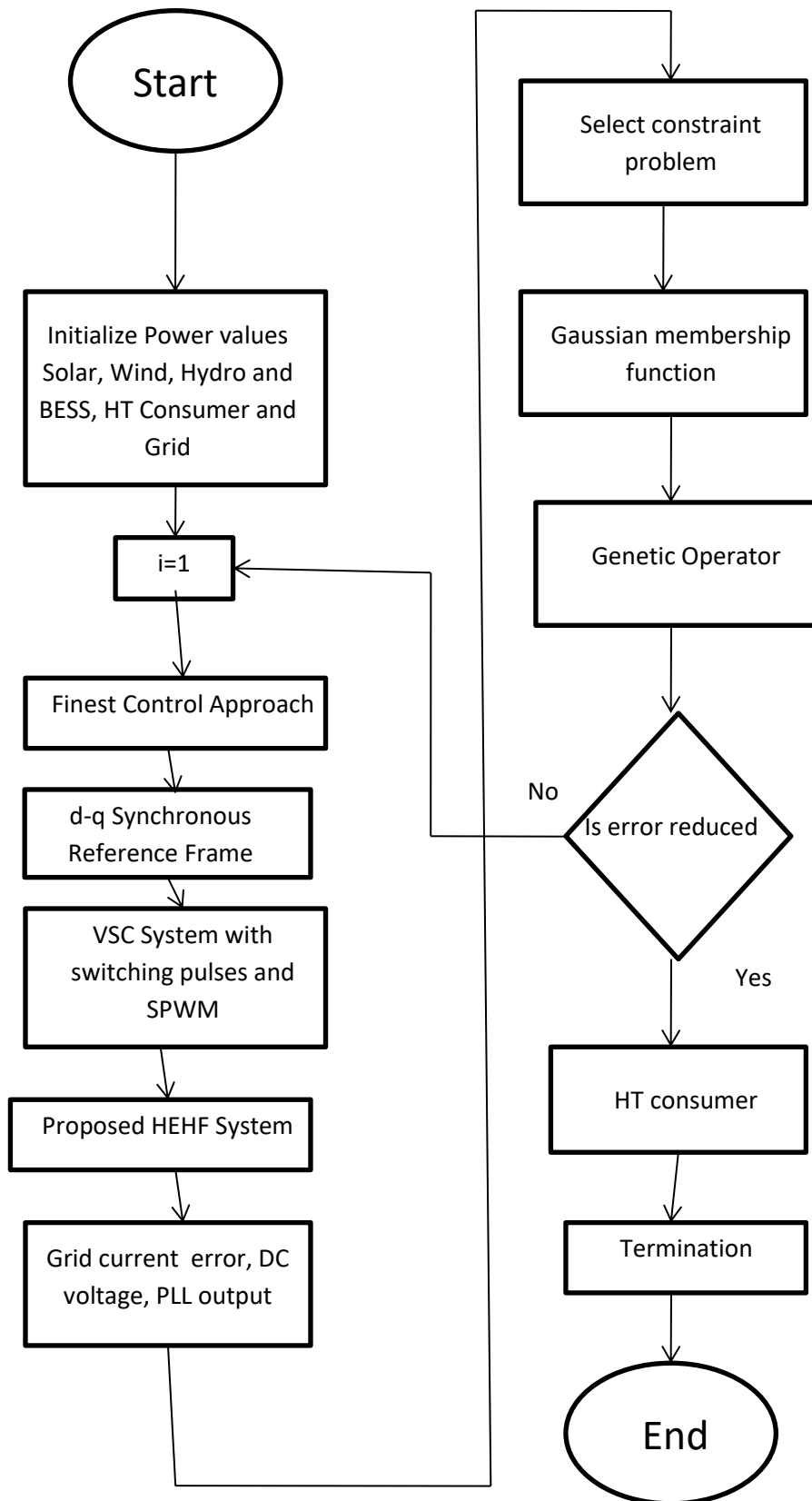
The separating operator is defined as follows:

$$\text{If } V_{dc}H > V_{dc}L, R_u \text{ is diminished, } R_u(u+y) = (1 + \frac{V_{dc}H - V_{dc}L}{y})R_u(u) \quad (5)$$

$$\text{If } V_{dc}H < V_{dc}L, R_u \text{ is enlarged, } R_u(u+y) = (1 + \frac{V_{dc}H + V_{dc}L}{y})R_u(u) \quad (6)$$

Here, the sensitivity threshold is denoted as y and represents the number of threshold limits. Once the output is optimized, the controller stops the process; otherwise, it repeats the process till a significant outcome is reached. The Overall workflow of proposed control method in grid coupled system is illustrated in Fig.3.

