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Necessity of artificial intelligence techniques for power quality issues in electric vehicles

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ABSTRACT

World transportation is in an electrified mass transitional phase due to the predominant features such as a greener environment, fewer maintenance requirements, improved reliability and energy management efficiency compared to conventional transportation. Numerous difficulties have emerged since electric vehicle sales hit record highs, including how electrified transportation works with the grid. Emerging innovations and technological advances in the field of artificial intelligence have led to the development of enhanced controllers for electric vehicle penetration with the grid. This work includes information on the integration of artificial intelligence strategies used for the mitigation of power quality issues. By merging artificial intelligence techniques into the grid, users can achieve efficient energy use and beneficial power interactions between the grid and electric vehicles. To assess the network's practicality, this research develops a charging model that uses a Tasmanian devil optimization (TDO) algorithm based on MATLAB software. According to research, TDO improves the waveform quality by reducing the THD with better performance and achieves efficient power transfer between the grid and EVs.

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1. INTRODUCTION

Every nation's desire to develop a greener environment is longer to build electric vehicles and offer healthier electricity from electrified transportation to all the electrified areas. The automobile industry is the world's largest transport sector and a major source of carbonaceous pollution. Although the electric car era started 100 years ago, electrified transportation became more popular in 2011 because of the increased focus on a carbon-free environment. Developments in battery packs, power electronics, and new technologies have contributed significantly to the popularity of electrified transportation. The Russian-Ukrainian conflict and pandemics like the Coronavirus have caused several issues, including chip and wire harness shortages and high demand for raw materials for batteries, which raises the initial cost of electric automobiles. Despite the shortages, the automotive industry has maintained its confidence and trust in certain advancements in grid voltage platforms up to 800 V, vehicle design (charging efficiency and battery performance), and material requirements. The efficient and cleaner delivery of electricity has been a global priority. The United States needs to invest around $125 billion to improve grid infrastructure before the complete transition to electric vehicles (EVs). Similarly, every nation must invest a sizable sum in upgrading its grid infrastructure.

Automobile manufacturers and consumers are not enthusiastic about the transition, despite the world's rapid shift from fossil fuel to electric transportation [1]. The future era is being hampered by several issues, including range anxiety, the dearth of charging stations, and the initial cost [2]. When it comes to the power grid, 70% of electric vehicle adoption may have an impact on power quality and jeopardize system stability. According to one study, 6 million EV adoption in California exceeds the capacity of one-fifth of feeders, necessitating massive upgrades in the coming years. The impact of charging load has serious consequences for utilities in the power grid if power grids are not properly upgraded [3]. Initially, traditional techniques along with proportional-integral (PI) controllers were combined to manage the factors impacting power quality and time–of–use pricing methods for improving the benefits of customer and utility. Despite the method's effectiveness, several issues and features need to be considered as electric vehicle technology advances and their widespread use elevates.

Artificial intelligence (AI) plays a critical role in the creation of critical real-life challenges in the intelligent automobile industry. Artificial intelligence implementation in the automobile industry, from EV production to grid integration, might well address the dependability, sustainability, and feasibility of EV adoption. AI techniques have been used in a variety of aspects of the electric vehicle industry, including optimum power efficiency; battery development (size, shape, manufacture, storage, and efficiency); driver assistance and risk assessment; and range anxiety and routing [4]. This article investigates the necessity and approaches of AI in power grid stability and efficient power supply during the integration of EVs into the grid. AI is expected to improve battery efficiency, alleviate range anxiety, and mitigate the effects of grid-connected EVs, potentially leading to advancements in the electrified automotive industry. Additionally, EV integration offers the power grid a dependable, practicable, and efficient power supply. However, the current literature is scattered with information about AI optimization in various EV fields. Researchers may find it challenging to identify the most crucial elements of each field as a result. This study examined AI algorithms to see how well they could work with EVs and the grid. The following outlines how the studies are organized: the methods used to address the problems of power quality is discussed in section 2 along with the benefits and drawbacks of each approach and their respective implications and the proposed methodology of Tasmanian devil optimization (TDO) is described in section 3. In section 4, the results of the EV integration are discussed, and section 5 presents the conclusions.

