THE SEU JOURNAL OF ELECTRICAL AND ELECTRONIC ENGINEERING (SEUJEEE), ISSN: p-2710-2130, e-2710-2149, Volume 02, Issue 02, JULY 2022
A SCHOLARLY PUBLICATION OF THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING, SOUTHEAST UNIVERSITY

A REVIEW ON PLUGGABLE HYBRID ELECTRIC VEHICLE CHARGING STATION FOR SMART GRID INTEGRATING RENEWABLE ENERGY

Imran Rahman and Ashraful Islam Mridha

***Abstract*—**Recent research towards using green technologies to reduce pollution and increase penetration of renewable energy sources in the transportation sector is gaining popularity. This has already created opportunities for researchers of diverse backgrounds to work together in developing ideas for the integration of large-scale renewable energy sources into the smart grid system as well as the adoption of Plug-in Hybrid Electric vehicles (PHEVs). The development of alternative energy systems to be used by electric vehicles requires successfully optimizing both systems. By facilitating the deployment of the Vehicle-to-Grid (V2G) idea, the evolution of the smart grid infrastructure on PHEVs may also be able to solve some of the current grid concerns. To accomplish the goal of a sustainable and carbon-free transportation system, the wide-scale adoption of PHEVs is essential to the development of the smart grid and the deployment of renewable sources. To do most of these tasks, mathematical models that heavily rely on computational intelligence-based optimization strategies must be developed. Higher penetration of PHEVs requires adequate charging infrastructure using a combination of renewable energy-based system and smart charging strategies. In this research, a State-of-Charge (SoC) optimization method for smart grid plug-in hybrid electric car charging stations that use renewable energy is proposed.

***Keywords*—**electric vehicles, V2G, renewable energy, state-of-charge, charging station, optimization, smart grid

I. INTRODUCTION

The transportation industry is responsible for about 55% of global oil consumption and around 25% of Emissions of carbon dioxide. According to research, the electrification of transportation could result in large drops in greenhouse gas emissions and decreasing reliance on oil [1]. Hybrid electric vehicles (HEVs) have become increasingly popular on the market during the past ten years. Recently created plug-in hybrid electric vehicles (PHEVs) promise to significantly improve better fuel economy by having a larger capacity rechargeable battery that can be charged from the energy grid and permitting the vehicle to continuously transit in an electric mode throughout an "all-electric-range" (AER) [2]. For the next smart power grid, integrating renewable energy is another difficulty. Production of renewable energy sources like wind and solar photovoltaic depends heavily on environmental conditions like the weather. As a result, the energy generated by those sources is often sporadic and subject to rapid fluctuations. Power reserves of greater scale are needed when adding such erratic power sources to the system. Being a regulated source and sink of power, the energy storage systems in PHEVs may significantly contribute to lowering the volatility in the output of renewable energy. [3]. The widespread integration of renewable energy sources into the power grid is hampered by a variety of factors [4] [5]. The availability of renewable energy sources, such as wind and solar photovoltaic (PV) electricity, is sometimes erratic and inconsequential to variations in demand. Whereas natural gas turbines may be ramped up and down to meet fluctuating demand, renewable energy sources such as wind and solar are only accessible when the wind blows or the sun shines. In this research, solar photovoltaic (PV) is considered the renewable energy source.

All of these strategies can be supported by electric vehicles with a smart power grid connection; thus, the exponentially growing use of electric vehicles (EVs) might be crucial to embedding renewable energy sources into emerging electrical grids. [6]. Smart power grid technologies usually call for paradigms that can address issues involving a significant number of extremely different participants, each of whom has its objectives and functions while acting in a fluid and turbulent environment [7]. By 2050, according to Electric Power Research Institute's (EPRI) forecasts (pragmatic saturation circumstance), PHEVs will resemble 62% of all the cars on American roads [4]. As a consequence, there is a rising need to consider the effects of this

Imran Rahman, is with the Department of Electrical and Electronic Engineering, Southeast University, Dhaka, Bangladesh (e-mail: imran.rahman@seu.edu.bd).

Ashraful Islam Mridha is with the Department of Electrical and Electronic Engineering, Southeast University, Dhaka, Bangladesh, (e-mail: ashraful.mridha@seu.edu.bd).