Fig. 3. Overall workflow of the proposed control method in the grid-coupled system



5 Result and Discussion

The implementation of this work is done using MATLAB/Simulink on the Windows platform. The novel HEEHF control method is developed in the microgrid system for removing the THD and power quality frequency as well as voltage regulation problems and unbalance in the systems. The validation of this research is verified using the consequences such as THD, active power, renewable power, error, and so on.

5.1 Case study

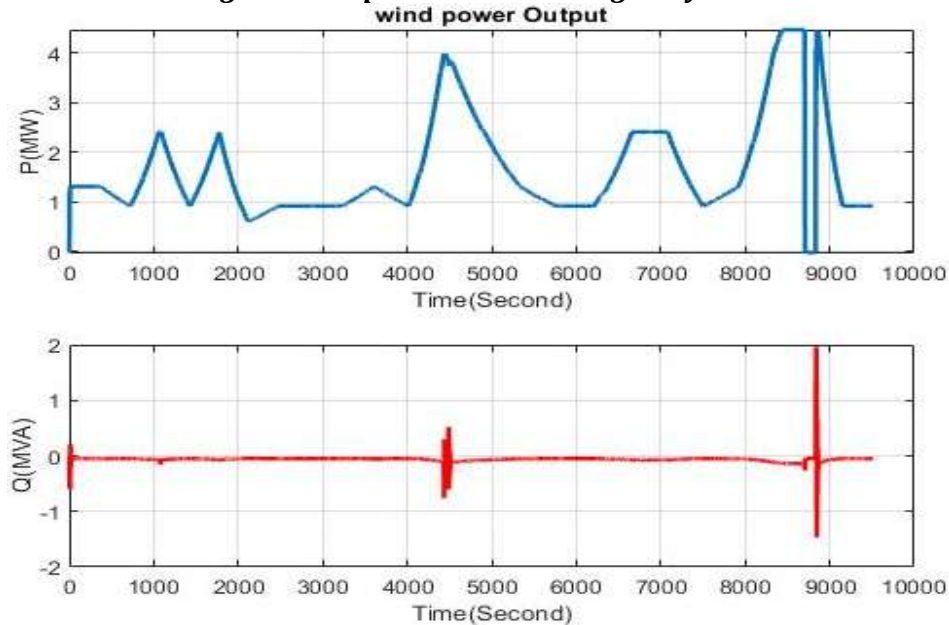
Consider the PV, hydro, and wind-based renewable energy system connected to the microgrid system. Table 1 is the data used for the case study for an HT consumer in the Distribution system.

Table 1. Data used for simulation

Parameters	Values
Voltage Source (LL)	415, 50 Hz
Current in R-phase	60 A
Current in Y-Phase	45 A
Current in B-phase	65 A
Internal impedance of voltage source	1 ohms, 0.03 mH
THD in voltage	327.69%
THD in current	327.69%

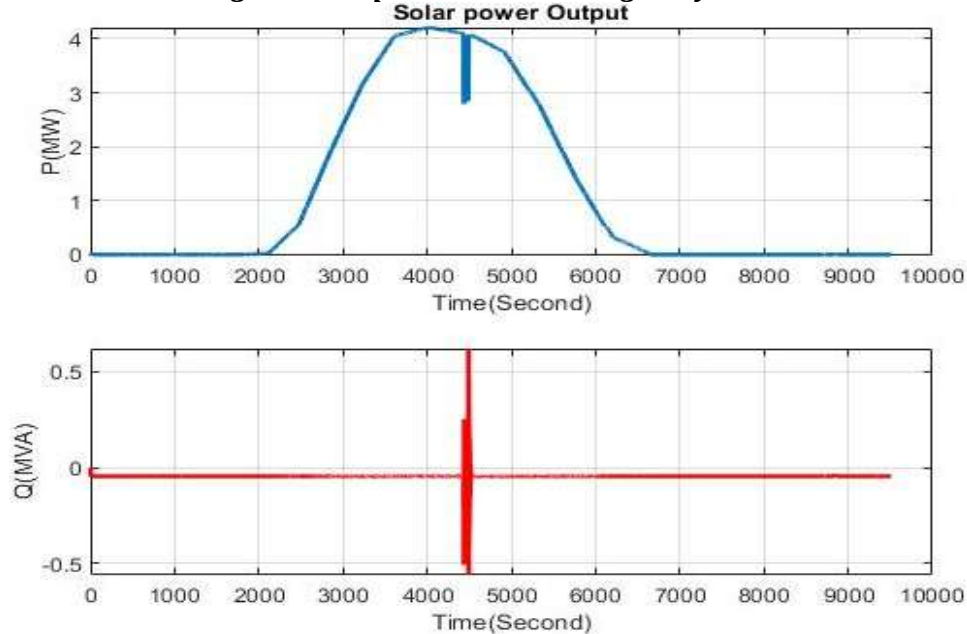
In that, the VSC is applied for the grid incorporation with the renewable resources. Here, the power quality problem arises due to the improper voltage and frequency regulation of the system. Thus, the novel HEEHF control method has been developed for the VSC system. The real power and reactive power of the scheme and the DC voltage, PLL output, and frequency parameters are initialized to the HEEHF control method.

