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Optimal Dispatch of Vehicle-to-Grid (V2G) Battery Storage using p-ELECTRE Method and its Impact on Optimal Scheduling of DGs in Distribution System

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Abstract—In recent past the number of electric vehicles (EVs) have increased significantly due to their various advantages to environment. With the proper charging and discharging of EVs with vehicle-to-grid (V2G), electrical system can get controllable storage/generations and at the same time EV owners can earn profits. This paper presents a novel dispatch strategy to determine, when and at what rate EV battery should charge/discharge in order to maximize profits to EV owners and responding to power system's requirements while considering the effect of renewable DG power availability. This objective depends on many criteria like buying and selling price of energy, battery state of charge (SoC), Renewable DG power availability, and load levelling. To solve these, a new multi-criteria decision analysis method, Probabilistic Elimination and Choice Expressing Reality (p-ELECTRE) is developed. The proposed optimal dispatch strategy is applied to 100 and 200 EV fleets with random travel plan. Further, the effect of these fleets with optimal dispatch strategy is tested on IEEE 33 bus distribution system with added DGs. Furthermore, optimal power dispatch of DGs in EV rich distribution system is obtained by BAT Optimization Algorithm (BOA). The simulation results demonstrate the feasibility and benefits of the proposed technique.

Keywords-distributed generations (DGs); electric vehicles (EVs); vehicle-to-grid (V2G); p-ELECTRE; bat optimization algorithm; optimal dg scheduling;

Nomenclature

$\hat{r}$	Normalized Decision Matrix	$g_{k,l}$	Dominant Discordance Matrix
$\{C_{k,l}\}$	Set of concordance index	$\check{a}$	Aggregate Dominance Matrix
$\{D_{k,l}\}$	Set of discordance index	P_{SoC}	Probability of choice selection based on SoC
$C_{k,l}$	Concordance Matrix	EP	Electricity price
$D_{k,l}$	Discordance Matrix	P_{EP}	Probability of choice selection based on EP
$\underline{c}$	Concordance threshold values	P_{Load}	Probability of choice selection based on Load
$\underline{d}$	Discordance threshold values	P_{a-PV}	Probability of choice selection based on availability of PV power (a-PV)
γ	Normalized Weight Matrix	EP_{max}	Maximum EP in the forecasted day
$f_{k,l}$	Dominant Concordance Matrix	EP_{min}	Minimum EP in the forecasted day

aPV_{max}	Maximum availability ratio of PV power on forecasted day	r_k	resistance of k^{th} line (pu)
		x_k	reactance of k^{th} line (pu)
aPV_{min}	Minimum availability ratio of PV Power on forecasted day	S_{pq}	Complex power flow through k^{th} line (P to Q line)
		α	Ratio of Real Power loss with and without DG
P	From bus (Starting bus) for k^{th} line	β	Ratio of maximum Voltage deviation with and without DG
Q	from bus(Ending Bus) for k^{th} line		
V_P	P^{th} bus complex voltage (pu)	φ	Ratio of operating cost of DG to its maximum operating cost
V_Q	Q^{th} bus complex voltage (pu)		

1. Introduction

Reduction of energy cost, emissions and usage of fossil fuels are the main reasons for growing concerns regarding the use of electric vehicles [1]. According to a new forecast published by Bloomberg New Energy Finance (BNEF), EVs would constitute up to 54% of new car sales by 2040[2]. The parked and connected EV can act like load while charging the battery and can feed back to the grid by discharging it. EVs will help the power system by adding additional load and help to maximize the absorption of the extra electricity generated by renewable sources [3]–[4]. With optimal charging and discharge criteria and V2G support, EVs will help the power system by providing support such as load levelling, spinning reserves, and voltage and frequency regulation.

In [5]–[7], the applications of V2G connected EV battery storage with significant storage/generation capacity to power systems are analyzed. The maximum benefits of EV battery storage and its impact on power system is affected by its charging strategies [8]. Strategically dispatched EV Battery storage helps to reduce the loss, improve the voltage profiles and relieve the congestion in the power system.

In recent times many researchers have focused to find the optimal dispatch strategies for EV batteries connected to the grid.[9] studied optimal dispatch strategy of EVs while focusing on frequency regulation of the electrical system. It also considered the travel demand of EVs while determining the dispatch strategy. Operational plans for a microgrid with EV fleet are obtained for

different users in [10]. A bi-directional coordinating dispatch of large scale V2G through a complementary modern interior point algorithm has been proposed in [11]. This study shows that the V2G technology is economically beneficial the electrical network as well as the EV user. Heuristic approach viz. particle swarm optimization (PSO) based determination of optimal dispatch strategy for EVs has been proposed in [12] in conjunction with optimal scheduling of distributed sources. Lu et al. [13] proposed an Analytic Hierarchy Process (AHP) for Dispatch of Vehicle-to-Grid Battery Storage.

From the aforementioned literature, it can be observed that there is a strong need for a better and accurate charging/discharging strategy for EV batteries. That strategy should make profits to EV owners and also attain better operational requirements to power system. From the literatures it is also observed that, the EV battery dispatch strategy depends on the different criteria like, battery characteristics, state of charge of the vehicles' batteries, cost to EV users, EV integration capacity to the grid, cost saving by observing selling and buying electricity price, rate of dispatch and system constraints like load levelling, contingencies etc. But the effect of renewable DG Power availability on battery dispatch strategy with V2G is not considered in the above literature. For each criterion, the dispatch strategy of EV battery will be different. For considering all the criteria at a time, every criteria needs to be weighed according to its importance.