technology on the electrical grid. The stability of the electricity system might be threatened by a large number of PHEVs.For instance, when several thousand PHEVs are put into the system within a brief span of time, the consumption on the electric grid must be carefully controlled to minimize disruption (e.g., during the early morning hours when people arrive at work). The seamless interaction of the vehicle with the grid is one of the primary goals. A complex system will be required to be created in order to control numerous battery loads from a cascade of PHEVs optimally in order to maximize customer satisfaction and alleviate grid interruptions [8]. Additionally, the demand pattern will have a considerable influence on the operation of power systems due to the variations in demands of the PHEVs parked on the ramp at any specified instant [9]. The grid will be put under the least amount of stress possible with proper management, which will also make it easier to generate and transmit electricity. The management of PHEV charging may be divided into two divisions depending on where the charging infrastructure is located: 1) Charging at residence, and 2) Charging in the general populace. The suggested optimization is concentrated on the public charging station for plug-in cars since it is anticipated that most PHEV/PEV charging would occur in public charging facilities [10]. One of the important parameters for accurate charging is State-of-Charge (SoC). The SOC estimation's accuracy determines how well the charging scheme can be controlled. Due to the close proximity of the over-voltage threshold to the terminal voltage when the battery is completely charged, overcharging lithium-ion batteries, in particular,in particular, should be avoided to prevent irreparable damage [11].

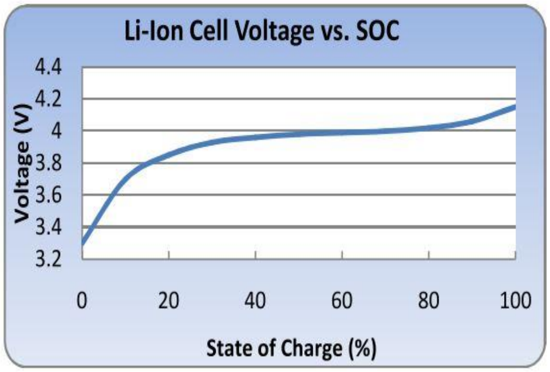

Fig. 1. Voltage of a lithium-ion battery vs. state-of-charge [11]

Figure 1 depicts a rough graph of a typical Lithium-Ion cell voltage vs SOC. The figure shows that charge balancing control and measurement circuits can rely on a measurable voltage difference when the slope of the curve is large enough to occur below 20 percent and above 90 percent. A brief description of battery SoC is discussed in the next section. In order to improve the performance of PHEVs in a charging station, a thorough study on how to maximize average SOC is required. The proposed research will investigate different control strategies in a renewable energy-based PHEVs charging station operating under various energy constraints and thus find a suitable mathematical framework for developing large-scale optimizations for allocating power. The market penetration of plug-in hybrid electric vehicles (PHEVs) and plug-in electric vehicles (PEVs), which is expected to be significant, raises a number of technological issues that must be resolved within the next ten years [5]. Electric vehicles of the future will be hooked into the grid and will have clean, renewable electricity used to recharge their onboard energy storage systems. Facilitating a seamless exchange of information between the plug-in hybrid electric vehicle and the power system is one of the main objectives [12]. So, an effective power allocation technique is necessary to enable the SoC of PHEVs as well as the general functionality of charging stations for large-scale PHEVs in smart power grid environments.

II. PROBLEM FORMULATION

Many technological issues need to be solved over the next 10 years [5] as a result of the anticipated significant market penetration of plug-in hybrid electric vehicles (PHEVs) and plug-in electric vehicles (PEVs).

Electric-powered automobiles of the future would be hooked into the grid and would have their onboard energy storage devices replenished with clean, renewable electricity. Making sure that the plug-in hybrid electric car and the power system communicate smoothly is one of the main goals [12]. In order to facilitate the SoC of PHEVs and the overall performance of charging stations for large-scale PHEVs in the context of a smart power grid, the best possible power allocation methodology is thus required.

A. Literature Review

The effective integration of plug-in hybrid electric vehicles (PHEVs) into the power system is a major impediment to the future smart power grid. As a result, during the past several years, academics from various fields have shown interest in this topic.Recent research advances have concentrated on a variety of technical aspects of plug-in hybrid electric vehicle (PHEV) integration into the smart power grid, including PHEV charging and control strategies, vehicle-to-grid (V2G) technology, and several application domains, including wind energy integration, frequency regulation, parking lot design, and involvement in power grids [16]. Recent survey studies in the topic of PHEV with renewable energy integration to smart power grid have been published. Various facets of PHEV research have been the subject of earlier articles. Several optimization techniques have been proposed in order to solve different problems like scheduling problem,infrastructure, smart charging terminals, inclusion in power markets, deployment of renewable energy, and smart parking. The next section will provide different concepts in the domain of PHEVs in smart power grid environment:

2.1 PHEV scheduling and charging

PHEVs collaborate with the grid when charging their batteries in the unidirectional mode of operation. Charging facilities techniques are required, which entails coordinating the charging of PHEVs on the grid to prevent increases in peak loads, lessen unpredictability in the production of renewable energy, and other factors [16]. In order to coordinate PHEV charging in real-time and reduce the overall cost of energy production and the related electric utility losses, a sustainable smart load governance (RT-SLM) technique has been proposed and developed in [17].. Three distinct time zones are used to simulate the outcomes of various charging scenarios, both uncoordinated and coordinated, at various PHEV penetration levels. These tactics are based on quadratic programming. To best schedule the PHEVs, a coordinated charging strategy is recommended in order to reduce power losses and increase the main grid load factor[19]. The link between feeder losses, load factor, and load variation is investigated in the context of coordinated charging in [20]. To lessen the impact of PHEVs on connected distribution networks, three optimum charging algorithms are constructed using these correlations, with the objectives of loss reduction, load factor maximization, and load variance minimization.With an emphasis on related optimization issues, the fundamental duties of an electric car charging provider are defined in [21].