Fig. 4. Wind power in the microgrid system



The input value has been trained using the genetic operator function using the equation. (1). Then, the trained data is given to the equation. (3) for validating with the fitness function. If the fitness function is high, then the system is normal; otherwise, the system is abnormal, and the error rate is estimated. Then, the calculated error value is categorized by the membership function, which is evaluated as low or high error for the current controller function. Then, the overall error value weights are updated. Afterwards, the fitness function of the system is applied based on the threshold estimation. If the condition is true, the error value should be controlled; otherwise, the normal function can be done. The process can be repeated till the finest solution is achieved. The designed system has attained wind power of 4MW, which is illustrated in Fig.4.

Fig. 5. Solar power in the microgrid system



The observation of wind power in the microgrid system shows the variation of power over a 0s to 10000s time period. Moreover, the solar power of the microgrid system is estimated that be shown in Fig.5. The initial power of solar is 1MW at the time of primary seconds. After increasing the time period, the power value is increased to 3.5kW at 4000s. Furthermore, the hydro system incorporated with the microgrid and its power value is calculated that as demonstrated in Fig.6. Here, the power value is attained as 5MW at the 10000s time interval. The observation clearly demonstrates that the output of reactive power is highly diminished, and this can improve the power factor of the system and enhance the power quality.

Fig. 6. Hydro power in the microgrid system

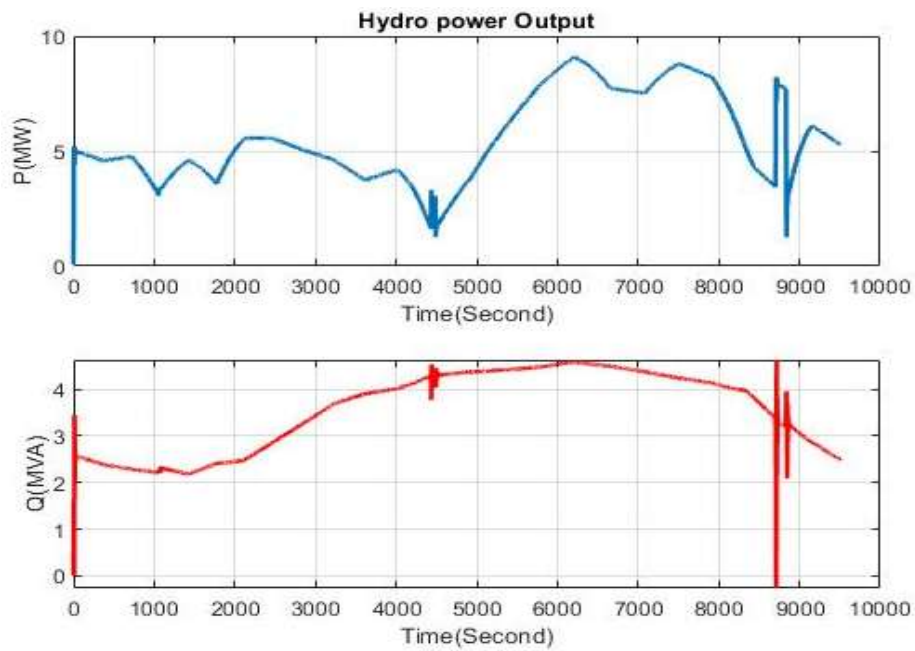
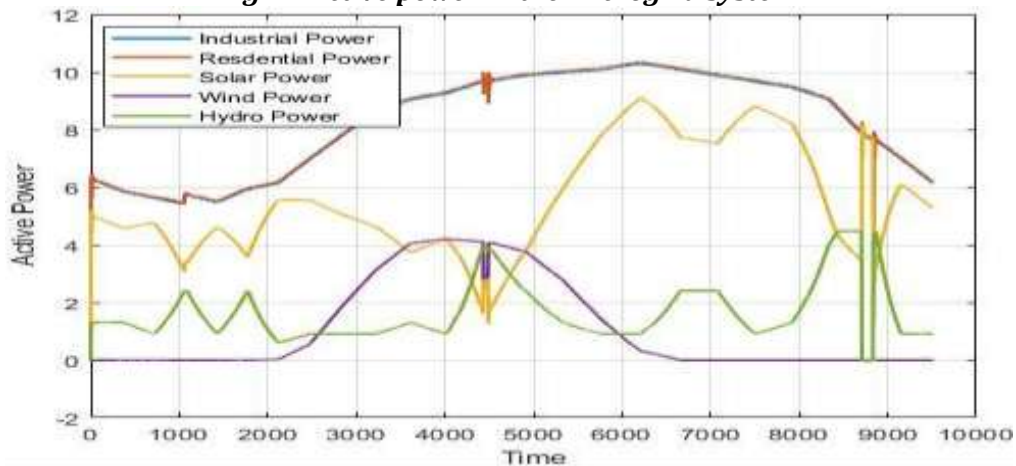


