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Enhanced GWO Controller Strategy for High Power Quality Improvement in AC Microgrids

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Abstract

The power quality issues are increasing every day in AC microgrids (MG) due to improper functionality of controllers. The conventional controllers like filters, regulators, fuzzy, and model predictive controllers (MPCs) are failed to maintain the optimal power flow in two parallel MGs, because these approaches are failed to optimize the fluctuations generated in the system. In general, the MGs contain both smart impedance (SI) and power electronically coupled distributed energy resources (PEC-DER) inverters, where the performance of MG purely depends on the continuous power flow of PEC-DER. Recently, nature-inspired and swarm intelligence-based approaches are resulted in superior performance for optimizing the controlling parameters in the MGs system. Therefore, this article develops the enhanced grey-wolf optimizer (EGWO)-based controller for MGs system, where the proposed EGWO-based controller is used to reduce the integral errors generated in the PEC-DER inverter by selecting the best environmental properties like terminal voltages, generated real power, and dc link voltage. In addition, it is also maintained that the synchronization between PEC-DER and SI converters, which is used to uphold the optimal power flow. Finally, the Simulink results shows that proposed EGWO controller-based PEC-DER resulted in reduced fault setting time (FST) and total harmonic distortion (THD) in MGs as compared to state-of-art controllers from the literature.

Keywords: microgrid, power electronically coupled distributed energy resources, smart impedance, grey-wolf optimizer, total harmonic distortion, fault setting time

1. Introduction

The contemporary power system network is made up of huge, interconnected AC MGs, each of which is made up of multiple controlling units with different capacity [1]. With a nominal frequency of 50Hz or 60Hz, an electrical power system generates, transmits, and distributes electrical power. The load demand grew or decreased in terms of kinetic energy stored in the AC MGs, resulting in changes in speed and, thus, system frequency. As a result, the researchers' primary concern for the successful operation of power control and frequency management. Maintaining targeted performance and stabilizing system responses following a disturbance caused by a short circuit loss [2] of generation, or load variation is what power system control entails. Because frequency is directly proportional to system loading, any abrupt change in system loading causes a significant deviation of frequency from its predetermined level, affecting the continuous flow of tie-line power [3] between nearby regulated zones. In ac motors and transformers, a permanent droop in frequency can result in the passage of strong magnetizing currents. It also has an impact on power system security [4], stability, efficiency, and reliability by degrading equipment, lowering overloading transmission systems, load performance, and causing unwanted protective device triggering. The frequency deviation has the potential to bring the entire system down, which is quite undesirable. Because the frequency generated in an electrical system is directly proportional to the generator's speed, the problem of frequency control [5] is directly transferred to the governor-turbine-generator set's speed control. The primary control, also known as the fly-ball governor, was used in the past to adjust the system frequency under the influence of load disturbance.

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However, the fly-ball mechanism [6] is incapable of controlling the system frequency due to the quick headway of the power system, the use of long transmission lines, large load demand, and the presence of system uncertainties such as modelling mistakes and changes in power system structures [7]. As a result, it is understood that in order to ameliorate the aforementioned difficulty, it is necessary to seek for and implement an alternative control theory in the power system. The PEC-DER [8] is used to achieve this property. The objective of this was to restore system frequency by altering power generation in response to load demand. PEC-DER [9], as an ancillary service in a power system, performs a crucial and basic function in ensuring that the power system's reliability is maintained at an appropriate level. It has become more important as the structure of power systems has changed, as has the number and complexity [10] of interconnected networks.

The successful operation of interconnected power systems is dependent on the matching of total power production with total load demand and related power system losses [11]. As demand deviates from its own nominal [12] level by an undetermined small amount, the operating point of the power system changes, and as a result, the system may suffer variations in nominal system frequency and planned tie line power transfers, which may have unintended repercussions [13]. Using system frequency and tie-line power flow data, calculate the necessary changes in power production needed to meet demand. Then, adjust the governor valve position to minimize the time average of area control error. Obtaining these results is accomplished by the determination of a control error [14] signal known as the area control error (ACE), which represents the real power imbalance between generation and load. ACE is the designation given to a regulated output of PEC-DER. Due to the fact that PEC-DER adjusts ACE to zero, both frequency and tie-line power problems are eliminated on their own. PEC-DER [15-16] has been characterized as one of the most essential control difficulties in the design and analysis of power systems, owing to the increasing size, changing structure, and complexity of contemporary power systems, as well as their increasing complexity. Therefore, this article introduces EGWO controller strategy for PEC-DER in AC MGs for high power quality improvement, where the EGWO technique is employed to reduce the integral errors generated in both PEC-DER inverter and SI converters, respectively.

Rest of the article is developed as follows: Section 2 deals with literature survey and their drawbacks. Section 3 deals proposed EGWO controller-based PEC-DER. Section 4 delas with the results analysis. Finally, section 5 concludes the manuscript.

2. Related work

In today's energy management systems, PEC-DER plays a critical role. During the previous few decades, the PEC-DER problem has been widely researched. The majority of the research concentrated on the PEC-DER with respect to static controllers like fuzzy controller. The first attempt in the area of PEC-DER was to manage the frequency of a MG system by utilizing the smart grid converter of a synchronous machine [17-19]. After it was discovered that this technique was insufficient, a supplemental control was added to the governor using a signal directly proportional to the frequency deviation plus its integral. This concept represents the traditional approach to power system PEC-DER. In [20] were among the first to publish in this crucial field of PEC-DER. The tie line bias control approach was used in these studies. In [21] demonstrated non-interactive control by assuming that (i) frequency and tie line powers controls do not interact, and (ii) that each control region is responsible for its own load variations. In [22] introduced a breakthrough optimum control concept for PEC-DER regulator designs in linked power systems. The authors [23] proposed a solution based on coordinated system-wide correction of time inaccuracy and unintended interchange in PEC-DER research that was successful. Supplementary [24] controllers were designed to successfully regulate the ACEs to zero. The research also aided in the development of a PEC-DER based on a variety of control [25] strategies. Large-scale systems with complicated nonlinear [26] dynamics are common in power systems. However, the majority of the research to date has been con ducted using linearized models of linked power networks. The PEC-DER response for small load perturbations [27] has been extensively accepted using linearized models of several power system components. When it came to the PEC-DER experiments, the influence of controllers was investigated in both continuous and discontinuous power system models [28]. A significant amount of research has been done on the modelling of different energy source dynamics for the purpose of PEC-DER analyses of power systems [29].