2. AI CONTROL SCHEMES IN EV-INTEGRATED SMART GRID

The deployment of a power grid with electric vehicles has numerous benefits for the environment, power utilities, and consumers. Figure 1 depicts the EV bidirectional charging process. The grid charging of EVs has been linked to a number of issues including an increase in peak demand, voltage unbalances, overloading, instability, and power quality issues [5]. Three penetration levels have been examined and peak demand has been increased from 2.20 MW with 10%, 20%, and 30% penetration levels following the effects of uncontrolled charging [6]. A Virginia tech electric service analysis of the various EV penetration levels during the summer and winter came to the conclusion that an elevated proportion of electric automobiles have been blended into the power system leading to increased demand and sales of electric energy in the distribution circuit [7]. An investigation into the effects of unchecked EV charging with 100% fleet charging on the British power grid revealed transformer overloads at the transmission level. The burden brought on by EV fleets could be lessened with smart charging to flatten the load [8].

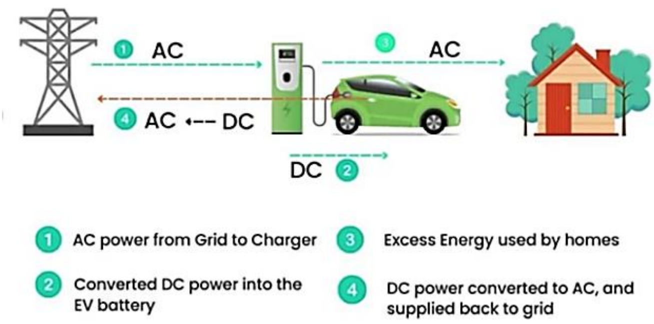

Figure 1. Bidirectional charging process

The voltage imbalances in residential distribution systems have been observed in Nakhon Sawan 2, Thailand, and it has been determined that a greater level of imbalance occurs at the end of the feeder as penetration levels of charging and discharging increase [9]. Case studies for PHEVs using various levels of chargers and an uncontrolled charging strategy were conducted. Fewer harmonics are produced when PHEV penetration is 30%, but level 1 chargers increase neutral current during fundamental frequency compared to all other chargers [10]. Five EVs were used in the analysis of harmonic distortion at the distribution side, and it was found that there is significant harmonic distortion and current harmonics increase to 12.2% and voltage harmonics to 11.4% in the absence of any filtering techniques. Utilizing optimization techniques, controlled charging could keep the harmonic distortion within acceptable bounds [11]. Level 1 chargers have a significant impact on the distribution system with 3rd harmonic currents between 12% and 16%, according to case studies conducted for the implementation of Portugal's electric mobility program [12]. In the residential distribution, the impacts of cable and transformer were assessed that 27.25% EV penetration causes overloading of cables considering harmonic currents [13]. The amount of electricity that a 42-EV fleet will need to charge was examined over the course of a year in a work environment in the Netherlands to ascertain the grid implications in order to meet the Dutch administration's targets for the year 2050. Transformer overloading is one of many power load issues brought on by the advancement of electrification. A reactive power compensation strategy was proposed to make up for the transformer overloading and extend transformer life by 49%. The effects of overloading issues were also studied in relation to the effects of EV charging [14]. Table 1 provides an overview of research and the development of artificial intelligence approaches for glitches with the performance of power.

Table 1. A short overview of AI strategies in previous studies with EV power quality issues