Fig. 7. Active power in the microgrid system



The active power obtained from the grid system is illustrated in Fig. 7. Initially, the real power is decreased from 0.9 MW to 10 MW at 3000s. After enclosing the proposed control approach, the real power has been improved to 10 MW at 10000s. The HT consumer's industrial and residential load power is denoted in Fig. 8a and Fig. 8b.

Fig. 8 (a) Active as well as power in the industrial load system

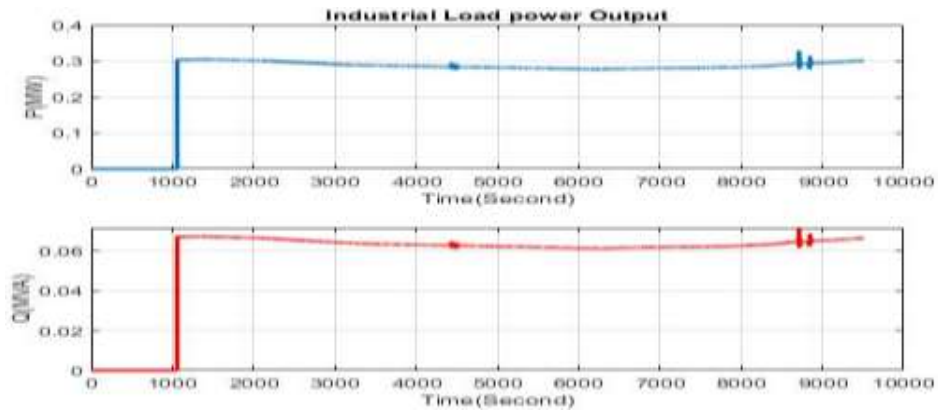
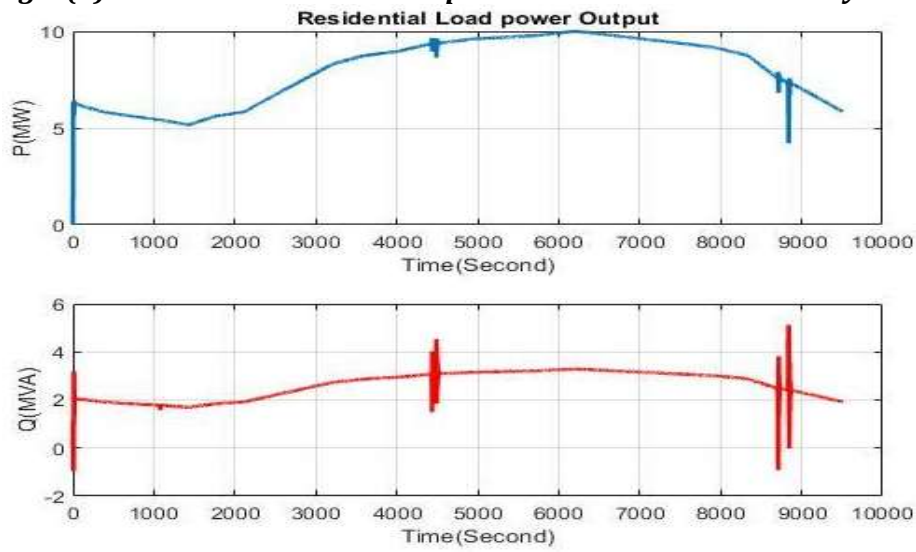
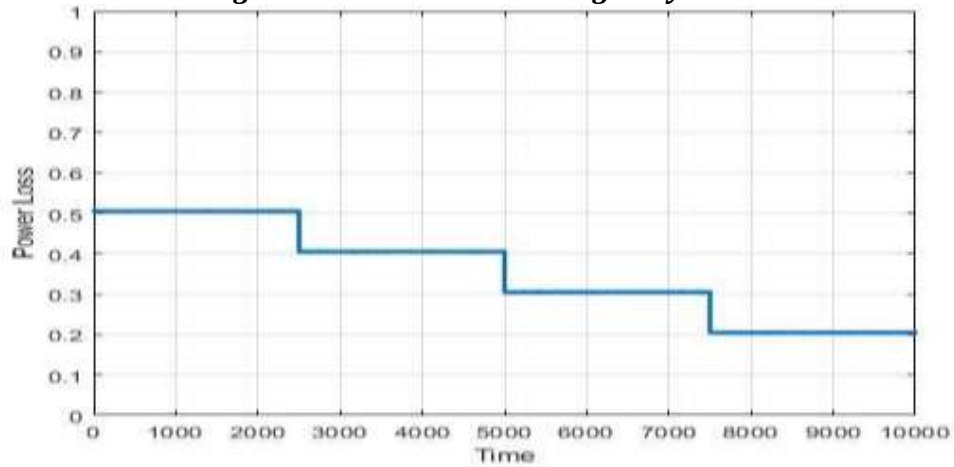