ELECTRE method is a type of multi-criteria decision analysis methods which simultaneously evaluates various criterions considering their precedence over each other in order to take a decision [14]. The ELECTRE method has been applied to many decision-making related to real world problems [15]–[16]. Instead of direct scores towards any action based on a criterion, probability of taking a decision based on the criterion is used in the proposed p-ELECTRE method. The p-ELECTRE evaluates criterions and determines the action in accord to probability of suggestive actions proposed by various independent factors while considering relative importance of criterions over each other depending upon the situation. A novel dispatch strategy for EV batteries based on probabilistic Elimination and Choice Expressing Reality (p-ELECTRE) is elaborated in this paper.

The new dispatch strategy is proposed by considering criteria viz. SoC, selling and buying electricity prices, load levelling and renewable DG power availability. For the first time, in this paper, the effect of renewable DG power availability to the dispatch strategy of EV battery is studied and considered as one of the criteria to develop the dispatch strategy of EV battery using multi criteria decision-making tool, p-ELECTRE. Renewable DG power availability affects both the electricity selling and buying market prices, system load demand, system congestion planning and also dispatch strategy of EV battery. With the high renewable DG power availability, the EV batteries are advised to charge more due to lower pricing of electricity and less effective on system load. Using the proposed strategy, effect of addition of 100 EVs and 200EVs to the system with different travel plans of one hour time interval is studied. In this study, real-time pricing data [17], load demand and PV power availability are considered. The proposed technique is tested on an IEEE 33 bus distribution system with added DGs. Further, the optimal dispatch of DGs in EV rich distribution system is obtained by BOA algorithm with loss, cost and voltage deviation as objectives to minimize.

The main contributions of the paper can be summarized as follows:

- 1) A new dispatch strategy of EV battery is proposed with newly developed multi criteria decision-making tool, p-ELECTRE.
- 2) First time, in this paper the renewable DG power availability is considered along with the SOC, electricity price and load levelling as the criteria to develop the dispatch strategy of EV battery.
- 3) Fleets of EVs containing 100 and 200 EVs based on proposed dispatch strategy is applied to a standard IEEE 33 bus radial distribution system with added DGs.
- 4) With BAT optimization algorithm, optimal dispatch of the DGs is obtained including strategic dispatch of EV fleets on distribution system for minimization of loss, cost and voltage deviation.

The paper is organized as follows: the proposed p-ELECTRE method is explained in section 2. Various criteria including renewable DG power availability; and proposed dispatch strategy of EV battery storage with p-ELECTRE method is detailed in section 3. Addition of EV fleets to distribution

system and their effects are analysed in section 4. The optimization problem is formulated and optimal dispatch of DGs with Bat algorithm is presented in section 5. Analysis of the obtained result and discussions are given in section 6 and conclusions are presented in section 7.

2. Probabilistic Elimination and Choice Expressing Reality (p-ELECTRE) Method

The p-ELECTRE method is highly recommended when there is a strong heterogeneity among the criteria to take a decision. The method used comprises of two main procedures:

- 1) Construction of two outranking relations: Concordance and Discordance.
- 2) An Exploitation Procedure.

Construction of the outranking relations is dedicated to analyze and compare comprehensively all kind of outcomes. The exploitation procedure aims toward choosing the most appropriate action based on either ranking or sorting.

As instantaneous values of the parameters are taken into consideration, direct scores in favor of actions cannot be marked, so in p-ELECTRE method probability is used to evaluate favor to an action based on instantaneous values of the criteria. These probabilities constitute the Decision Matrix (DM). Probabilities make the decision matrix uniform and are also easy to analyze. The DM prioritizes either of potential actions exclusive of each other based on their current values. The complete DM formation for optimal dispatch of EV is elaborated in Section 3. Normalization of DM is done using equation (1).

$$\hat{r}_{i,j} = \frac{DM_{i,j}}{\sqrt{\sum_{i=1}^m DM_{i,j}^2}}, i = 1, 2, \dots, m; j = 1, 2, \dots, n; \quad (1)$$

Where $\hat{r}_{i,j}$ is normalized decision matrix, i and j are temporary variables. Here m represents total number of dispatch actions and n represents total number of criteria.

Considering all the criteria at a time, every criteria needs to be weighed. The weights are according to relative importance of criteria. Weightage to each criterion is provide as

$$W = [W_1 \ W_2 \ W_3 \ \dots \ W_n] \quad (2)$$

Normalized Weight Matrix ($\gamma_{i,j}$) is calculated using Equation (3).

$$\gamma_{i,j} = \hat{r}_{i,j} * w_j \quad (3)$$

The set of concordance and discordance index ($\{C_{k,l}\}$ and $\{D_{k,l}\}$) are formed as shown in Equation (4) and Equation (5). Where k is the choice number.

$$\{C_{k,l}\} = j; \gamma_{k,j} \leq \gamma_{l,j}, j = 1, 2, \dots, n \quad (4)$$

$$\{D_{k,l}\} = j; \gamma_{k,j} \geq \gamma_{l,j}, j = 1, 2, \dots, n \quad (5)$$