With grid constraints on both power and voltage, a novel method for recharging electric drive automobiles is proposed. It is assessed in a model environment based on the power infrastructure of the Danish Islands. The authors in [22] suggests a distributed charging system for PHEVs where customers may choose their preferred charging rates. The authors demonstrate, using a kind of congestion pricing, how important price data is for managing usage mandate and balancing network feed. Results illustarte appropriate pricing, the onus of load scaling be transferred from the grid to the end users. The literature addresses the impact of charge plans and other pricing circumstances in a variety of ways. Certain research [23] or smart charging are the only topics covered [24]. Smart charging alludes to some degree of automatic control over the vehicle's charging by the utility or system operator. Others just compare two charging methods, such as straightforward charging and delayed charging.Comparing several charging techniques, such as a mix of simple, staggered, nighttime, sophisticated, and smart with V2G, is the most popular modeling strategy. [6].

2.2 Applications in renewable energy integration

The most significant influence on the electrical system that PHEVs might have is their capacity to help with the integration of renewable energy sources into the current electrical system [9]. The future smart power grid has further difficulties integrating renewable energy. Wind and solar photovoltaic energy generation are heavily reliant on environmental variables like the weather. Because of this, the energy derived from such sources has a propensity to be sporadic and subject to rapid fluctuations. The grid needs power reserves of greater scale before introducing such unpredictable power sources. Due to their ability to act as both a regulated source and sink of energy, PHEV energy storage systems can significantly contribute to lowering the volatility in the production of renewable energy. Various technological problems with the incorporation of renewable energy have been reviewed in recent review papers. Richardson researches how PHEVs help to integrate renewable energy sources including wind, solar, and biomass. The survey's emphasis is on computational and algorithmic techniques. In addition to several recent ground-breaking ideas, many case studies on initiatives employing PHEVs for the integration of wind energy are provided.

2.3 Vehicle-to-grid (V2G)

The majority of the literature on PHEVs and the electric power grid is based on models, which is probably because there aren't many real-world systems that are big enough to analyze. V2G cars have undergone a few proof-of-concept experiments with a single car, but no systems-level empirical evaluationshave been done. Long-term, system scale planning models and hourly time-series models are the two basic groups into which the models utilized in the literature may be separated. For the PHEVs to operate cost-effectively in the V2G mode, both charging and discharging to the grid must be managed. The relevant literature places a lot of emphasis on various intelligent scheduling and charging methods for PHEVs.

The vehicles are scheduled using the Binary Particle Swarm Optimization (BPSO) technique, and the results demonstrate the need for advanced control and protection to prevent any negative effects from the significant bidirectional power surges to the batteries and inverters of the individual plug-in vehicles. A V2G algorithm is created to efficiently schedule energy and auxiliary services in order to maximize profit for aggregators, while also giving the utility flexibility, peak load shaving, and low charging rates. For metropolitan Texas households, driving profiles were created using data from the 2009 National Highway Travel Survey. Results demonstrate that the algorithm provides substantial financial advantages to customers and aggregators for various battery replacement prices, adding additional system benefits.

2.4 Infrastructure facilities

The growth of EV infrastructure amenities such as charging systems and parking areas has been hampered by new opportunities and challenges brought about by smart power grid. Recent advancements in the renewable energy sector have opened the door to the possibility of a green infrastructure system that will reduce the burden of PHEVs in traditional grid-dependent charging infrastructures. Birnie proposes solar PV arrays built over parking lots to charge commuter vehicles during the day. The paper sketches out a rough sketch of such a system and evaluates the potential energy production from a single parking space. Li et al. [20] conduct a similar analysis using Alberta, Canada data. The authors calculate the size of solar PV panel required to meet a PHEV's daily energy requirements. Neumann et al. [21] investigate the large-scale deployment of parking lot solar car chargers. This study installs solar carports on all available large parking lots in a medium-sized Swiss city; the authors estimate that solar energy could meet 14-50 percent of the city's passenger transportation energy demand under the proposed system. Letendre discusses PV parking lot charging and other business models for charging PHEVs with solar energy. Parking lot chargers could be grid-connected or stand-alone units, with the capacity to meet daily PV demand. The Local Energy Storage (LES) for the ideal size of the charging facility is built using a cost-cutting framework.