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When designing an optimum control system with respect to a certain performance target, power engineers may make use of PEC-DER regulator design approaches that are based on modern optimal control theory to achieve their goals. In [30] authors were the first to use this approach in their work on optimal PEC-DER regulator design. TAIPS (two-area interconnected power system) was employed in the experiment, and it was comprised of two similar nonrepeat thermal turbine power facilities. A novel formulation for the optimal PEC-DER method is proposed by the author [31]. It is necessary for the viability of an optimum PEC-DER system that all state variables be available for feedback [32]. Using an observer, we can rebuild the unavailable states from the accessible outputs and controls, which is the next step to take. [33] A large number of significant contributions have been made in the domain of state reconstruction. In [34], the authors investigated the PEC-DER of a TAIPS using differential approximation and an observer. In order to achieve zero asymptotic error, even for the nonlinear model [54], the observer has been designed to take advantage of the fact that the nonlinearity [35] of the power system model, notably the tie line power flow, is measurable. There have been PEC-DER systems based on an optimum observer, applying a nonlinear transformation, as well as reduced-order system models employing a local observer, described in the literature. Using a two-stage technique, the authors propose a basic generating unit model that is geared toward PEC-DER, as well as a method for detecting the transfer function of the model in [36]. Sub optimal PEC-DER regulator designs were proposed because to practical problems in implementing regulators based on feedback of all state variables [37]. The use of a sub optimal and near-optimal PEC-DER concept. In [38] authors provide a thorough examination of several PEC-DER control techniques in various environments. In [39] authors establish the advantage of a fractional order (FO) controller over an integral order (IO) controller. For a possible solution to the PEC-DER problem, the authors of [40] used state feedback controllers. In [41] authors provide a sliding mode controller for analyzing the dynamic behavior of interconnected power systems in depth. The authors discussed an intelligent PEC-DER based on fuzzy logic theory in [42]. The PEC-DER technique based on artificial neural networks (ANN) is easily implemented in [43]. It was shown in [44] that the proposed controller outperformed ANN, FLC, and conventional controllers in a four-area connected power system, and that the proposed controller beat all of these controllers. Design and presentation of an adaptive neuro-fuzzy inference system (ANFIS) for a three-area hydrothermal MGs are reported in the paper [45]. When it came to PEC-DER, they employed a type-2 fuzzy logic controller with a feedback error learning approach in the reconstructed power system. In [46] authors used an ANN with a genetic algorithm (ANN-GA) to increase the performance of EC-DER and SI, although the performance of this system still has to be improved. Further, ANFIS has been integrated with craziness-based particle swarm optimization (CRPSO) to generate the ANFIS-CRPSO [47] controller. The THD and FST in EC-DER systems are significantly reduced when using this controlling technology, as opposed to numerous other present alternatives.

3. Proposed EGWO based PEC-DER control strategy

Power deregulation is projected to result in cheaper electricity prices, enhanced consumer service, and increased system efficiency as a result of competition. However, it poses a number of technological hurdles in terms of conceptualization and integrated operation. Fundamental difficulties, such as guaranteeing the economic, secure, and stable functioning of the power system while supplying electricity of required quality in terms of voltage and frequency magnitude, must be effectively handled in the deregulated market. When electricity is sold on the traditional market, a single utility is responsible for maintaining the physical flow of electricity, meeting consumers' demands for proper voltage and frequency levels, maintaining the system's security, economics, and reliability, settling electricity bills with customers, as well as ensuring proper control, protection, and all other measures necessary for the system's proper operation. While system operation and guaranteeing appropriate power transactions at all times are key responsibilities of the electrical system operator, a large number of these operations are now recognized as independent services in the new competitive energy market.

Additional services include, among other things, power for loss make-up, THD, delivering necessary voltage support, organizing start-up power, and spinning reserve in the system. Associated services are referred to as "Ancillary services" in the restructured environment. In a restructured environment, as previously indicated, THD is considered to be one of the supplementary services. Distribution Companies (DISCO) can contract independently with a Generation Companies (GENCO) for power in the restructured environment, and these transactions are supervised by the independent System Operator (ISO). With the formation of GENCOs, Transmission Companies (TRANSCOs), and DISCOs, the restructured environment is more decentralized. The deregulated structure's several GENCOs and DISCOs allows a DISCO to contract with any GENCO for electrical transactions, allowing the DISCO to choose which GENCO it wants to do business with. For example, a DISCO may have an agreement with a Genco in another section of the country. A transaction of this kind is referred to as a "bilateral transaction." All transactions must be handled by a significant organization known as an ISO, who oversees the whole system. It is the ISO's responsibility to provide a variety of "ancillary services," one of which is THD. An in-depth investigation of THD after deregulation was conducted in this research in order to acquire a better knowledge of the THD issue in a deregulated environment.

3.1 PEC-DER's control strategies

The PEC-DER inverters are critical in operation of MGs because they allow for more reliable, adaptable, and optimum operation while reducing the time required for FST. Recently, control systems based on grid-forming (GF), and grid-support based GF (GCGF) have been developed to ensure that MGs operate at their optimum performance levels. But these control approaches were plagued by operating mode transition issues in the MGs, which made them ineffective. As a result, whether the shift is planned or caused by a defect in the system, it is undesirable. Normally, the GF technique supports the island mode, and the GCGF method supports both the grid-connected (GC) and the island operational modes. However, none of these two ways was successful in providing either consistent stable voltage and frequencies for the MG. As a result, these two technologies must be used in conjunction with GCGF and grid feeding control strategies in order to ensure efficient functioning. Once again, these combinations make the control system exceedingly complicated, resulting in it using more power and time than necessary. As a result, in order to increase the MG performance, the control methods of PEC-DERs must be updated on a constant basis. In this case, the GF control mechanism, which is frequently utilized since it tries to maximize energy export while simultaneously providing the maximum profit, is the most profitable.

Optimization techniques were used to achieve active and reactive reference powers and reference currents in this procedure, and the results were typically satisfactory. Maximum power point tracking is a well-known optimization technique that is applied in this regulating mechanism. However, it has the drawback of increasing THD as well as FST. Further, the reference powers and reference currents inserted by PEC-DERs into MG in order to get accurate measurements of phase angles and amplitudes in this situation. In most cases, the maximum power is inserted by PEC-DER in MGs, and the reactive power resulted as zero. As a result, this approach does not allow changes in the frequency and voltage of the network.