The $C_{k,l}$ shown in Equation (6) comprises of voting power of the criteria that clearly are in favor of a particular choice. For an outranking relationship to be validated a sufficient majority of criteria should be in favor of the statement. Whereas, $D_{k,l}$ shown in Equation (7) implies that when the condition of the argument is valid, none of the criteria of the minority is strongly in opposition to a statement.

$$C_{k,l} = \sum_{j \in \{C_{k,l}\}} (w_j) \quad (6)$$

$$D_{k,l} = \frac{\max\{|\gamma_{k,j} - \gamma_{l,j}|\} \forall j \in D_{k,l}}{\max\{|\gamma_{k,j} - \gamma_{l,j}|\} \forall j} \quad (7)$$

To get a crisp dissimilarity among the contexts in and against a particular action, threshold indices and matrices are used. A threshold index is an average agreement or disagreement marker such that the elements in concordance/discordance matrices are strongly in favor of/against a choice if they exceed the threshold value, else otherwise. The threshold indices for concordance and discordance matrices are given in Equation (8) and Equation (9) respectively.

$$\underline{c} = \frac{\sum_{k=1}^m \sum_{l=1}^m C_{k,l}}{m(m-1)} \quad (8)$$

$$\underline{d} = \frac{\sum_{k=1}^m \sum_{l=1}^m D_{k,l}}{m(m-1)} \quad (9)$$

The comparison of elements with respective threshold indices yields dominant concordance f and discordance g matrices, shown in Equation (10) and Equation (11), which signify the actions which are in context are better choice than the other.

$$f_{k,l} = \begin{cases} 1, & \forall C_{k,l} \geq \underline{c} \\ 0, & \forall C_{k,l} \leq \underline{c} \end{cases} \quad (10)$$

$$g_{k,l} = \begin{cases} 1, & \forall D_{k,l} \geq \underline{d} \\ 0, & \forall D_{k,l} \leq \underline{d} \end{cases} \quad (11)$$

$$[\ddot{a}] = [f] * [g] \quad (12)$$

It is observed that the action associated to the row in dominant concordance matrix f and the column in dominant discordance matrix g which contains maximum numbers of 1 are a better choice than other alternatives. Hence, employing matrix multiplication in Equation (12) yields the highest digit as compared to all other elements of the resultant matrix in the row associated to the most favorable choice. The above mentioned improvisation is better suited for choosing a dispatch action than using the elimination process in the actual ELECTRE method [14] which very often leads to a situation of indecisiveness.

3. Dispatch Strategy of Electric Vehicle Battery with p-ELECTRE

3.1 Battery Characteristics

The battery considered in the EVs has the following characteristics: [13] rated capacity: 100Ah; nominal current: 20A; nominal voltage: 240V; Peukert capacity: 182.06Ah; charge/discharge currents: 2A/10A/30A; effective available capacity: 158.5Ah/114.87Ah/92.21Ah; discharge current when on-road: 20A. For a constant discharge current i_d over a time period t , the SoC of the battery is calculated as shown in Equation (13), where C_a is the effective available capacity.

$$SoC(t) = 1 - \frac{i_d * t}{C_a} \quad (13)$$

3.2 Interval Matrix (IM)

Interval matrix is formed by dividing the parameters such that the first and last rows of the IM contain the minimum and maximum values of concerned parameter. In order to calculate the probability of each potential action based on the parameters associated to various criteria, the range of parameters is

divided into certain intervals. The intermediary rows contain upper/lower limits of the intervals.

		SoC	EP(€/kWh)	Load(MW)	a-PV
min	Interval1	0.4000	0.0234	1.7736	0.0000
1	Interval2	0.4667	0.0298	1.9879	0.1641
2	Interval3	0.5333	0.0362	2.2021	0.3281
3	Interval4	0.6000	0.0426	2.4164	0.4922
4	Interval5	0.6667	0.0489	2.6306	0.6563
5	Interval6	0.7333	0.0553	2.8449	0.8203
max		0.8000	0.0617	3.0591	0.9844

Table 1. Interval Matrix of 24 Hours Forecast Data

For example, the second row acts as upper limit for 1st interval as well as lower limit for 2nd interval. Unless otherwise the upper and lower limits of various criteria are not changed, the IM remains unchanged. Based on the references data of EP, Load and a-PV, the upper and lower bounds of these criteria for the study period of 24 hours is shown in Table 1.

3.3 Charging and discharging criteria

In this paper four criteria viz. SoC, EP, load and a-PV are used and either of seven potential actions (choices) viz. EV battery charge at 30A, 10A, 2A, neutral, discharge at 2A, 10A, 30A are to be determined.

3.3.1 State of Charge (SoC)

The main criterion to take dispatch decision of battery is its SoC. In the EV battery health point of view, the SoC need to be maintained with in permissible limits i.e. SoC_{max} and SoC_{min} . The probability of taking the decision (choice) with respect to SoC is calculated using Equation (14)

$$P_{SoC,i} = 1 - \left| \frac{SoC - IM_{i,1}}{SoC_{max} - SoC_{min}} \right| \forall i = 1, 2 \dots m \quad (14)$$

It must be noted that weightage of SoC is always kept higher in order to avoid frequent deep cycle operations.