Objective	Technique Used	Limitations	Implications
Charging Coordination of large-scale electric vehicles [19]	The Multi-Agent Selfish Collaborative architecture (MASCO) algorithm requires complete EVs charging coordination at the transformers	Integration of RES and EMS is not considered	MASCO balanced energy costs and transformer overloads. Reduces the peak loads and overloads at the transformer by improving the safety and economic operation of the power system.
Coordinated charging to safeguards the power grid [20]	Seven models are used to predict the power rating of EVCS	Accuracy of algorithm cannot be predicted	The model is based on 200 residential households. LSTM model provides an accuracy of 95.3%. The ML method provides reliable solution for coordinated charging and LSTM classifier provides the best result. Reduces voltage swings and interruptions to power.
To study System stability, Frequency deviation, Power mismatch issues of AGC [21]	PSO and FOA applied to AGC for the frequency management	System does not mention about the number of electric vehicles	Thermal and EV acceptance, as well as analysis of step load disruption and random load disruption, have been chosen as the two study areas. When compared to the PSO algorithm, the firefly algorithm boasts a significantly higher delay margin, reduced settling time, and low oscillation.
Purpose of achieving good harmonic compensation [22]	Hybrid active series power filter along with PI and PSO are used.	Algorithm is applied to specific battery charger load and Renewables are not considered	Harmonics in loading conditions such as resistive inductor (RL) and battery loading conditions have analyzed. PSO and PI work together to reduce the total harmonic distortion of battery chargers from 21.83% to 3.99%. Compensates harmonics in source current and load voltage.
To maintain optimal power control strategy for frequency stabilization [23]	PSO and fuzzy based charging strategy is proposed for frequency stabilization in microgrids	Uni directional mode of charging was considered for frequency stabilization	Analyzed the charging models of EVs that causes impacts on the AC grid. The proposed method was able to regulate the frequency coordination by EVs.
To minimize the Harmonics injected by EVs [24]	Hybrid Fuzzy-PI model used to regulate the impacts caused by EV chargers	Variable switching frequency of hysteresis controller leads to switching losses	Two control techniques are used 1) Hysteresis controller to provide switching pulses of VSI 2) The proposed technique reduces Total Harmonic Distortion (THD) from 13.66 to 1.60% in phases A and from 13.83% to 3.82% in phases B and C.
Enhance the grid-interactive photovoltaic-based electric automobile system's power quality [25]	DSTATCOM based ANFIS control technique was modelled.	Inspection of the effects on the grid does not take an abundance of electric automobiles into account.	Proposed topology was evaluated under unbalanced conditions. DSTATCOM mitigates the harmonics challenges and balanced supply currents by using ANFIS based reactive power control technique
Optimization of bidirectional dc-dc converter during the incorporation of EVs [26]	An optimization process based on Golden Eagle Optimization (GEO) has been implemented for dual stage photovoltaic system.	GEO optimization doesn't provide accurate results in multi-objective problems.	Control of residential systems with electric vehicles has been analyzed. The incorporation of the algorithm provides a reduction in transients in the system and achieves shorter settling time.
In this research TDO optimization utilize exploration and exploitation stages to obtain the optimal solution to analyze the problems with electrical reliability brought on by EVs [27].			

3. PROPOSED METHOD

The subsection that follows below provides an explanation of the suggested method. The high exploration and exploitation potential of TDO creates an appropriate balance between indicators to successfully address the problems with EVs. The primary source of inspiration for TDO is the Tasmanian devil's reliance on hunting for food. The results of the simulation demonstrate a high capacity for the exploration of search space and identifying the primary area that is optimal for the optimization process.

3.1. The proposed TDO optimization

The TDO optimization proposed relies on how the Tasmanian devil behaves with feeding mechanisms on live prey and carnivore hunting. The major technique behind TDO optimization is finding the different areas of space and obtaining the optimal solution. The flowchart of the optimization technique is explained in Figure 2. The exploration and exploitation phase of TDO helps to maintain an equilibrium for finding solutions. In the exploration stage, metaheuristic algorithms can identify the most desirable region, and in the exploitation stage, they may merge on the greatest overall result. The searching process for food by the Tasmanian devil determines the exploration process and the hunt for the most viable solution is determined by the Tasmanian devil's acquiring behavior. The TDO design makes the assumption that for each Tasmanian devil, the positions of other populace members in the quest space correspond to places where there is a carrion. In (1) by replicating one of these scenarios, the K^{th} population member is randomly selected to be the I^{th} Tasmanian devil's target carrion. Therefore, K^{th} must be selected at random from 1 to N, and I must be selected at random from 0 to N.

$$D_I = A_K, I = 1,2,\ldots,K \in \{1,2,\ldots,N|K \neq I\}, \tag{1}$$

Where D_I represents the carrion that the Tasmanian devil has made his choice to ingest. A distinct spot in the search area is chosen for the Tasmanian devil depending on the chosen carrion.

There are two stages for the animal during the exploitation phase, the animal either selects the target and consumes the prey or pursues the prey once it comes near. The vantage point of the remaining population's members is taken into account as the precise spot of the prey in the second phase when updating the Tasmanian devil. K, an inherent random number ranging between 1 and N that is the antithesis of I, is chosen at random from the population to be the prey. In (2), the choice of prey is modeled and beyond the discovery of the prey, a different location for the Tasmanian devil is determined.

$$F_I = A_K, I = 1,2,\ldots,N|K \in \{1,2,\ldots,N|K \neq I\} \tag{2}$$

The radius of the neighborhood, which can be calculated using in (3), indicates the range that the Tasmanian devil follows its prey. Where R is the radius of the neighborhood surrounding the point where it was attacked, t is the duration of the iteration counter, and T is the highest possible number of iterations.