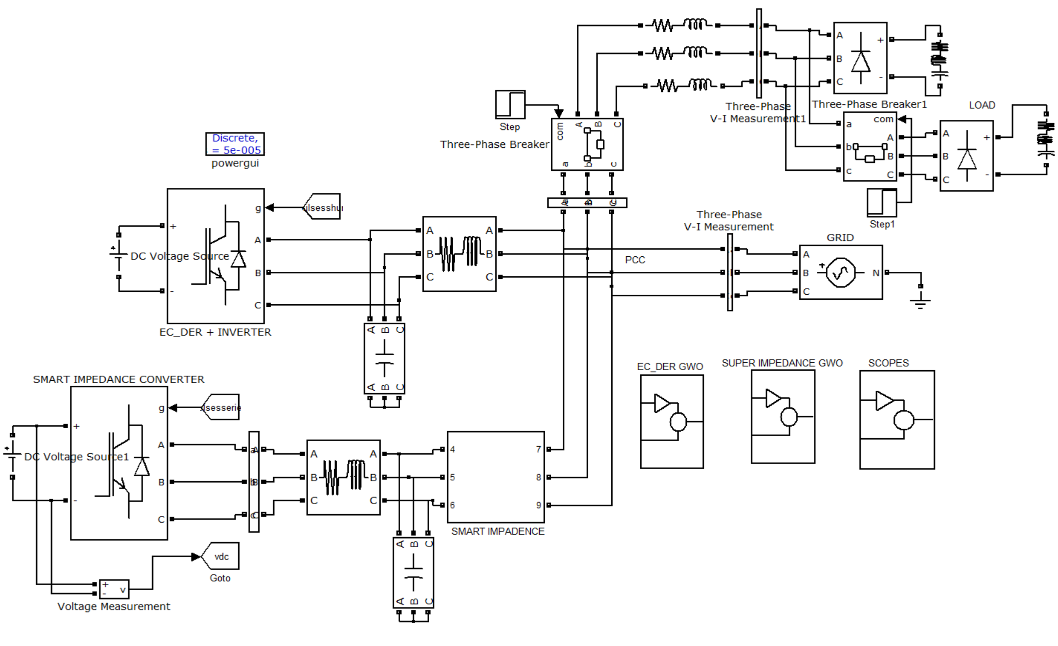

Figure 1. Proposed EGWO controller-based PEC-DER system.

Typically, MGs needs continuous power supply, which is achieved by the employment of the GF control technique, which operates in an isochronous fashion. When GF, the reference voltage is determined by taking the amplitude, phase angle, and frequency of the MG into consideration. The PEC-DER then keeps track of the reference voltage in a continuous manner. As a result, the continual monitoring of voltage results in a greater time expenditure. A GCGF control method was created in conjunction with the progress of GF in order to tackle this difficulty. PEC-DERs are given power sharing authority via the use of a droop control system, which regulates their active and passive capabilities and shares these powers with them. The GCGF control technique was likewise derived from the fundamentals of the GF approach to control. This approach is quite popular since it allows for both island and GC modes of operation to be used simultaneously. This study was primarily concerned with the building of a two parallel MG environment, which is constructed by PEC-DERs and SI equipped MGs. To obtain the best possible performance of the MG, the EGWO controller is used in this study.

Figure 1 depicts the full system architecture of the proposed smart grid system with PER-DER inverter and SI converter in conjunction with the EGWO controller. This controller, when used in conjunction with a PEC-DER system, allows for the correction of reactive power and harmonics to be perfect. The mismatch of non-linear loads in PEC-DERs is common RESs are directly connected to the MG in these systems. The EGWO controller has the capacity of automatically adjusting the produced reference current to account for all sorts of fluctuations in the environment. Variations in currents, voltages of combined RESs, source current, and grid tariff are all common occurrences, which reduced the performance of system. As a result, the EGWO controller achieves perfect balance between the non-linear load systems. In order to do this, the EGWO runs in three different modes of operation that are determined by gain values. It is possible to estimate these gain values by introducing three separate system circumstances into the system. The battery current, voltage level availability, and RES circumstances are the variables to consider. In addition to considering the different modes of operation, the EGWO controller takes into account the seven different situations in order to improve the power control problems. Monitor one irrelevant load and one critical load, (ii) Monitor four irrelevant loads, (iii) Monitor one individual critical load, (iv) Monitor two critical loads separately, (v) Monitor two dynamic loads separately, (vi) Monitor the operation of the grids, and (vii) Monitor the operation of all of the loads The compensation current is created by EGWO utilizing the optimum weights λ_V and λ_i, which are selected based on correct mode selection and scenario selection by EGWO.

3.2 EGWO controller for PEC-DER

First order controllers such as I, PI, and PID, which are often used in the automation sector, do not have the ability to cope with system parameter fluctuation throughout a broad range of frequency operation. It has been suggested to use a non-fragile controller to address the issue of controller gain uncertainty in order to improve the flexibility of system operation for a broad variety of dynamic conditions as well as disturbance rejection capabilities. It is possible for fragility concerns to reveal the accuracy of controller implementation to the extent that it results in a trade-off between implementation precision and performance degradation to occur. It is possible to simply avoid this uncertain aspect of the controller with good controller design, such as using a non-fragile controller design. The selection of PEC-DER and SI parameters is a critical factor for its proper operation. The proper tuning of PEC-DER and SI parameters has become a difficult task for researchers due to the rapid expansion of modern power systems. Traditional approaches take a long time to fine-tune the controller parameters, making them time consuming. These methods, once again, do not generate satisfactory results for the modern power system, which is prone to instability. To address this issue, this work implemented EGWO -based metaheuristic optimization strategies with the goal of achieving improved solutions to the PEC-DER and SI problems.

In this research, an EGWO-based bio-optimization technique for controlling strategy is provided, in which fractional order optimum weights are employed to enhance the performance of a THD system over a broad variety of dynamic conditions. Figure 2 displays the control strategy and basic block diagram of the proposed EGWO controller. More specifically, it achieves three major objectives: (I) strong disturbance rejection capability; (II) set point tracking with regard for dynamic response; and (III) consideration for tight loop stability. The proportional of the PEC-DER is multiplied with a slanted component with the transfer function in a traditional tilt integral derivative controller. The derivative section of the SI, increases the speed of the controller reaction while simultaneously increasing the magnitude

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of the control inputs to the MG. Furthermore, any high frequency noise in the input signal may cause huge noise signals to be amplified and sent to the MG, which generally results in difficulties in the actual application.