3.3.2 Electricity Buying/Selling Price

To earn more profits, EV owner should charge the battery when the electricity buying price is low and discharge the battery when the selling price is high. Hence electricity prices are an important factor for dispatch action. The below Equation (15) is used to evaluate the probability of taking the decision (choice) with respect to EP. The data of EP is taken from the reference [17].

$$P_{EP,i} = 1 - \left| \frac{EP - IM_{i,2}}{EP_{max} - EP_{min}} \right| \forall i = 1, 2 \dots m \quad (15)$$

3.3.3 System Load

The system load is a crucial factor which affects the overall system-wide behaviors. It is taken as a criterion for the determination of dispatch action such that during heavy load period, in order to avoid certain consequences, the EVs are expected to discharge and aid to load management. During low load situation the EVs can re-charge themselves. The probability evaluation of an action based on load demand is done as in Equation (16).

$$P_{load,i} = 1 - \left| \frac{Load - IM_{i,3}}{Load_{max} - Load_{min}} \right| \forall i = 1, 2 \dots m \quad (16)$$

3.3.4 Renewable DG power availability

In view of ill-effects of high fossil fuel consumption and economy of electric power generation from a renewable source, it is encouraging to incorporate availability of renewable energy source as a decisive factor for EV dispatch. In order to promote more consumption of renewable energy EV is expected to charge more during the availability period. The concerned equation for the same is shown in Equation (17).

$$P_{aPV,i} = \left| \frac{aPV - IM_{i,4}}{aPV_{max} - aPV_{min}} \right| \forall i = 1, 2 \dots m \quad (17)$$

3.4 Decision Matrix (DM)

In the decision matrix, the elements represent the probability of taking the particular action (row) based on the state of the criterion (column). The Decision Matrix has prioritized potential actions (choices) for every criterion.

A typical case is considered for study with decisive parameters, SoC of 0.7827, EP at 0.0295€/kWh, Load of 2.4842MW and a-PV of 0.8748 of its rated value and its probability of taking the decision (choice) values is shown in Table 2.

<i>(Choice)</i> <i>Potential Action</i>	<i>Criteria</i>			
	<i>SoC</i>	<i>EP</i>	<i>Load</i>	<i>a-PV</i>
Charge with 30A (Choice-1)	0.0433	0.8407	0.4473	0.8887
Charge with 10A (Choice-2)	0.2100	0.9926	0.6139	0.7220
Charge with 2A (Choice-3)	0.3766	0.8259	0.7806	0.5553
No Charge/Discharge (Choice-4)	0.5433	0.6593	0.9473	0.3887
Discharge with 2A (Choice-5)	0.7100	0.4926	0.8861	0.2220
Discharge with 10A (Choice-6)	0.8766	0.3259	0.7194	0.0553
Discharge with 30A (Choice-7)	0.9567	0.1593	0.5527	0.1113

Table 2. Probability of taking potential action w.r.t. criteria

Since the SoC is very high the decision matrix has high probability to opt choice-7 i.e. discharging at maximum available rate. If the decision was to be determined based only on SoC the choice would be obvious. As there are other parameters which create a situation of indecisiveness such as price suggests to charge at medium rate (choice-2), load level suggests the vehicle not to participate in V2G operation (choice-4) whereas abundance of renewable generation clearly inspires to charging at highest rate (choice-1).

In such a situation the relative weightage assigned to various criteria plays an important role in determining the dispatch action. The weights are user defined and are varied in order to prioritize one criterion over the other. In this paper the weights are to be taken in the predefined order as $W =$

$[W_{SoC}W_{EP}W_{Load}W_{a-PV}]$. The proposed p-ELECTRE method is applied here to find the appropriate decision (choice) for dispatch of EV battery.

For illustration purpose, in accord to above presented example following weights are considered $W=[0.4 \ 0.1 \ 0.4 \ 0.1]$. With these weightings the p-ELECTRE method in simulation, utilizing Equation (1) to Equation (17) results into suggesting the choice of neither charging nor discharging (choice-4).

Figure 1. Data Communication Chart

The detailed data communication chart is depicted in Figure 1, which describes the procedure of real-time data collection of SoC from EVs, load information from distribution system operator (DSO), price from electricity markets (EMs) and available PV power from panels. The collected data is analyzed and with help of proposed p-ELECTRE dispatch strategy, optimal dispatch action is fed back to EVs.

Hour	SoC-initial	SoC-min	SoC-max	Choice	P-flow (kW)	Cost (€)	Sn	Price (€/kwhr)	Load (MW)	aPV (pu)	SoC-final
1	0.692	0.4	0.8	5	-0.302	-0.0088	0	0.029	2.017	0	0.68
2	0.68	0.4	0.8	5	-0.302	-0.0076	0	0.025	1.903	0	0.667
3	0.667	0.4	0.8	5	-0.302	-0.0076	0	0.025	1.833	0	0.654
4	0.654	0.4	0.8	5	-0.302	-0.0072	0	0.023	1.787	0	0.642
5	0.642	0.4	0.8	5	-0.302	-0.0071	0	0.023	1.773	0	0.629
6	0.629	0.6	0.8	2	2.089	0.0522	0	0.025	1.797	0.041	0.716
7	0.716	0.4	0.8	0	0	0	0.2	0.025	1.851	0.181	0.516
8	0.516	0.4	0.8	3	0.302	0.0077	0	0.025	1.991	0.387	0.529
9	0.529	0.4	0.8	3	0.302	0.0088	0	0.029	2.175	0.580	0.541
10	0.541	0.5	0.8	2	2.089	0.061	0	0.029	2.328	0.749	0.628
11	0.628	0.4	0.8	0	0	0	0.1	0.029	2.484	0.874	0.528
12	0.528	0.6	0.8	1	7.808	0.2811	0	0.036	2.638	0.959	0.854
13	0.854	0.4	0.8	0	0	0	0.2	0.052	2.779	0.984	0.654