Related Works

The paper's previous section provides a summary of recent research in four major areas of PHEV integration in smart power grids. As the research will mainly focus on the optimization techniques for solving issues related to renewable energy-based charging station for plug-in hybrid electric vehicles in smart power grid environment, the current section will explore different optimization methods applied in this area. Future smart power grid and smart city visions envision the widespread use of electric vehicles that can be charged either on- or off-board and run on an electric power source [9]. Because PHEVs would put a load on the power grid, embryonic charging infrastructure is a major obstacle to the widespread adoption of electric vehicles [4]. In light of this, it is crucial to establish a specified number of charging stations for electric vehicles in suitable locations. Researchers have proposed a variety of techniques for achieving this goal [3][4]. Charging stations must be installed at residences, businesses, markets, and shopping centers in order to keep electric vehicles powered up and operating reliably. It was suggested by authors that in order to maintain grid stability and use energy efficiently, it is necessary to build smart recharging station with effective communication infrastructure [5]; Utility, substation control center, charging station, and electric vehicle communication Furthermore, an analysis of recharging stations is being conducted in terms of charging characteristics [6]. As a result, work is being done to create an efficient, dependable, robust, and cost-effective charging infrastructure. As a result, numerous methodologies and techniques for the deployment of PHEV charging stations have been proposed [4]. The widespread use of electric vehicles can result in a significant increase in power load in local areas, particularly during peak hours. Non-linear charging loads can also cause high harmonics and poor power factor, which can have a significant impact on the local utility company. The installation of a PV charging station for plug-in electric vehicles is an appealing technology because it can optimize power consumption during peak hours.

Several studies are reported in the literature on optimization of PHEV charging station in smart grid but most of the papers discuss without mentioning the issue of renewable energy integration and state-of-charge (Soc) of the battery . Some current papers discuss the charging rate strategies in smart grid environment. In previous studies, the superiority of smart charging to dumb charging and dual tariff charging have been demonstrated well. Vasirani and Ossowski put forward an allocation mechanism inspired by a lottery scheduling method for allocating the available power to various simultaneous plugged-in PEVs. Authors also evaluated

. In [7], authors demonstrated how the demand for charging may be satisfied with only a few number of public charging stations, highlighting the significance of user-vehicle-grid interaction as well as the deployment optimization challenge.The grid, particularly the distribution resources, might potentially experience a major demand from supplying electricity to a sizable fleet of PHEVs, hence techniques and algorithms for efficient charge planning have received a lot of attention [10–13].

III. CHALLENGES AND RESEARCH ISSUE

Prior review paper literature paid minimal attention to several of the fields, including optimization of charging stations and renewable energy integration, notably PV-based charging infrastructure design. Plug-in vehicles could be charged during low demand periods when there is excess capacity on the grid, reducing grid strain and avoiding major generation and transmission infrastructure additions [8]. Quality of service of a recharging station is measured in terms of how fast the vehicles' battery is charged and discharged, provision of electric supply for recharging PHEVs, delay in accepting charging request by vehicle owner, long term effect on battery performance, and pricing [5]. Suggested potential locations for charging station include driveways, Phone booths [2], parking lots, restaurants, stores, coffee shops and shopping malls [5]. The electric vehicle charging station will utilize advanced design and technology allowing electricity to flow from the site's normal electric service to the charging stations or for the solar system to provide available electricity to fuel the cars reducing the cost of the driver's fuel bills [6]. It is expected that mostly recharging will occur at home even if there is a sufficient public charging station network. It does not necessarily mean that there is no or lower need of public smart charging stations because many residences do not have adequate facilities for recharging PHEVs [8].

Furthermore, the goal of smart charging is to charge the car when it is most advantageous, which could be based on some other statistic, the lowest electricity price, the lowest demand, or any other circumstance [9].

Here, the main research focus area is to optimize the average State-of-Charge (SoC) of renewable energy-based Dc fast charging station for plug-in hybrid electric vehicles in smart grid environment.

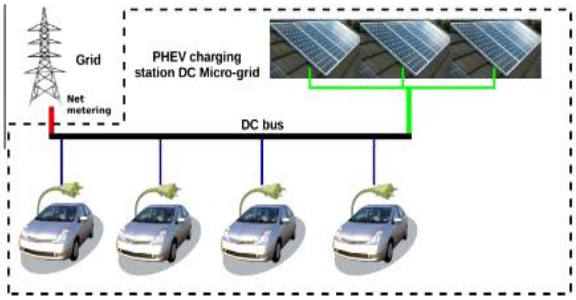

Fig. 2. PV based workplace charging concept.