Fig. 8(b) Active as well as reactive power in the residential load system



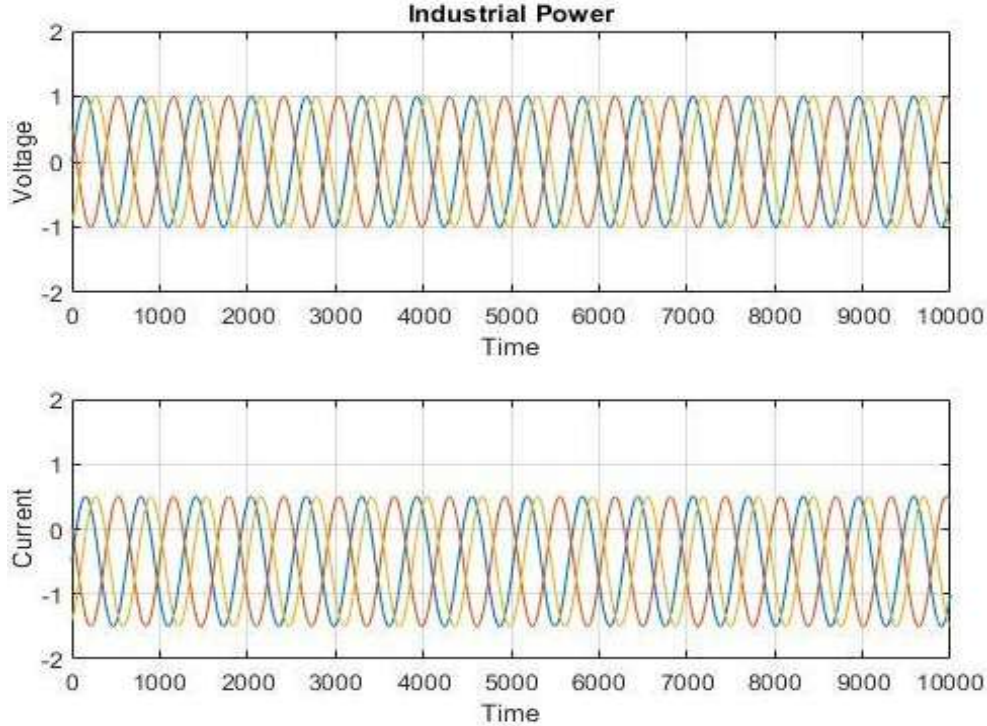
Moreover, the power loss from the proposed microgrid system is estimated, which is illustrated in Fig.9. Here, the obtained power loss is 0.2 MW, which shows the effective performance of the proposed HEEHF control method.