Hour	SoC-initial	SoC-min	SoC-max	Choice	P-flow (kW)	Cost (€)	Sn	Price (€/kwhr)	Load (MW)	aPV (pu)	SoC-final
14	0.654	0.5	0.8	4	0	0	0	0.054	2.913	0.958	0.654
15	0.654	0.4	0.8	0	0	0	0.1	0.055	2.973	0.88	0.554
16	0.554	0.4	0.8	3	0.302	0.0172	0	0.056	3.041	0.754	0.566
17	0.566	0.4	0.8	4	0	0	0	0.061	3.059	0.589	0.566
18	0.566	0.6	0.8	1	7.808	0.4568	0	0.058	3.051	0.397	0.892
19	0.892	0.4	0.8	0	0	0	0.2	0.053	2.906	0.192	0.692
20	0.692	0.4	0.8	5	-0.302	-0.0162	0	0.053	2.812	0.048	0.679
21	0.679	0.4	0.8	5	-0.302	-0.011	0	0.036	2.744	0	0.66
22	0.66	0.4	0.8	5	-0.302	-0.0093	0	0.030	2.556	0	0.654
23	0.654	0.4	0.8	5	-0.302	-0.0089	0	0.029	2.386	0	0.641
24	0.641	0.4	0.8	5	-0.302	-0.0088	0	0.029	2.186	0	0.629

Table 3. Dispatch Action of Single EV with Renewable DG Power Criteria

Table 3 illustrates the dispatch action of a random EV for a period of 24 hours with time interval of 1 hour. The choices opted by the p-ELECTRE algorithm ranges from choice-1 to choice-7 for charging/discharging action at various rates. Choice presented by '0' means that the EV is on-road and does not participate in power exchange with grid in either way.

In Table 3, the randomly chosen EV starts with a respective higher SoC (randomly considered) while EP and Load demand at the initial hour are relatively on the lower side, so the algorithm opts for discharging but at a lower rate. During the day when the renewable energy source is available in comparative abundance, the algorithm supports charging while maintaining the SoC within acceptable range, the rates being decided by cumulative effect of other criteria.

The parameter S_n is used to depict the randomly generated 24 hours travel plan of an EV. A non-zero S_n value at any hour implies that the vehicle is on road and is going to lose SoC equal to the value in travel at that hour. While a zero value of S_n means that the EV is parked at the charging station and does participate in charging or discharging. It should also be noted that the vehicle in the preceding hour of travel tends to store extra energy equal to the travel requirement for next hour in addition to the minimum SoC to be maintained.

4. Addition of EV Fleets to Distribution System

The proposed p-ELECTRE based dispatch strategy is applied for 100EVs and 200EVs. Variation of

state of charge over a period of 24 hours for a fleet of 100 EVs is shown in Figure2, it can be noted that not many vehicles surpass the SoC limits by large margin. Figure 3 shows the variation of state of charge over a period of 24 hours for a fleet of 200EVs, and it follows similar trend as that of 100 EV fleet.

Figure 2. SoC vs Time (100 EVs)

Figure 3. SoC Vs Time (200EVs)

The proposed p-ELECTRE based dispatch strategy with 100EVs and 200EVs was tested on standard IEEE 33 bus distribution system.

Figure 4. Effect of EV Loads with Different weights on actual load

Figure 4 illustrates the cumulative impact of 100 as well as 200 EV fleets on the actual load demand throughout a day subject to weightage for various decision making criteria. Different sets of weights are considered to highlight their effect on decision making. The first set of weights (see legend) does not consider the presence of renewable energy source; it is observable that the vehicles charge less during the availability period. They charge/discharge only in response to other criteria. Contrary to above statement, when more weight is given to a-PV, there is significant rise in power consumed by EVs during the availability period of solar power while responding to other criteria meekly. When more weight is given to load demand the fleet of EVs cumulatively responding to system load discharge at a higher rate during the hours of high demand whereas they tend to charge during the low demand period. Similar trend follows for the case of more weight to the electric price. There is significant rise in the load (within handling capability of system) during the last hours as most EVs try to charge themselves owing to travel throughout the day and lower prices and system load. For further studies in later section the set of weights [0.4 0.2 0.3 0.1] is considered. This set of weights is observed to inflict most impact on the system load curve.

Both the fleets of 100 and 200 EVs show similar behavior but differ at the level of cumulative impact to the system. Relative higher weight is awarded to SoC to keep the decision favorable to the EV owner by maintaining the battery health.

5. Bat Algorithm Implementation for Optimal Scheduling of DGs in Distribution System

From the previous section, especially from Figure 4, it is clearly observed that the distribution system load varies as an effect of dispatch action taken by EVs. The optimal scheduling of the DGs in EV rich distribution system is described in this chapter. While finding the optimal dispatch of the DGs with BAT optimization algorithm, total generating cost of DGs, power loss and voltage deviations are considered as objectives to minimize. It should be noted that the EVs connected to distribution system are optimally dispatched using p-ELECTRE method with suitable weight for each criterion. The appropriate weight selection is illustrated in previous section.