Fig. 2 displays a surface parking garage with several charging stations, PV panels on the top, and a bidirectional grid connection. The grid connection is built to deliver excess PV energy to the grid through net metering and to meet any charging demand that is larger than the PV production. The system controller must compromise both the benefits of the PHEV/EV customer and the desire of the power utility. On the one hand, the charging strategy must accommodate the PHEV/EV customer's preferences. Minimize the total charging cost for customers who are willing to pay when the electricity cost is below the expected threshold, for example. Customers who require maximum SoC of battery during charging time, for example, require the strategy to maximize the SoC of vehicles, etc. On the other hand, the system must also satisfy utility desires, such as minimizing the power consumption of charging spot systems subject to allowed power from utility, particularly during peak hours, and so on [7].

IV. HYPOTHESIS AND RESEARCH OBJECTIVE

With existing laws and regulations, fifty percent of new cars sold in the near future will be green energy vehicles, predict the Electric Power Research Institute and the International Energy Agency [1]. A scenario where charging solely takes place at night in the user's home, however, will not be feasible; as a result, public charging stations, as well as rapid charging technologies, as well as rapid charging technologies have emerged. The conventional grid-connected charging station was the major subject of earlier investigations on PHEV charging. Millions of PHEVs being charged at once might overwhelm the electrical system, raise emissions, and substantially change economic aspects [7]. Therefore, this study takes into account a stand-by grid connection and a plug-in hybrid electric car charging station that is powered by renewable energy.

The majority of the approaches utilized in the earlier literature are standard metaheuristic ones, such as PSO [9], GA [8], EDA [10], IPM [8], etc. It has become clear through time that the one typical technique has several drawbacks. In order to solve many difficult optimization issues, researchers are now merging one metaheuristic with another (meta-) heuristic. This process is known as hybridization. Hybrid techniques combine a number of metaheuristic algorithms that are effective in locating comprehensive solution that cannot be found with any comprehensive approach in a reasonable amount of time.

So, the research objectives are:

(1) The suggested study intends to provide some justice in the distribution of PHEVs' median states of charge (SoC) at each time step.

An innovative hybrid optimization technique (PSO-GSA) will be used to the Plugin Hybrid Electric Vehicle issue in order to accomplish the aforementioned objective. The suggested improvement will assist guarantee that each vehicle reaches a sufficient level of battery power even in the case of an early departure. It is anticipated that combining the exploration and exploitation capabilities of GSA [8] with PSO [6] would provide superior results than a single classical optimization approach.

(2) The suggested study will make it possible to compromise the advantages of both PHEV owners and charging station operators via flexible charging management strategies.

In this dissertation, it is assumed that every car is V2G competent. In other words, once connected, every car has high-tech power electronics that can enable two-way power flow and two-way communication. The algorithm will thus enhance the current charge management tactics used in the charging stations by optimizing the mean SoC.

V. METHODOLOGY

As described in the last section that, there has been a very few attempts from the researchers to apply hybrid meta-heuristic algorithms for solving the problems related to PHEVs in smart grid environment. In order to efficiently charge and discharge PHEVs, a mix of To solve the UC issue and increase reliability, Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) algorithms were developed in [8].

When compared to other methods like the original GSA, PSO, and GA, GSA hybrids have shown outstanding outcomes. For instance, the problem of sluggish searching speed in GSA iterations has been effectively solved by the PSOGSA hybrid [4]. Both gravitational search algorithm (GSA) and particle swarm optimization (PSO), which are both meta-heuristic algorithms, are based on the laws of gravity and mass interaction and the social behaviors of flocking birds, respectively [7].

In this study, a novel hybrid particle swarm optimization and gravitational search algorithm (PSOGSA) that combines PSO and GSA features is proposed to maximize the average SoC for PHEVs at the following time step while taking into account a variety of real-world constraints, including charging time, the current SoC, and the cost of energy. The hybrid PSO-GSA algorithm's advantage is that it is mostly resistant to the non-linear character of the issues under consideration.

.

The standard PSO and standard GSA:

In this section, we provide a brief description of standard PSO and standard GSA.

A. *Standard Particle Swarm Optimization*

The evolutionary computation method known as PSO was originally out by Kennedy and Eberhart. The PSO took its cues from flocking bird behavior. To discover the optimal answer, it employs a number of particles (candidate solutions) that flit around in the search space. They all turn to the best particle (or best solution) in their path in the meantime. In other words, particles take into account both their own best solutions and the best solution that has been discovered so far.

When modifying its location, each particle in the PSO should take into account its current position, velocity, distance from pbest, and distance from gbest (Fig. 3.). The following is a mathematical model of PSO:

$$V_i^{t+1} = wv_i^t + c_1 \times \mathrm{rand} \times (\mathrm{pbest}_i - x_i^t) + c_2 \times \mathrm{rand} \times (\mathrm{gbest} - x_i^t) \quad (1)$$

$$x_i^{t+1} = x_i^t + V_i^{t+1} \quad (2)$$

Where v_i^t is identified as the velocity of particle i at iteration t, w is a weighting function apparently used as described.

$$\omega = \omega_{\max} - \frac{w_{\max} - \omega_{\min}}{\mathrm{Itre}_{\max}} \mathrm{Itre} \quad (3)$$

0.9 and 0.4 are the recommended numbers for $w_{\max}$ and $\omega_{\min}$. For c_2 and c_1 the value series of 1 to 2 is appropriate.