Fig. 9 Power loss in the microgrid system



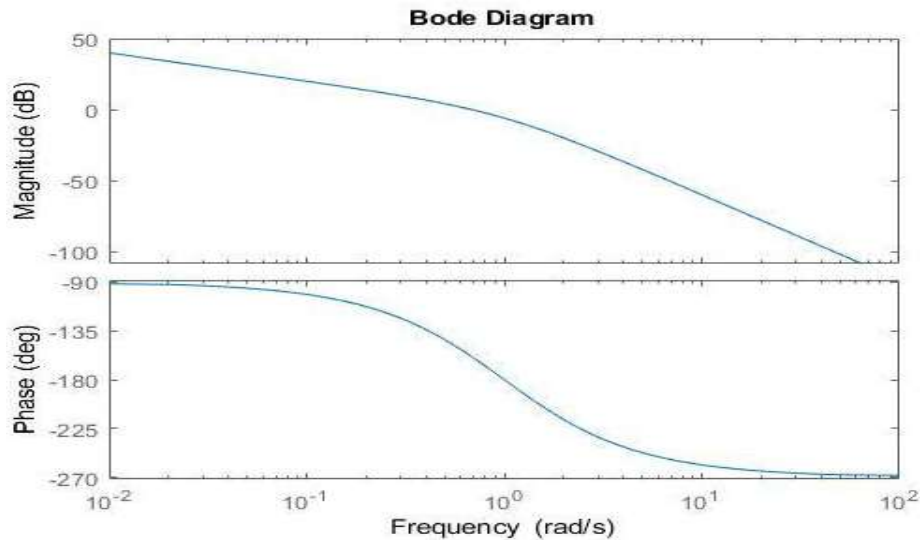
The voltage of the grid system is regulated by the proposed system that is shown in Fig. 10. The regulated voltage is maintained constant in the range of 1.3V, and the current is maintained at 0.05s till 10000s.

Fig. 10 Voltage and current regulation in the microgrid system



This investigation provides the stability analysis of the projected control method in a microgrid system. All parameters of the controller are optimized to improve the power quality of the scheme under changing load conditions, which does not influence the stability of the system. The proposed Bode plot for stability analysis is illustrated in Fig.11.

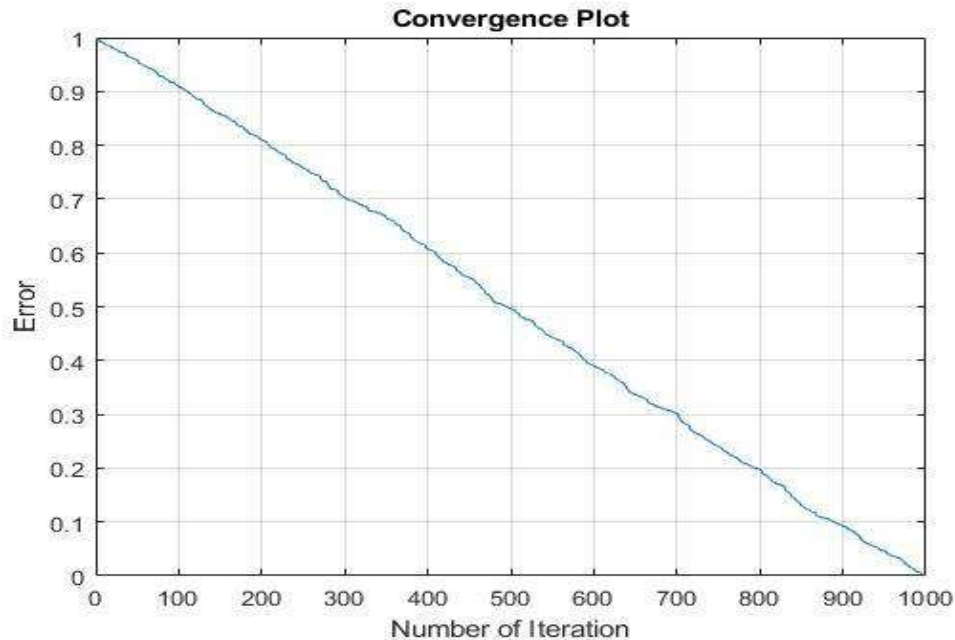
Fig. 11 Bode plot for stability analysis



The positive gain margin is infinity, and the phase margin is 140° . Thus, the increased phase and gain margin effectively improved the stability of the system. Moreover, the

Error value obtained in the proposed system is demonstrated in Fig. 12. The achieved error percentage is 0.002%.