5.1 Bat Optimization Algorithm

The Bat Optimization Algorithm (BOA)[18] is a real coded population based meta-heuristic optimization method based on the echo-location behaviour of micro-bats. The echolocations of the bats are the possible solutions and are updated and adjusted with a motivation of finding the location with maximum availability of food. BOA tunes the frequency to dynamically monitor the mobility of a swarm of bats. A micro-bat flies randomly within the non-linear search space with a velocity (vel) at position (solution) (x_i) with a variable frequency (bf) or wavelength and loudness (A). As it searches and finds its prey, it changes frequency, loudness (A) and pulse emission rate (pr).

5.2 DG Scheduling using BAT optimization Algorithm

The optimal DG scheduling problem in a distribution system is formulated as a constrained multi-objective optimization problem with system losses, cost and voltage deviation indices as objectives to minimize.

5.2.1 Objective1: System loss

Optimal dispatch of DGs has a great impact on the system losses. The index of system loss(α), to be minimized is defined in Equation (18).

$$\alpha = \frac{\text{Total loss with DG}}{\text{Total loss without DG}} \quad (18)$$

Backward Forward Sweep algorithm is employed for the load flow studies, and the equations for calculating total loss are as shown in Equation (19) and Equation (20).

$$S_{\text{loss}} = S_{pq} - S_{qp} \quad (19)$$

$$\text{Total loss} = \sum_{k=1}^{\text{line}} S_{\text{loss}}(k) \quad (20)$$

Where, S_{pq} is power flow of the line exist between p-bus to q-bus and S_{qp} is power flow of the line connected from q-bus to p-bus, S_{loss} is the total loss in that line. Total loss is the sum of all line losses.

5.2.2 Objective2: Voltage deviation

DG optimal dispatch can lead to significant changes in voltage profile at each node throughout the distribution systems. The indices of voltage deviation (β) which are to be minimized is defined in Equation (21).

$$\beta = \frac{\text{Voltage Deviation with DG}}{\text{Voltage Deviation w/o DG}} \quad (21)$$

The voltage deviation (VD) is maximum voltage deviation of any of the system bus with respect to substation bus which maintains 1p.u voltage. It is defined in Equation (22).

$$VD = \left| \max \left(\frac{V_{\text{substn}} - V_i}{V_{\text{substn}}} \right) \right| \forall i = 2, 3, \dots, \text{nbus} \quad (22)$$

5.2.3 Objective3: Cost

Economy of operation is one of the major criteria during optimal dispatch of DGs. In this study DG cost is considered to be quadratic in nature [19-20] which is shown in Equation (23). Where a_i, b_i, c_i are

the cost coefficients of the i^{th} DG. The cost index (φ) formation is shown in Equation (24), it is the ratio of generation cost of DGs and maximum generation cost of all DGs.

$$\text{Cost} = a_i * P_i^2 + b_i * P_i + c_i \quad (23)$$

$$\varphi = \frac{\text{generationcostwithDG}}{\text{max.generationcost}} \quad (24)$$

5.2.4 Objective function

Weighted sum multi objective optimization is used by combining all the indices with equal weights i.e. equal importance to all considered objectives. The multi objective function used is defined as Equation (25).

$$OF = \min \{ \alpha, \beta, \varphi \} \quad (25)$$

The complete algorithm for optimal dispatch of DGs by bat algorithm in distribution system having optimal dispatch of EV batteries by p-ELECTRE is given in Figure 7 flowchart.

6. Results Analysis and Discussion

For testing impact of the proposed dispatch strategy on a distribution network, an EV rich IEEE 33 distribution system containing four different DGs is considered. One gas turbine is placed at Bus-6 with maximum capacity of (2+j0.8) MVA, one PV is considered at Bus-25 with maximum capacity of (0.5+j0.0) MVA, at 15 Bus one fuel cell is taken with a maximum capacity of (0.6+j0.5) MVA and diesel generator is connected at Bus-30 with maximum capacity of (1+j0.8) MVA capacity. Two charging stations/parking lots are considered where the EV fleets can charge or discharge. These charging stations are connected to two of the buses numbered 17 and 29 and it is assumed that they both equally bear the cumulative impact of dispatch actions of all vehicles.

Figure 5. Flow chart of Optimal scheduling of DGs using BOA along with p-ELECTRE based EV dispatch

Hour	System								Slack Power (MW)
	DG1 (GT) (MW)	DG1 (GT) (MVAR)	DG2 (PV) (MW)	DG3 (FC) (MW)	DG3 (FC) (MVAR)	DG4 (DiGe) (MW)	DG4 (DiGe) (MVAR)	Total cost (€)	
1	0.452	0.268	0.000	0.368	0.167	0.327	0.522	109.57	0.898
2	0.456	0.267	0.000	0.370	0.174	0.316	0.451	108.72	0.797
3	0.570	0.330	0.000	0.294	0.102	0.328	0.459	126.45	0.648
4	0.306	0.269	0.000	0.343	0.153	0.441	0.505	107.70	0.699
5	0.498	0.350	0.000	0.386	0.123	0.353	0.438	123.41	0.544
6	0.373	0.193	0.021	0.289	0.208	0.368	0.391	101.87	0.787
7	0.434	0.230	0.057	0.372	0.142	0.381	0.405	126.10	0.651
8	0.378	0.563	0.179	0.401	0.124	0.408	0.408	147.65	0.678