$$R = 0.01\left(1 - \frac{t}{T}\right), \tag{3}$$

Figure 3 depicts the envisioned rapid recharging station configuration for outlets, which was modelled using Simulink/MAT. A solar panel is operated at standard test conditions 1000 W/m^2 and 25 ºC are used as the generation source along with a grid and five EVs with each of 40kW are implemented and analyzed in this research. The EVs are then connected to bidirectional DC-DC converter which consists of dual port which can simultaneously charge from the PV array and grid. Moreover, the hybrid three-level full-bridge isolated buck–boost DC-DC converter will be bidirectional, capable of supplying grid with power from vehicle batteries (V2G) and grid to vehicle (G2V). This converter functions as a Buck converter in the G2V operation mode to regulate the voltage and current respectively during the battery imposing stages. In order to ensure the proper operation of the full-bridge AC-DC bidirectional converter, the converter acts as a boost converter, which is utilized during V2G to raise the batteries voltage to a suitable link to DC voltage. For the improvement of the power quality of the grid, the research employs the metaheuristic algorithm Tasmanian devil optimization (TDO) [15] implemented for EV recharging and releasing. The Tasmanian devil's feeding strategy of live prey and carrion served as the inspiration for TDO. The process of searching for nutritional food by the Tasmanian Devil in different search areas indicates that the exploitation index gives a superior solution, which identifies the ideal search field. In this research, the mathematical model of TDO is used for getting the optimal value for the PWM pulses which is adapted from [16], and the PWM pulses are given to the boost converter for switching of MOSFET switch to give the optimal signal value (ON and OFF). TDO offers better equilibrium between analysis and accomplishment and provides a strong performance than other optimization algorithms.