The advantages of PSO are:

i) Ability to search very large spaces of candidate solutions.
ii) Capable of consistently delivering accurate results.

iii) Reliable and adaptable.
iv) Adaptable to a wide range of problems while requiring minimal computational resources.

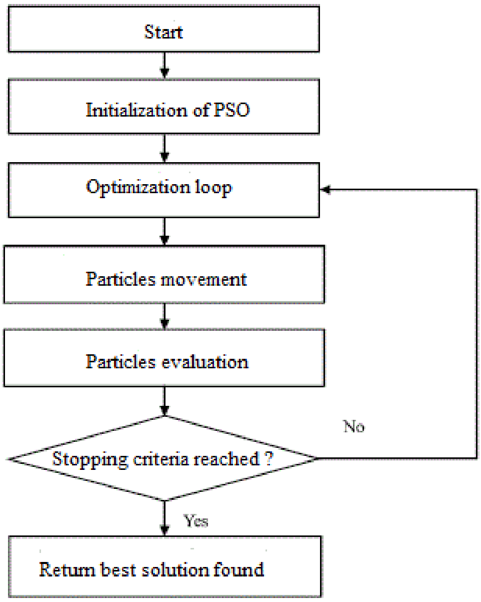

Fig. 3. Standard PSO Flowchart

The typical PSO has a few of limitations, including premature convergence and entrapment in local optima. Trajectory stability analysis has been used to generate PSO convergence findings, and it has required a fair amount of analysis and effort.

B. *Standard Gravitational Search Algorithm*

GSA is a brand-new heuristic optimization technique that Rashedi et al. introduced in 2009. One way to conceptualize GSA is as a collection of agents (candidate solutions) whose masses are proportional to the value of their fitness function. Gravitational forces between masses have drawn people together for countless years. The mass will be heavier the stronger the attraction force. Because of this, the heavier masses, which are probably close to the global optimum, pull the other masses toward them in proportion to their distances (Fig. 4). This is how the gravitational force is defined:

$$F_{ij}^{d}(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\varepsilon}\left(x_{j}^{d}(t) - x_{i}^{d}(t)\right) \quad (4)$$

The $G(t)$ is calculated as

$$G(t) = G_0 \times \exp(-\alpha \times \mathrm{iter}/\mathrm{maxiter}) \quad (5)$$

Where iter is the current iteration, max_iter denotes the maximum number of iterations, α and G_0 denote the descending coefficient and beginning value, respectively.

The total force acting on agent i in a problem space of dimension d is determined using the following equation:

$$F_i^d(t) = \sum_{j=1,j\neq i}^{N} \mathrm{rand}_j F_{ij}^d(t) \quad (6)$$

Where rand_j denotes a random number in the interval from 0 to 1 and can be represented in a matrix format as[0,1] .

Since an agent's acceleration is inversely proportional to its mass and proportional to the result force, the acceleration of all agents should be calculated as follows.:

$$ac_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (7)$$

Where specific time is denoted by t and total mass of the object I is M_{ii}.

The position and velocity of all the agents are estimated like this:

$$vel_i^d(t+1) = \mathrm{rand}_i \times vel_i^d(t) + ac_i^d(t) \quad (8)$$

$$x_i^d(t+1) = x_i^d(t) + vel_i^d(t+1) \quad (9)$$

In this case, rand_i is a random type number where the interval lies in the range of [0, 1].

All masses in GSA are first initialized with random values. Each mass represents a potential solution. Following initialization, all masses' velocities are determined using (8). The accelerations, total forces, and gravitational constant are determined as (5), (6), and (7), respectively. Mass locations are determined by utilizing (9). In the end, GSA will be halted by fulfilling an end requirement.

The advantages of GSA are:

i) Capable of solving highly nonlinear optimization problems of complex engineering systems.
ii) Perform efficiently in terms of CPU time.
iii) Perform better than other optimization algorithms like PSO and ACO in terms of

convergence speed and avoiding local minima.