Hour	DG1 (GT) (MW)	DG1 (GT) (MVAR)	DG2 (PV) (MW)	DG3 (FC) (MW)	DG3 (FC) (MVAR)	DG4 (DiGe) (MW)	DG4 (DiGe) (MVAR)	Total cost (€)	System load + <i>EV</i> load (MW)	Slack Power (MW)
9	0.462	0.429	0.269	0.420	0.072	0.404	0.476	178.96	2.206	0.657
10	0.185	0.362	0.371	0.454	0.098	0.507	0.676	190.14	2.344	0.834
11	0.508	0.360	0.352	0.501	0.249	0.512	0.528	233.36	2.555	0.688
12	0.561	0.433	0.418	0.533	0.172	0.532	0.652	264.78	2.759	0.721
13	0.544	0.375	0.466	0.511	0.271	0.453	0.785	252.05	2.802	0.836
14	0.535	0.660	0.430	0.510	0.123	0.600	0.670	278.42	2.923	0.855
15	0.602	0.466	0.428	0.456	0.249	0.650	0.639	302.28	3.025	0.896
16	0.578	0.659	0.360	0.594	0.115	0.551	0.785	265.58	3.091	1.018
17	0.483	0.392	0.285	0.552	0.299	0.537	0.767	224.89	3.098	1.253
18	0.676	0.554	0.186	0.535	0.243	0.477	0.646	231.07	3.037	1.175
19	0.680	0.379	0.088	0.474	0.153	0.460	0.775	205.66	2.945	1.255
20	0.513	0.426	0.023	0.433	0.172	0.393	0.719	140.64	2.676	1.327
21	0.488	0.536	0.000	0.494	0.114	0.523	0.635	164.37	2.736	1.244
22	0.559	0.469	0.000	0.419	0.128	0.542	0.566	177.28	2.611	1.101
23	0.606	0.395	0.000	0.476	0.191	0.469	0.566	174.44	2.399	0.856
24	0.579	0.381	0.000	0.375	0.085	0.416	0.518	149.99	2.224	0.862

Table 4.Optimal Dispatch Of DGs With Addition Of 100evs

Hour	DG1 (GT) (MW)	DG1 (GT) (MVAR)	DG2 (PV) (MW)	DG3 (FC) (MW)	DG3 (FC) (MVAR)	DG4 (DiGe) (MW)	DG4 (DiGe) (MVAR)	Total cost (€)	System load + <i>EV</i> load (MW)	Slack Power (MW)
1	0.080	0.675	0.000	0.537	0.173	0.453	0.608	107.03	2.178	1.199
2	0.180	0.546	0.000	0.462	0.189	0.473	0.541	111.28	2.014	1.087
3	0.068	0.574	0.000	0.367	0.228	0.568	0.562	121.20	1.853	0.925
4	0.016	0.680	0.000	0.404	0.077	0.522	0.560	111.06	1.796	0.877

Hour	DG1 (GT) (MW)	DG1 (GT) (MVAR)	DG2 (PV) (MW)	DG3 (FC) (MW)	DG3 (FC) (MVAR)	DG4 (DiGe) (MW)	DG4 (DiGe) (MVAR)	Total cost (€)	System load + EV load (MW)	Slack Power (MW)
5	0.063	0.465	0.000	0.385	0.222	0.472	0.402	99.28	1.785	0.934
6	0.220	0.610	0.010	0.435	0.159	0.460	0.517	111.37	1.856	0.959
7	0.156	0.145	0.089	0.497	0.175	0.518	0.608	138.75	2.031	0.933
8	0.212	0.671	0.190	0.542	0.156	0.453	0.639	150.42	2.220	1.043
9	0.028	0.050	0.223	0.578	0.271	0.564	0.630	176.14	2.310	0.954
10	0.215	0.283	0.348	0.533	0.313	0.508	0.693	193.78	2.365	0.985
11	0.131	0.035	0.432	0.593	0.298	0.705	0.672	264.85	2.545	0.825
12	0.039	0.521	0.353	0.593	0.336	0.658	0.685	230.08	2.666	1.072
13	0.314	0.793	0.466	0.556	0.242	0.845	0.736	334.89	2.707	0.851
14	0.210	0.607	0.470	0.595	0.395	0.715	0.777	282.24	2.878	1.110
15	0.012	0.498	0.353	0.598	0.295	0.802	0.735	277.86	2.872	1.134
16	0.278	0.492	0.314	0.531	0.314	0.837	0.768	294.06	2.920	1.253
17	0.033	0.387	0.251	0.094	0.370	0.814	0.728	224.36	2.093	0.953
18	0.201	0.187	0.198	0.555	0.242	0.728	0.735	227.05	2.782	1.318
19	0.167	0.316	0.095	0.530	0.359	0.633	0.714	173.38	2.703	1.464
20	0.057	0.138	0.021	0.481	0.348	0.617	0.706	146.36	2.529	1.428
21	0.135	0.612	0.000	0.572	0.263	0.625	0.789	155.05	2.804	1.626
22	0.053	0.127	0.000	0.574	0.227	0.548	0.705	130.91	2.904	1.802
23	0.087	0.046	0.000	0.594	0.432	0.832	0.597	223.04	3.188	1.786
24	0.162	0.261	0.000	0.583	0.237	0.628	0.638	158.38	2.686	1.489