Fig. 12 Error value obtained in the proposed system



The response of the HEEHF control method is to regulate the voltage of the system. Thus, the phase error, individual harmonics are estimated, which confirms the frequency and voltage regulation. The THD value obtained in the proposed system is demonstrated in Fig.13. Thus, it proved that the proposed system has achieved 0.03% of THD, which is the acceptable level of IEEE standards. The THD value obtained without the controller is illustrated in Fig.14.

Fig. 13 THD value obtained in the proposed system

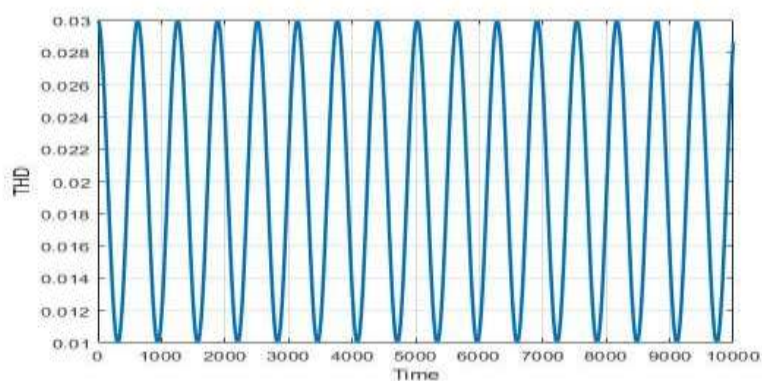
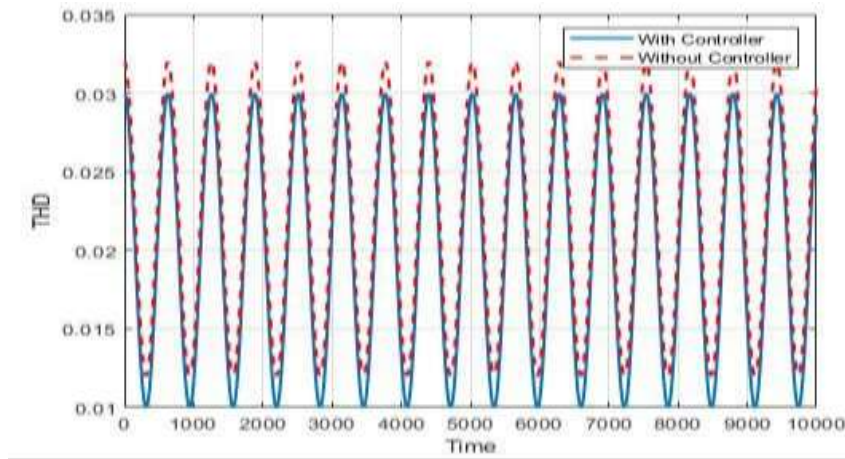