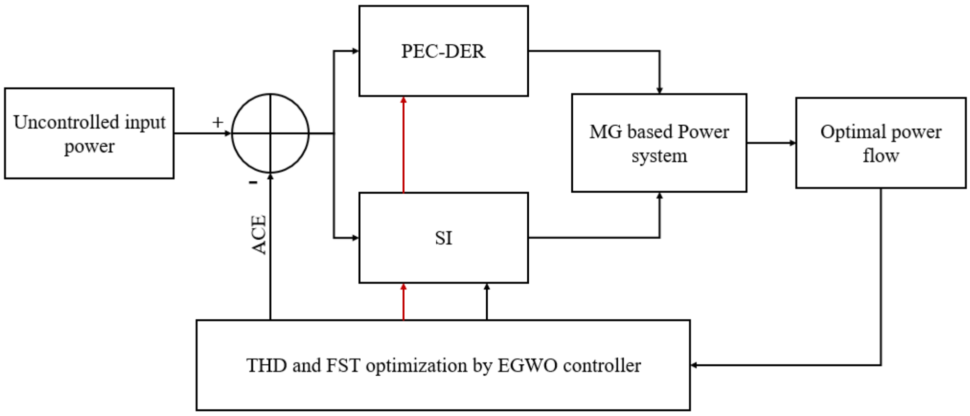

Figure 2. PEC-DER and SI control strategy using EGWO.

To overcome such challenges, a filter may be applied to the ACE based double derivative term, preventing chattering caused by noise from occurring since it vitiates high frequency noise, which is the most practical solution. In interpretation of this, the use of a double derivative with a fractional order controller in THD is advocated. The control function of the EGWO controller is represented by the expression.

$$C_{EGWO} = \left[\frac{P_{PEC-DER}}{S_{PEC-DER}} + \frac{P_{SI}}{S_{SI}} + f_{EGWO}(THD, FST)\right] \quad (1)$$

Here, C_{EGWO} represents the control function, $P_{PEC-DER}$ represents the PEC-DER power output, P_{SI} represents the SI power output, $S_{PEC-DER}$ represents the transfer function of PEC-DER, S_{SI} represents the transfer function of SI, and f_{EGWO} is the fitness function of EGWO.

3.3 Analysis of EGWO

The EGWO technique is an effective power level selection method. Figure 3 details the EGWO power level selection technique's overall design. The first step determines the population's beginning positions. These locations will automatically update based on the available population in discrete and continuous searching space. In the second phase, each population's variable weights are calculated, and their locations change as a result. Thus, the ideal power levels for each demographic are chosen. It is usually used to adaptively seek for the optimal power level combination utilizing varying weights. The optimal power level combination offers the lowest THD, FST and the most available power levels. The EGWO technique for enhancing power level selection uses PEC-DER specific power levels as input variable weights. EGWO with momentum helps drive PEC-DER specific power level gradient vectors in the right directions, resulting in faster convergence and reduced overall harmonic distortion. As a consequence, we may use a low power level set to optimize THD, FST. Momentum is a moveable average of the PEC-DER specific power level gradients. Then this work uses it to change the network's weight.

The algorithm for EGWO is designed by studying grey wolves' hunting mechanism, leadership hierarchy, and social behavior. Wolves generally live in packs, with wolves from each of the four strata of the wolf population represented. In this group, the alpha (α) wolf dominates, followed by the beta (β) and delta (δ) wolves, who are intermediate dominant, and finally the omega wolf, who is the least dominant. The wolves will commence the hunting mechanism under the wolves' leadership. To comprehend the grey wolf's hunting process mathematically, we need to know: These possibilities include encircling, hunting, and attacking.

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Encircling prey: Encircling prey is the initial phase of the hunting mechanism. The grey wolf's position in the search space changes automatically based on the prey's location. To mathematically define encircling, three coefficients are determined.

$$\overrightarrow{D_\alpha} = |\overrightarrow{C_1}.\overrightarrow{X_\alpha(t)} - \overrightarrow{X(t)}|,\ \overrightarrow{D_\beta} = |\overrightarrow{C_2}.\overrightarrow{X_\beta(t)} - \overrightarrow{X(t)}|\ ,\overrightarrow{D_\delta} = |\overrightarrow{C_3}.\overrightarrow{X_\delta(t)} - \overrightarrow{X(t)}| \quad (2)$$

The grey wolf's position vector is $\overrightarrow{X(t)}$, and its current iteration's coefficient vectors are $\vec{A}$, $\vec{C}$ and $\vec{D}$. The alpha position vectors are $\overrightarrow{X_1}$, the beta position vectors are $\overrightarrow{X_2}$, and the delta position vectors are $\overrightarrow{X_3}$. They are calculated as follows:

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1}.\overrightarrow{D_\alpha}\ ,\ \overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_1}.\overrightarrow{D_\beta} \text{ and } \overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_1}.\overrightarrow{D_\delta} \quad (3)$$

$$\overrightarrow{X(t)} = \frac{\overrightarrow{X_1} + \overrightarrow{X_2} + \overrightarrow{X_3}}{3} \quad (4)$$

As seen in the equation above, position vectors are vital in power level selection. If the dominant wolves approach the grey wolves, the grey wolves are pushed back by the average weights of delta, beta, and alpha. The alpha wolf chooses the best strength levels because they are closer to prey. The alpha wolf becomes the leader. It has the lowest probability power levels.

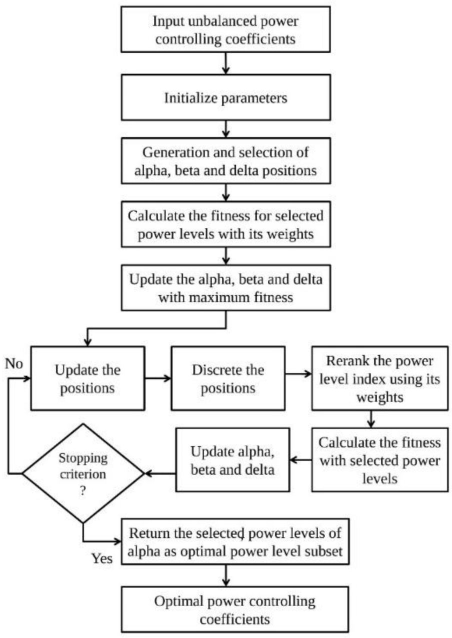

Figure 3. Power controlling operation by EGWO.