Table 5.Optimal Dispatch of DGs with Addition of 200EVs

Table 4 and Table 5 illustrates the scheduling of the four considered DGs in the distribution network to provide for the modified system demand due to addition of fleets of 100 and 200EVs respectively. The tables show the generation of active and reactive power for each DGs based on their specification satisfying the various objectives viz. reduction of voltage deviation, reduction of system losses and minimization of cost. The results obtained for each hour are the best solution obtained by 1000 iterations of BOA. In these tables, DG2 i.e. solar PV park is observed to dispatch near maximum

of its available power at the hour owing to its lowest generating cost. Total load demand of the system is considered with weights [0.4 0.2 0.3 0.1] for optimizing various objectives.

Figure 6. Voltage profile of the Distribution System.

The basic objective of optimal dispatch of DG is to enhance the voltage profile and to reduce the losses in the system while considering economy is achieved. Figure6 shows the voltage profile of the system with and without DGs. In this figure lines marked as (—) and (—O—) show the voltage profile after addition of 200 and 100 EVs respectively without considering DGs. While the lines marked as (—Δ—) and (—*—) show voltage profiles after addition of DGs to the system It is evident that the after optimal dispatch of DGs the voltage profile is very well enhanced. The losses in the system are also less after DG scheduling.

	100EVs	200EVs	Only DGs	100EVs+ DGs	200EVs+DGs
Total loss (MW)/ day	2.2863	2.3079	0.2334	0.2367	0.366
Total cost (DG + EV costs) (€)/day	-6.9809	-40.938	4303.54	4369.99	4393.33
Voltage deviation (PU)	0.0532	0.0551	0.0092	0.0094	0.0109
Total Slack Power (MVA)	68.8313	69.0408	23.0393	23.4268	31.690

Table 6.Optimal Dispatch of DGs with Addition of 200EVs

Table 6 illustrates the comparison for various scenarios of EV rich distribution system with and without DGs integration. The inherent character of EVs is to act as a load, as the EVs are capable of

V2G operation this effect is not very predominant. Further the benefits of scheduling DGs in a distribution system are clearly seen in this table. It can be observed that with the increase in number of EVs there is increase in system losses, voltage deviation and total power imported from the grid.

The total loss of the system in considered day is 1.9MW and with 100EVs addition it is increased to 2.28MW. The total loss throughout the day increases slightly by about 1% after addition of another 100 EVs as compared to pre-existing 100EVs in the system. This is due to optimally dispatched EVs using p-ELECTRE are added to the distribution system. With optimal dispatch of DGs along with the EVs, it can clearly observed that there is a very significant reduction in power loss, almost 90% i.e. 2.2863MW to 0.2367MW in case of 100 EVs and about 85% in case of 200 EVs i.e. 2.3079MW to 0.366MW.

As shown in the table, although the EVs act as a load to the system, owing to the p-ELECTRE based optimal dispatch of EVs, they are on whole able to earn profits by 6.98€ in case of 100 EVs fleet and 40.93€ in case of 200 EVs fleet throughout the day without compromising in their travel plans. When the DGs are dispatched the generating cost of all the DGs amounts to 4303.54€ per day without any EVs in the system. With 100 EVs addition to the system, the cost of generation amounts to only 1% higher as compared to the scenario when no EVs are present. Whereas, the total cost of generation increased by 2% only with connection of 200EVs to the system. This is achieved because of the optimal dispatch strategy enabled EVs are charging and discharging at appropriate hours to earn profits through the day.

To point out other benefits of DG scheduling within the distribution system the impact of scheduling on maximum voltage deviation across the day is shown. The voltage deviations of 0.0532pu and 0.0551pu, observed by addition of 100EVs and 200EVs respectively are reduced to 0.0094pu and 0.0109pu with addition of DGs. Similarly a significant reduction in grid dependence is observable after the addition of DGs to the microgrid. Elaborately, the power import from grid which was 68.83MVA and 69.04MVA for the day after addition of the 100EVs and 200EVs respectively is reduces to

23.42MVA and 31.69MVA respectively. The huge difference between the imported powers in later case is due to the attempt made by DG scheduling algorithm to reduce the power loss and voltage deviation caused by increase in demand.

7. Conclusion

This paper has proposed a dispatch strategy using p-ELECTRE method which uses a probabilistic approach while taking decision. This method takes into account the parameters such as state of charge, electricity price, system load and availability of renewable power throughout the day. Decision is taken based on relative prioritization of one factor over the other. This strategy keeps EV owners' interest above all by avoiding deep cycle operation of battery and charging during low buying price period and discharging during high selling price period. This strategy also considers grid owner's interest by discharging EVs during high demand period. Availability of solar power is also considered in the decision making by motivating EV users to utilize the renewable energy by charging during abundance. The impact of fleets of 100EVs and 200EVs with proposed strategy was examined on standard IEEE 33-bus radial distribution system subject to different sets of weights to various criteria. Optimal scheduling of four DGs in EV rich distribution system is obtained using BOA. Optimal dispatch is obtained while meeting the system load and reducing the losses, cost and voltage deviation.

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