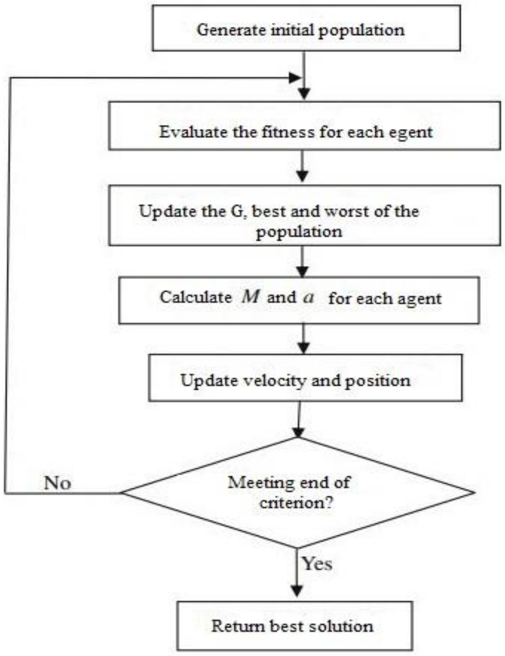

Fig. 4. Standard GSA Flowchart

C. The Hybrid PSOGSA algorithm

To increase the average SoC for Plug - in hybrid electric Vehicle at the next time step, a revolutionary hybrid particle swarm optimization and gravitational search method (PSO-GSA) with PSO and GSA features is suggested in this investigation. In 2010 [7], Mirjalili and Hashimor devised the hybrid population-based algorithm known as PSOGSA. The fundamental concept underlying PSOGSA is to fuse (Gbest), the social thinking function of PSO, with the local search functionality of GSA. The following equation is suggested for fusing these algorithms:

$$V_i(t+1) = w \times V_i(t) + c_1' \times \text{rand} \times ac_i(t) + c_2' \times \text{rand} \times (\text{gbest} - X_i(t)) \quad (10)$$

Where $V_i(t)$ is denoted as the agent $i's$ velocity at iteration t, a weighting factor is identified as c_j', a weighting function is dentoed as w, a random number is called as rand which has a range of from 0 to 1, $ac_i(t)$ is the acceleration of agent i at iteration t and $gbest$ is the optimum solution so far (Fig.5).

In each iteration, the positions of particles are updated as follow:

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (11)$$

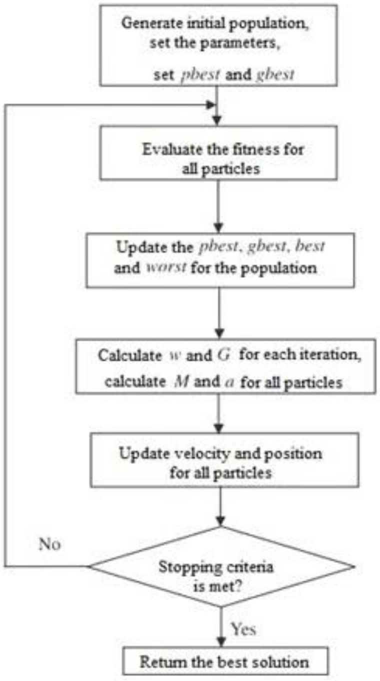

Fig. 5 Flowchart of Hybrid PSOGSA

VI. CONCLUSION

All population-based meta-heuristic algorithms, including PSO and GSA, must maintain a good balance between exploration and exploitation in order to handle challenging optimization problems. These two crucial elements should be included in a better algorithm to guarantee the greatest outcome. In PSO, pbest essentially determines the exploration ability whereas gbest mostly determines the exploitation ability. In GSA, the exploration, the sluggish movement of heavier agents, and the elimination of participating agents may all be assured by choosing the right values for specific parameters ($G_0$and α). In order to facilitate the SoC of PHEVs as well as the overall performance of charging stations for significant penetration of PHEVs in smart power grid, an efficient power allocation mechanism is needed.

VII. REFERENCES

[1] “On certain integrals International Energy Agency (lEA), Transport, Energy and C02-Moving Towards Sustainability, 2009.
[2] "Environmental assessment of plug-in hybrid electric vehicles," Volume 1: Nationwide greenhouse gas emissions, Electric Power Research. Institute (EPRI), Palo Alto, CA, Tech. Rep. 1015325,