Thus, alpha positions are dominating because their weights are greater than the other wolves in equation (3). The following work is speculated based on the foregoing considerations. The alpha wolves hunt and search, while the beta wolves observe, and the delta wolves play a minor role. The dominating grey wolves are encircling the prey. The alpha is closest to the grey wolves, while the beta is next closest to the pack after the leader. Finally, delta is placed third. Depending on the prey location, all wolves may shift positions and leadership degrees. The omega wolves are the position changing wolves. This phenomenon may be used to choose the appropriate power level for multi-objective optimization. This is achieved by updating the minimum or maximum locations. During the search, the temporary prey and PEC-DER power levels are chosen. But, when hunting, precise prey is chosen, and PEC-DER power levels are chosen accordingly.

Because the omega wolves' placements change, the positions evaluated in equation (3) must be updated regularly. The EGWO algorithm is expanded with variable weights for this purpose. The procedure is as follows. After the hunt, the wolf closest to the prey is regarded as the alpha, and the others are ignored. The alpha wolf shift's locations and hunts for

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fresh prey based on the power levels available. If the power levels are attained, the alpha weight is set to 1.0 and the other wolves' weights are set to zero. These initialization weights are self-updating with prey placements and power levels. In the ultimate state, the delta, beta, and alpha all have the same weight and perfectly surround the prey. From the commencement of the prey-based power level search operation, all wolves automatically update their wolf rank. It implies beta replaces alpha, delta replaces alpha, and original alpha discovers power levels depending on cumulative iteration number (it). As the alpha wolf gets the prey, its weight is lowered, but the beta and delta wolves' weights are boosted. Thus, all weights are added up to 1 and the result is 1. Thus, the equation (3) is modified by the variable weights. Mathematically, the above-mentioned hypothesis is;

$$\overrightarrow{X(t+1)} = w_1 \overrightarrow{X_1} + w_2 \overrightarrow{X_2} + w_3 \overrightarrow{X_3} \quad (5)$$

$$w_1 + w_2 + w_3 = 1 \quad (6)$$

Alpha, beta, and delta weights are w_1, w_2 and w_3 and this weight meets the criteria $w_1 > w_2 > w_3$. Despite having the greatest priority, alpha's weight dropped from 1 to 0.33 throughout the search. Similarly, the delta and beta weights increased from 0 to 0.33. The cosine function is employed with an angle [0, arcos (1/3)] on the weight w 1, and the cumulative iteration number changes all weights. Thus, this approach applied the arc-tangent function to it, yielding an angular parameter (φ).

$$\varphi = \frac{1}{2}\arctan(it) \quad (7)$$

$$\theta = \frac{2}{\pi}.arccos\frac{1}{3}.\frac{2}{\pi} \quad (8)$$

if $it \longrightarrow \infty, \theta \longrightarrow arccos\,(1/3), \ = 1/3$, Then the weight coefficient w_2 will be calculated easily. Thus, the new positions by using the new weight coefficients are calculated as follows

$$w_1 = \cos\theta \quad (9)$$

$$w_2 = \frac{1}{2}\sin\theta\cos\varphi \quad (10)$$

$$w_3 = 1 - w_1 - w_2 \quad (11)$$

The omega wolves' location is altered by $\vec{A}$ s directives and regulating parameter a. If $\vec{A} > 1$, the grey wolves have moved or fled from dominants. At the same time, an omega wolf moves away from the prey, allowing other wolves to hunt. In optimization, this is called global power level search. If $\vec{A} < 1$, the grey wolves go closer to the dominants and ultimately catch the victim. In optimization, this is called local power level search. The wolves' direction is determined by the random numbers $\overrightarrow{r_1}$and $\overrightarrow{r_2}$, which are regulated by the regulating parameter (rp).

$$\vec{A} = 2\alpha\overrightarrow{r_1} - rp \quad (12)$$

$$\vec{C} = 2\overrightarrow{r_2} \quad (13)$$

From a high of 2, the rp decreases linearly to zero. It may be computed as follows:

$$rp = 2(1 - \frac{it}{N}) \quad (14)$$

The users initialize N, which is the maximum number of iterations. Finally, the PEC-DER design requires ideal power levels to minimize THD, FST. With the fitness function, we can determine the ideal power level and improve classification efficiency.

$$f_{EGWO} = rp * P + (1 - rp)\frac{NN-L}{L} \quad (15)$$

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The total number of power levels in the dataset is NN, the duration of the chosen power level is L, and THD and FST optimization is represented by P, respectively.

4. Results and discussion

This section gives the detailed implementation and simulation analysis of proposed EGWO controller strategy, which is designed using MATLAB/SIMULINK software environment. The current, voltage and power-based simulation waveforms are observed in order to validate the performance of system. Further, the power quality improvement is measured by using the factors THD, FST and power factor. Table 1 presents the values of parameters employed for simulations.

Table 1. Simulink parameters with their corresponding values.

Parameter	Value
Input inductance	4.7mH
Capability	315kVA
Operating frequency	1kHz
DC-link capacitance	5800uF
Output filter capacitance	100uF
Output phase voltage	220V
Output filter inductance	4.9mH

The energy router's main voltage is 10kV, and the output load phase voltage is 220V with 0.8 power factor lag and full load. Unlike the standard power transformer, the energy router has an additional function that should be used to manage power quality. Unbalanced three-phase loads will be simulated together with grid voltage diameters and swells along with large harmonic components at the grid voltage on and off to assess the efficiency of the power quality management.

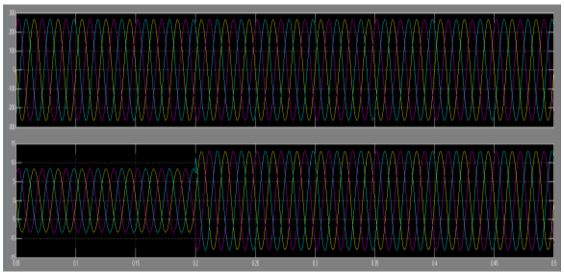


Figure 4. Conventional ANFIS-CRPSO [47] based PEC-DER1 and PEC-DER2 current waveforms.