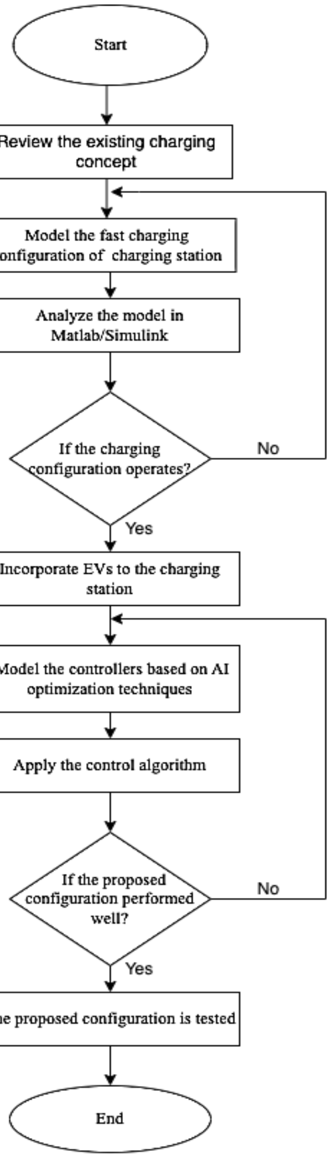

Figure 2. Flowchart for the proposed approach

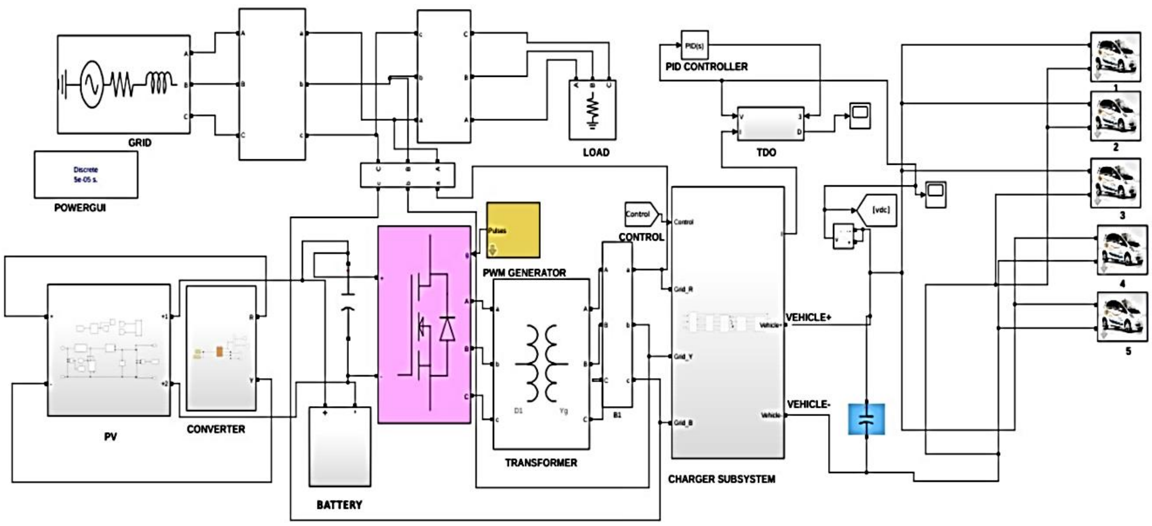

Figure 3. Simulink model of proposed fast charging station configuration

4. RESULTS AND DISCUSSION

The results were compared before and after the TDO optimization algorithm incorporated into the speedy charging station topology served as the foundation for the proposed electrical charging location implementation [17]. The analysis of the V2G and G2V modes of operation generated the following findings in the following graphs. As fast as EVs become tied to the grid, the performance of grid is enhanced by the TDO optimization's optimal PWM values. Electric vehicle battery operations during G2V operation are depicted in Figure 4. According to the graph, SOC rises during G2V operation, indicating that electric vehicles are receiving grid power. These results change in the polarity of power from positive to negative as battery voltage rises and battery current falls to a negative value. Figure 5 shows the battery operation of electric vehicles during V2G operation.

The graph shows that the SOC decreases, battery current and voltages rise, and the polarity of power remains positive indicating that during V2G operation, the vehicle supplies the grid with power. The effectiveness of the TDO algorithm when integrating electric vehicles into the grid is demonstrated by the analysis of total harmonic distortion. The Tasmanian devil optimization strategy aids the optimizer in finding the best solutions depending on the feeding mechanism of the Tasmanian devil. When connecting electric vehicles, the grid current's THD is 26.655% as shown in Figure 6, and when connecting TDO, the grid current's THD declines to 9.2466% as shown in Figure 7.