Jul. 2007.
[3] G. Shafiullah, A. MT Oo, A. Shawkat Ali, and P. Wolfs, "Potential challenges of integrating large-scale wind energy into the power grid–A review," Renewable and Sustainable Energy Reviews, vol. 20, pp. 306-321, 2013.
[4] Boyle G, editor. London: Earthscan; 2007.
[5] Harvey LDD. "Energy and the new reality 2: carbon-free energy supply", London: Earthscan; 2010.
[6] H. Lund and W. Kempton,"Integration of renewable energy into the transport and electricity sectors through V2G," Energy policy, vol. 36, pp. 3578-3587, 2008.
[7] A. R. Hota, M. Juvvanapudi, and P. Bajpai, "Issues and solution approaches in PHEV integration to the smart grid," Renewable and Sustainable Energy Reviews, vol. 30, pp. 217-229, 2014.
[8] W. Su and M.-Y. Chow, "Computational intelligence-based energy management for a large-scale PHEV/PEV enabled municipal parking deck," Applied Energy, vol. 96, pp. 171-182, 2012.
[9] W. Su and M.-Y. Chow, "Performance evaluation of a PHEV parking station using particle swarm optimization," in Power and Energy Society General Meeting, 2011 IEEE, 2011, pp. 1-6.
[10] W. Su and M.-Y. Chow, "Performance evaluation of an EDA-based large-scale plug-in hybrid electric vehicle charging algorithm," Smart Grid, IEEE Transactions on, vol. 3, pp. 308-315, 2012.
[11] A. Shafiei and S. S. Williamson, "Plug-in hybrid electric vehicle charging: Current issues and future challenges," in Vehicle Power and Propulsion Conference (VPPC), 2010 IEEE, 2010, pp. 1-8.
[12] L. Zhang, T. Brown, and S. Samuelsen, "Evaluation of charging infrastructure requirements and operating costs for plug-in electric vehicles," Journal of Power Sources, vol. 240, pp. 515-524, 2013.
[13] J. Chiasson and B. Vairamohan, "Estimating the state of charge of a battery," Control Systems Technology, IEEE Transactions on, vol. 13, pp. 465-470, 2005.
[14] W.-Y. Chang, "The State of Charge Estimating Methods for Battery: A Review," ISRN Applied Mathematics, vol. 2013, 2013.
[15] Jingyu Yan; Chongguo Li; Guoqing Xu; Yangsheng Xu, “A novel on-line self-learning state-of-charge estimation of battery management system for hybrid electric vehicle”, Intelligent Vehicles Symposium, 2009 IEEE.
[16] A. R. Hota, M. Juvvanapudi, and P. Bajpai, "Issues and solution approaches in PHEV integration to the smart grid," Renewable and Sustainable Energy Reviews, vol. 30, pp. 217-229, 2// 2014.
[17] Deilami S, Masoum AS, Moses PS, Masoum MAS. “Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile.” IEEE Trans Smart Grid 2011;2(3):456–67 (Sept.).
[18] Mets K, Verschueren T, Haerick W, Develder C, Turck FDe. “Optimizing smart energy control strategies for plug-in hybrid electric vehicle charging.” In: Network operations and management symposium workshops (NOMS Wksps), 2010 IEEE/IFIP, pp. 293–299,19–23 April; 2010.
[19] Clement K, Haesen E, Driesen J. “Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids.” In: Power systems conference and exposition, 2009. PSCE‘09. IEEE/PES, pp. 1–7,15–18 March; 2009.
[20] Sortomme E, Hindi MM, MacPherson SDJ, Venkata SS. “Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses.” IEEE Trans Smart Grid 2011;2(1):198–205 (March).
[21] Sundstrom O, Binding C. “Flexible charging optimization for electric vehicles considering distribution grid constraints.” IEEE Trans Smart Grid 2012;3 (1):26–37 (March).
[22] Fan Zhong. “Distributed charging of PHEVs in a smart grid,” smart grid communications (SmartGridComm). In: 2011 IEEE international conference, pp. 255–260, 17–20 Oct.; 2011.
[23] Hodge B, Huang S, Shukla A, Pekny J, Reklaitis G. “The effects of vehicle-to-grid systems on wind power integration in California. “Computer Aided Chemical Engineering 2010;28:1039–44.
[24] Short W, Denholm PA. “Preliminary assessment of plug-in hybrid electric vehicles on wind energy markets.” Golden, CO: National Renewable Energy Laboratory; 2006.

Imran Rahman received BSc. Engg. degree from the Department of Electrical and Electronic Engineering, Islamic University of Technology (IUT), Bangladesh in the year 2011 and MSc. degree from the Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS (UTP), Bandar Seri Iskandar, Malaysia in the year 2016. Currently pursuing PhD. under 'USM Global Fellowship' from the School of EEE, Universiti Sains Malaysia (USM). His current field of research is Computational Intelligence and Smart Grid. He has been serving as a Lecturer in the Department of Electrical and Electronic Engineering in Southeast University. He formerly held a Lecturer position at Leading University, Sylhet.

In 2021, **Ashraful Islam Mridha** graduated from Islamic University of Technology (IUT) with a Bachelor of Science in Electrical and Electronic Engineering.His current studies at Islamic University of Technology are for a Master of Science in Electrical and Electronic Engineering (IUT).He has been a Lecturer in Southeast University's Electrical and Electronic Engineering Department. He formerly held a Lecturer position at Dhaka International University. As part of the Bengal Future Leader Program, he also held a Management Trainee Officer position with Bengal Group of Industries.His areas of interest in study include power electronics, electric vehicles, machine learning, reinforcement learning, power and energy.