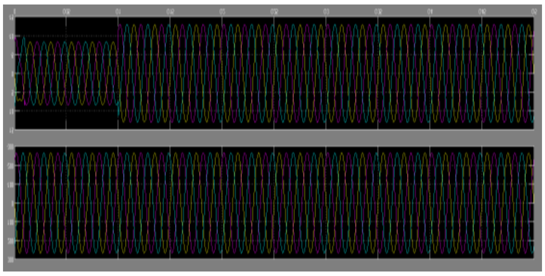
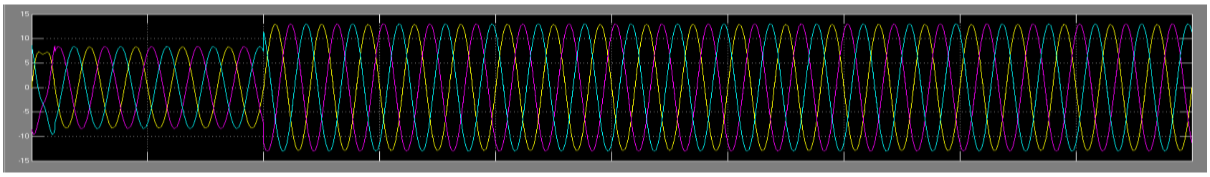
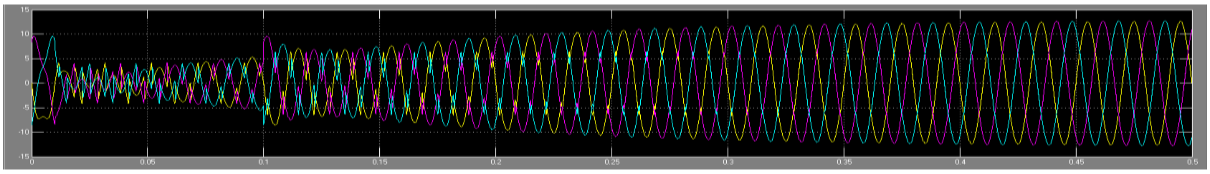


Figure 5. EGWO controller-based PEC-DER1 and PEC-DER2 current waveforms.



(a)



(b)

Figure 6: EGWO based MG stability performance. (a) load current, (b) zoomed display of EGWO based load current.

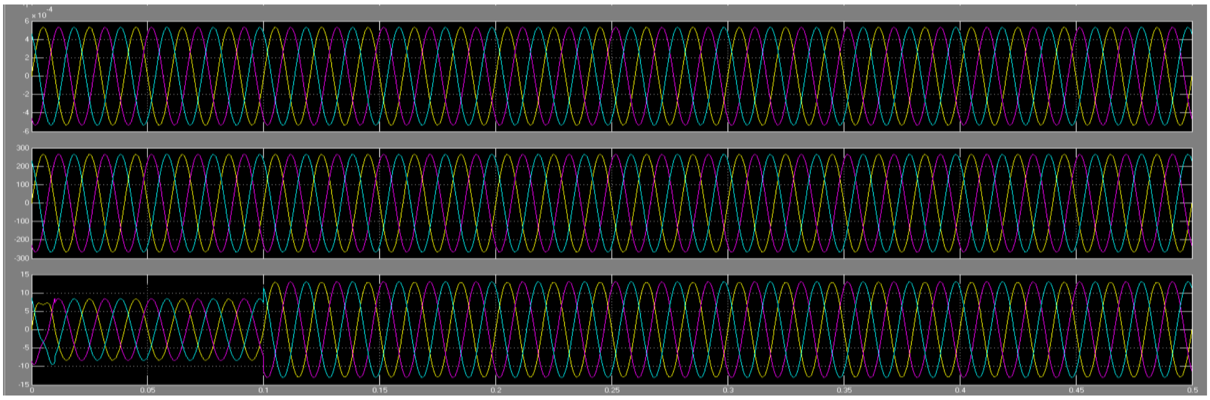


Figure 7. Voltage and current performance of EGWO based PEC-DER1 (a) output current, (b) output voltage. (c) output power.

Figure 4 depicts the current waveforms of PEC-DERs with and without ANFIS-CRPSO [47] in both the positive and negative directions. Figure 5 depicts the EGWO regulated current waveform of the PEC-DER, which avoids the generation of load side harmonics and changes the PCC behavior into a quasi-infinite bus. As a result, the negative consequences of the connections and interactions between the different components of the MG may be mitigated. The adjustment times for fault currents and voltages have been shortened from 0.2 to 0.1 second, respectively. It is specified in Figure 6 and Figure 7 that the three phase currents of the first PEC-DER are perfect. The load currents and output voltages, as well as the currents of the first PEC-DER, are settled even more quickly, with a time interval of 0.1 sec, while in the traditional system, the settlement occurs at 0.3 sec.

Harmonic spectrum shaping for resonance mitigation: By employing Harmonics spectrum shaping to create the gate pulses in rapid succession, the EGWO controller is able to limit the amount of resonance in the PEC-DER systems that are being used. While the standard MPC [24], ANN-GA [46], and ANFIS-CRPSO [47] based passive damping methods are effective in decreasing system losses, the EGWO based harmonics spectrum shaping approach increases system efficiency by minimizing system losses. As a result, the PEC-DERs is capable of responding to gate pulses and transients that are very quick. By making use of the SI In addition, the resonance frequencies have been decreased as well. EGWO act in parallel with the decrease of resonance frequencies produced in the converter output, as a result. This parallel operation is characterized by the use of a new hybrid cost function, which is described as follows:

$$g = \lambda_V \left|\left(\mathrm{V}_{PEC-DER_{i(k+1)}} - \mathrm{V}_{ref_{PEC-DER_i}}\right)\right|^2 + \lambda_i \left|\left(\mathrm{i}_{PEC-DER_{i(k+1)}} - \mathrm{i}_{ref_{PEC-DER_i}}\right)\right|^2 \tag{16}$$

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EGWO controller is used to determine the weight coefficients $\lambda_V$and λ_i, which are then used in this equation. In order to minimizes current THD (THD_i), and voltage THD ((THD_v) given in the EC-DER system, these weights are determined with the help of the best-fit cost functions. In general, the EGWO controller raises the I in order to reduce harmonic uncertainties and to allow for more precise construction of $\lambda_i - \text{THD}_i$ based droop. The λ_v value is often kept at a high level in order to reduce the amount of unneeded flowing current. In any case, the EGWO controller was created to maintain the highest possible voltage and current quality under seven different circumstances and three different MG operating modes. As demonstrated in Figure 7, by properly preserving both λ_i and λ_v, it was possible to reduce distortion power efficiently and reach a THD value of 2.20 percent, as shown in Figure 7.