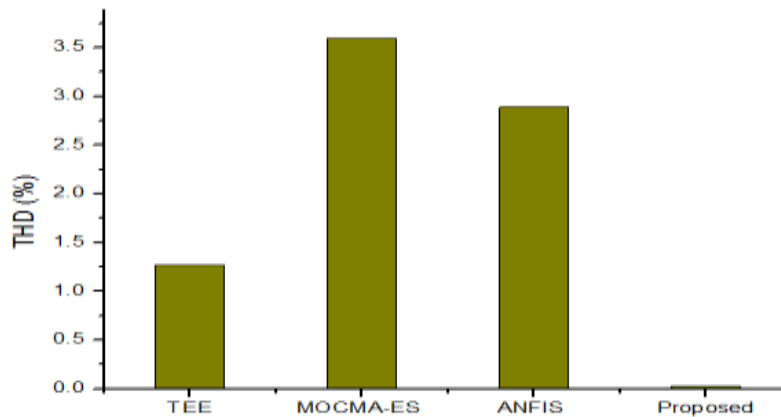
Fig. 14 THD with and without controller



5.2 Comparative analysis

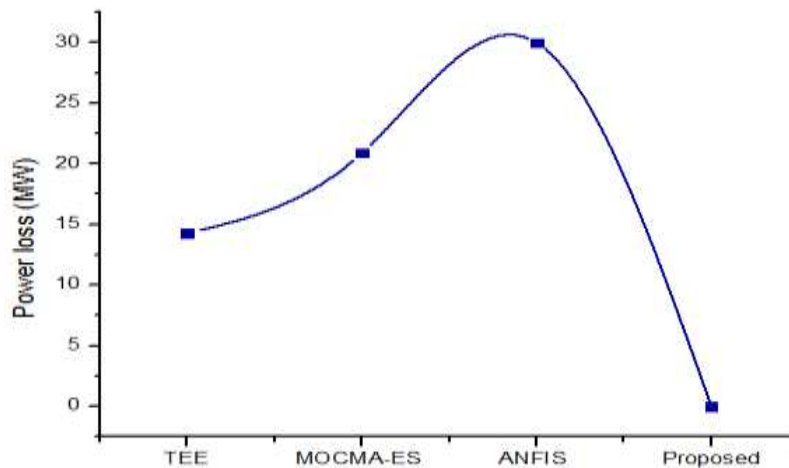
The performance of the proposed HEEHF control method in the microgrid system is compared with the different conventional methods, such as Techno-Enviro-Economic (TEE) [19], Adaptive Neuro-Fuzzy Inference System (ANFIS) [21], and Multi-Objective Covariance Matrix Adaption-Evolution Strategy (MOCMA-ES) algorithm [20]. The THD obtained from the proposed system is compared with the existing methods, as shown in Fig.15.

Fig. 15 Comparison of THD over existing methods



The observation shows that the proposed THD has attained 0.03% while compared to the other methods it is very less. Because the conventional TEE, MOCMA-ES, and ANFIS methods have attained a high amount of THD 1.27%, 3.6% and 2.89% respectively, compared to the projected method.

Fig. 16 Comparison of THD over existing methods



Consequently, the estimated power loss from the proposed system is compared with the conventional methods, such as TEE [19], MOCMA-ES [20], and ANFIS [21], as exemplified in Fig. 16. The comparison shows that the proposed technique has significantly reduced the power loss over other existing methods. Moreover, the overall performance comparison over different methods is detailed in Table 2.

Table 2. Overall performance comparison of different methods

Techniques	TEE [19]	MOCMA-ES [20]	ANFIS [21]	HEEHF (Proposed)
THD	1.27	3.6	2.89	0.03
Power loss (MW)	14.3	20.90	30	0.2
Error	1.05	0.5	0.36	0.002
Stability	Slightly stable	unstable	Difficult to stable	stable
Convergence	Slow	Slow	Very Slow	Fast

The overall comparison demonstrates that the proposed technique has accomplished supreme function in terms of lower THD, power loss, and error rate. Also, a high amount of stability and rapid convergence has been attained.

5.3 Discussion

The merits and limitations of the different methods are discussed in Table 3 based on the overall comparison of results. The conventional method has certain significant advantages; however, while comparing with the proposed method, it has a few disadvantages.

Table 3. Merits and Limitations of the different methods over the proposed technique

Author	Methods	Merits	Limitation
[19]	TEE	1. Effectively improved the environmental impacts	1. Convergence is low 2. Requires large training databases

		2. Provides real time hemodynamic monitoring	
[20]	MOCMA-ES	Design is easy	Computational period is high, THD is high over other methods
[21]	ANFIS	Training iteration is more	1.High computational cost 2.Values are not changed after so many iterations
Proposed	HEEHF	Highly reliable and handled huge amount of voltage and power rates for regulation	--

The THD values attained from this system are within the range of the IEEE standard of 519-2014 limit. However, the proposed method has reduced the THD by a very small amount over other methods. Moreover, the power loss and error are reduced significantly in this way; the stability of the system is improved. While comparing with the other approaches, the overall performance of the proposed method is superior. Thus, it is more suitable for the improvement of microgrid systems.

6. Conclusion

In relation to the power grid, a microgrid is an electricity-generating system that consists of a collection of loads with distributed generators that are all controlled by the same energy management tools and devices, which operate as a unified, controllable entity. Microgrid has emerged as a critical research component in the fields of smart grids and distributed energy systems. Also, the microgrid is mostly comprised of numerous renewable energy sources that take advantage of various technical developments, like power electronics-based equipment, to generate electricity. However, because of its inconsistent output, it can result in a diverse selection of power quality incidents. For this reason, the novel HEEHF control method is developed for the VSC system. The efficacies of the proposed evaluation criterion, as well as the improvement in power quality, are demonstrated by the results of simulations. Thus, the proposed control method in the grid system validated the power quality, and reliability has been enhanced compared to the existing approaches. In the future, the performance of the microgrid system will be tested with various cases under different load conditions.

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