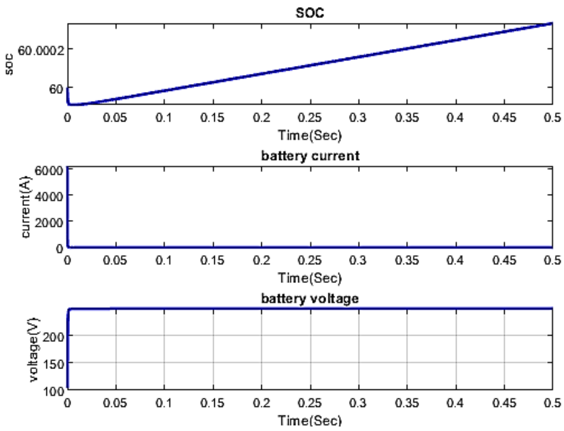

Figure 4. Battery parameters during the operation of G2V

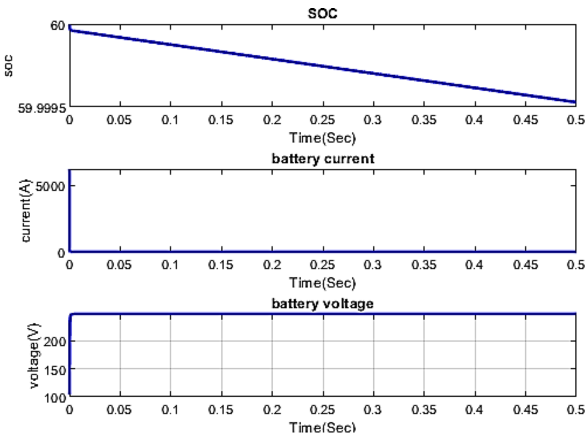

Figure 5. Battery parameters during the operation of V2G

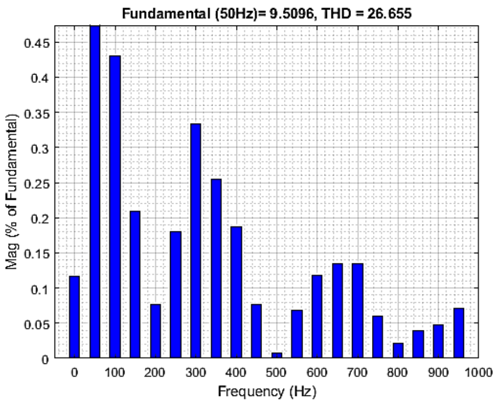

Figure 6. THD of grid current when EVs are connected at the outlet for charging

Despite the fact that the grid harmonic current has been somewhat reduced by the integration of TDO optimization with electric vehicles, indicating improved performance and efficiency, it still exceeds the desired limits. The analysis claims that when many EVs need to be charged, the grid's competence to serve up power will be significantly less efficient once electric vehicles are connected to it. Hybrid incorporation of TDO optimization with Deep learning solutions [18] could provide the best alternative for reducing the issue and will maintain the power quality issues within the desired limits.

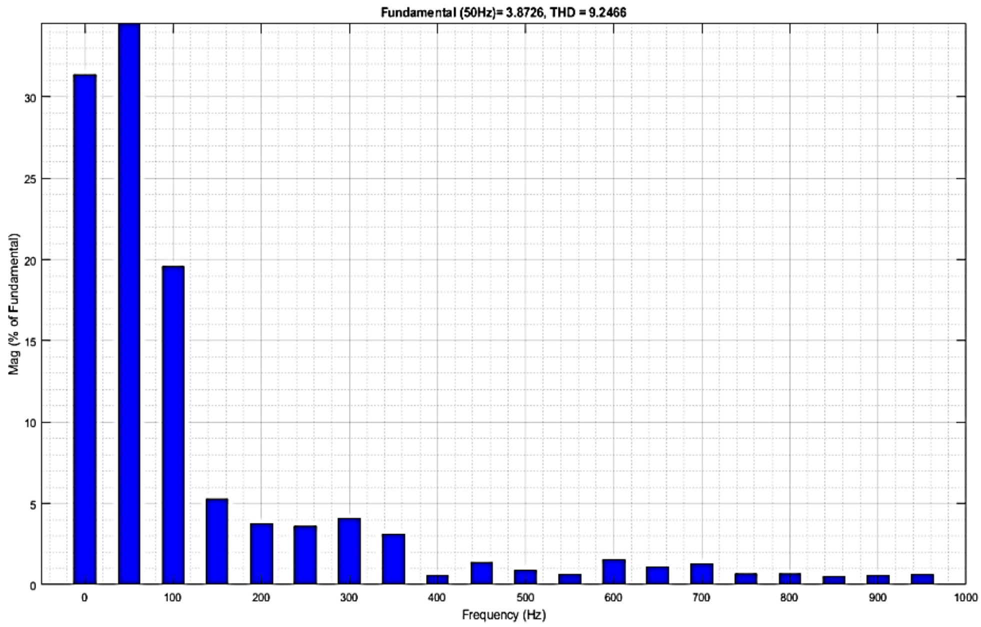

Figure 7. THD of grid current when EVs are connected at the charging station along with TDO

5. CONCLUSION

To successfully adopt EVs, this article examines the different approaches of AI techniques used for power quality problems in order to effectively weave electric automobiles into the power grid which covers the approach, developments, and limitations. Electric vehicle (EV) embraces upsides the world to achieve carbon-free transportation. Acceptance of electrification is dependent not only on consumers, but also on the availability of materials required for the development of EVs, grid integration for the charging and recharging process, and the innovation gap. This study presents the significance of V2G integration into the power grid to overcome the barriers to widespread adoption to enhance grid integration. The study reports that AI optimization techniques overcome the limitations of traditional analytical techniques and reveal improved accuracy for enhancing load balancing, charging, and discharging coordination between grid and EVs. In this research, the power quality problems caused by EV integration are analyzed using MATLAB/Simulink with a metaheuristic optimization algorithm called Tasmanian Devil Optimization. Even though the TDO provides better results in reducing harmonics, the optimization techniques couldn't be able to meet the desired limits. With the TDO optimization, the harmonics were reduced to 9.24% and able to provide better V2G and G2V transfer of power. As a result, this research reduced the total harmonic distortion to an extent and provided efficient energy transfer between the grid and vehicles by providing better consumer benefits. The integration of optimization algorithm, TDO with electric vehicles for the improvement of power quality differs this research from other research work which offers better performance in real-world problems. To obtain better accuracy, a hybrid amalgamation of TDO with other AI techniques along with hybrid filters with numerous electric vehicles is suggested for further research. This research successfully demonstrated the necessity of AI techniques in future during the transformation of the electrification era.

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