Table 2 compares the performance of proposed EGWO based PEC-DER controller with conventional MPC [24], ANN-GA [46], ANFIS-CRPSO [47] controllers. The performance of proposed method resulted in superior for both the input resistance parameters such as THD and FST. From the comparison, it is observed that the proposed EGWO controller resulted in the decreased THD and FST.

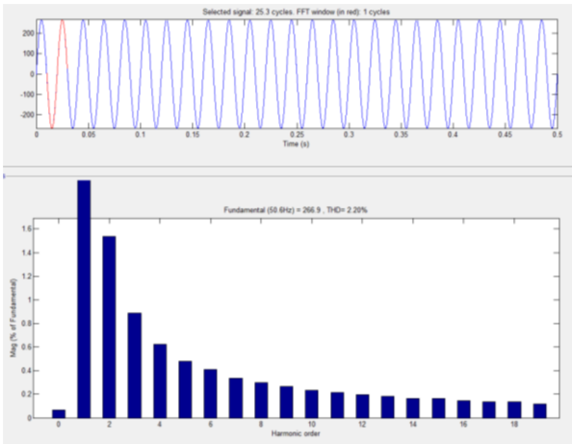

Figure 7: THD analysis of EGWO based PEC-DER i.e., 2.25%.

Table 2: Performance comparison of proposed EGWO controller with existing controlling methods.

Variable	Description	Proposed EGWO	ANFIS-CRPSO [47]	ANN-GA [46]	MPC [24]
r12&r22	grid side resistance	0.01 Ω	0.01 Ω	0.02 Ω	0.02 Ω
IH5, IH7	non-linear load in fifth and seventh harmonics	1,3,5,7,9,11 ABC Peaks	3,5,7,9 AB peaks	3 and 5 A peak	7 and 5 A peak
*r*11&*r*21	converter side resistance	0.01 Ω	0.03 Ω	0.04 Ω	0.04 Ω
% THD	The distortion of the system must be minimized.	2.25%	6 %	18%	26-30%
FST	This time should be minimized.	0.1 seconds	0.2 seconds	0.3 seconds	0.5-0.6 seconds
Power factor	This should be maximized	1 (unity)	0.9	0.8	0.7

5. Conclusion

This article is focused on the problems presented in power quality, which has been achieved by implementing the EGWO controller for PEC-DER and SI based MGs system. In addition, the proposed EGWO controller is used to decrease the integral errors caused in the PEC-DER inverter and SI converter by choosing the optimal environmental parameters, such as terminal voltages, generated actual power, and dc link voltage. Further, it additionally maintained the synchronization between the PEC-DER and SI converters, which was necessary to ensure that the optimum power flow is always maintained. The obtained simulation findings reveal that the proposed EGWO controller produced lesser values of FST and THD in MGs as compared with state-of-the-art controllers.

References

1. Nosratabadi, Seyyed Mostafa, Rahmat-Allah Hooshmand, and Eskandar Gholipour. "A comprehensive review on microgrid and virtual power MG concepts employed for distributed energy resources scheduling in power systems." *Renewable and Sustainable Energy Reviews* 67 (2017): 341-363.
2. Photovoltaics, D. G., & Storage, E. (2018). IEEE standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces. *IEEE Std*, 1547-2018.
3. Howell, Shaun, et al. "Towards the next generation of smart grids: Semantic and holonic multi-agent management of distributed energy resources." *Renewable and Sustainable Energy Reviews* 77 (2017): 193-214.
4. Wang, Zhong Lin. "Entropy theory of distributed energy for internet of things." *Nano Energy* 58 (2019): 669-672.
5. Zia, Muhammad Fahad, Elhoussin Elbouchikhi, and Mohamed Benbouzid. "Microgrids energy management systems: A critical review on methods, solutions, and prospects." *Applied energy* 222 (2018): 1033-1055.
6. Rubino, Luigi, Clemente Capasso, and Ottorino Veneri. "Review on plug-in electric vehicle charging architectures integrated with distributed energy sources for sustainable mobility." *Applied Energy* 207 (2017): 438-464.
7. Howell, S., et al. "Semantic interoperability for holonic energy optimization of connected smart homes and distributed energy resources." *eWork and eBusiness in Architecture, Engineering and Construction*. CRC Press, 2017. 259-267.
8. Feng, Xianyong, Li Qi, and Jiuping Pan. "A novel fault location method and algorithm for DC distribution protection." *IEEE Transactions on Industry Applications* 53.3 (2017): 1834-1840.
9. Abdella, Juhar, and Khaled Shuaib. "Peer to peer distributed energy trading in smart grids: A survey." *Energies* 11.6 (2018): 1560.
10. Baghaee, Hamid Reza, et al. "A decentralized power management and sliding mode control strategy for hybrid AC/DC microgrids including renewable energy resources." *IEEE transactions on industrial informatics* (2017).
11. Li, Yong, et al. "Flexible voltage control strategy considering distributed energy storages for DC distribution network." *IEEE Transactions on Smart Grid* 10.1 (2017): 163-172.
12. Baghaee, Hamid Reza, et al. "A new current limiting strategy and fault model to improve fault ride-through capability of inverter interfaced DERs in autonomous microgrids." *Sustainable Energy Technologies and Assessments* 24 (2017): 71-81.
13. Telukunta, Vishnuvardhan, et al. "Protection challenges under bulk penetration of renewable energy resources in power systems: A review." *CSEE journal of power and energy systems* 3.4 (2017): 365-379.
14. Marzband, Mousa, et al. "Optimal energy management system based on stochastic approach for a home Microgrid with integrated responsive load demand and energy storage." *Sustainable cities and society* 28 (2017): 256-264.
15. Nick, Mostafa, Rachid Cherkaoui, and Mario Paolone. "Optimal planning of distributed energy storage systems in active distribution networks embedding grid reconfiguration." *IEEE Transactions on Power Systems* 33.2 (2017): 1577-1590.
16. Faisal, Mohammad, et al. "Review of energy storage system technologies in microgrid applications: Issues and challenges." *Ieee Access* 6 (2018): 35143-35164.
17. Cheng, Zheyuan, Jie Duan, and Mo-Yuen Chow. "To centralize or to distribute: That is the question: A comparison of advanced microgrid management systems." *IEEE Industrial Electronics Magazine* 12.1 (2018): 6-24.
18. Rehmani, Mubashir Husain, et al. "Integrating renewable energy resources into the smart grid: Recent developments in information and communication technologies." *IEEE Transactions on Industrial Informatics* 14.7 (2018): 2814-2825.
19. Hahn, Adam, et al. "Smart contract-based campus demonstration of decentralized transactive energy auctions." *2017 IEEE Power & energy society innovative smart grid technologies conference (ISGT)*. IEEE, 2017.
20. Mahmud, Khizir, et al. "An internet of energy framework with distributed energy resources, prosumers and small-scale virtual power MGs: An overview." *Renewable and Sustainable Energy Reviews* 127 (2020): 109840.
21. Quint, Ryan, et al. "Transformation of the grid: The impact of distributed energy resources on bulk power systems." *IEEE Power and Energy Magazine* 17.6 (2019): 35-45.

22. Ceseña, Eduardo Alejandro Martínez, et al. "Integrated electricity–heat–gas systems: techno–economic modeling, optimization, and application to multienergy districts." *Proceedings of the IEEE* 108.9 (2020): 1392-1410.
23. Krishan, Om, and Sathans Suhag. "An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources." *International Journal of Energy Research* 43.12 (2019): 6171-6210.
24. Obaid, Zeyad Assi, et al. "Frequency control of future power systems: reviewing and evaluating challenges and new control methods." *Journal of Modern Power Systems and Clean Energy* 7.1 (2019): 9-25.
25. Shafik, Muhammed Badeaa, et al. "Adequate topology for efficient energy resources utilization of active distribution networks equipped with soft open points." *IEEE access* 7 (2019): 99003-99016.
26. Shrestha, Ashish, et al. "Peer-to-peer energy trading in micro/mini-grids for local energy communities: A review and case study of Nepal." *IEEE Access* 7 (2019): 131911-131928.
27. Roslan, M. F., et al. "Microgrid control methods toward achieving sustainable energy management." *Applied Energy* 240 (2019): 583-607.
28. Rathor, Sumit K., and D. Saxena. "Energy management system for smart grid: An overview and key issues." *International Journal of Energy Research* 44.6 (2020): 4067-4109.
29. Heidari, A., S. S. Mortazavi, and R. C. Bansal. "Stochastic effects of ice storage on improvement of an energy hub optimal operation including demand response and renewable energies." *Applied Energy* 261 (2020): 114393.
30. Muttaqi, Kashem M., Md Rabiul Islam, and Danny Sutanto. "Future power distribution grids: integration of renewable energy, energy storage, electric vehicles, superconductor, and magnetic bus." *IEEE Transactions on Applied Superconductivity* 29.2 (2019): 1-5.
31. Worighi, Imane, et al. "Integrating renewable energy in smart grid system: Architecture, virtualization and analysis." *Sustainable Energy, Grids and Networks* 18 (2019): 100226.
32. Dorri, Ali, et al. "SPB: A secure private blockchain-based solution for distributed energy trading." *IEEE Communications Magazine* 57.7 (2019): 120-126.
33. Wu, Changsheng, et al. "Triboelectric nanogenerator: a foundation of the energy for the new era." *Advanced Energy Materials* 9.1 (2019): 1802906.
34. Lai, Jingang, et al. "Distributed voltage regulation for cyber-physical microgrids with coupling delays and slow switching topologies." *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 50.1 (2019): 100-110.
35. Wen, S., Wang, Y., Tang, Y., Xu, Y., Li, P., & Zhao, T. (2019). Real-time identification of power fluctuations based on LSTM recurrent neural network: A case study on Singapore power system. *IEEE Transactions on Industrial Informatics*, *15*(9), 5266-5275.
36. Pourbehzadi, Motahareh, et al. "Optimal operation of hybrid AC/DC microgrids under uncertainty of renewable energy resources: A comprehensive review." *International journal of electrical power & energy systems* 109 (2019): 139-159.
37. Akrami, Alireza, Meysam Doostizadeh, and Farrokh Aminifar. "Power system flexibility: an overview of emergence to evolution." *Journal of Modern Power Systems and Clean Energy* 7, no. 5 (2019): 987-1007.
38. Kim, M. S., Haider, R., Cho, G. J., Kim, C. H., Won, C. Y., & Chai, J. S. (2019). Comprehensive review of islanding detection methods for distributed generation systems. *Energies*, *12*(5), 837.
39. Heydari, Rasool, Tomislav Dragicevic, and Frede Blaabjerg. "High-bandwidth secondary voltage and frequency control of VSC-based AC microgrid." *IEEE Transactions on Power Electronics* 34.11 (2019): 11320-11331.
40. Bajaj, Mohit, and Amit Kumar Singh. "Grid integrated renewable DG systems: A review of power quality challenges and state-of-the-art mitigation techniques." *International Journal of Energy Research* 44.1 (2020): 26-69.
41. Nejabatkhah, Farzam, Yun Wei Li, and Hao Tian. "Power quality control of smart hybrid AC/DC microgrids: An overview." *Ieee access* 7 (2019): 52295-52318.
42. Baghaee, Hamid Reza, et al. "Anti-islanding protection of PV-based microgrids consisting of PHEVs using SVMs." *IEEE Transactions on Smart Grid* 11.1 (2019): 483-500.
43. Gholinejad, Hamid Reza, et al. "A hierarchical energy management system for multiple home energy hubs in neighborhood grids." *Journal of Building Engineering* 28 (2020): 101028.
44. Hassan, Waqas, Dylan Dah-Chuan Lu, and Weidong Xiao. "Single-switch high step-up DC–DC converter with low and steady switch voltage stress." *IEEE Transactions on Industrial Electronics* 66.12 (2019): 9326-9338.

JOURNAL OF ALGEBRAIC STATISTICS
Volume 13, No. 2, 2022, p. 1655-1668
https://publishoa.com
ISSN: 1309-3452

45. Zia, Muhammad Fahad, et al. "Energy management system for a hybrid PV-Wind-Tidal-Battery-based islanded DC microgrid: Modeling and experimental validation." *Renewable and Sustainable Energy Reviews* 159 (2022): 112093.
46. Karthik, M. Vijay, and Priyanka Chaudhary. "Power Quality Enhancement in AC Microgrids Using Integrated Genetic Algorithm in ANN." *2021 5th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*. IEEE, 2021.
47. Karthik, M.V., Chaudhary, P. A novel integration of ANFIS-CRPSO based high power quality improvement in AC microgrids. *Energy Syst* (2022). https://doi.org/10.1007/s12667-022-00506-7