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Implementing PSO to Phase Balance by Plug-in Electric Vehicles in Smart Grid

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Abstract

The necessity of transport electrification is already unquestionable due to, among other facts, global Greenhouse Gas (GHG) emissions and fossil-fuel dependency. In this context, electric vehicles (EVs) play a basic role. Such vehicles are regularly seen by the network as simple loads whose needs have to be supplied. However, they can contribute to the correct operation of the network or a micro grid and the provision of additional services and delay the need to reinforce the power lines. Increased deployment of distributed generation resources (DGRs) and plug in electric vehicles (PEV) usage in the utility grid is the key driver for the phase imbalance between the three phases of any distribution system. Phase imbalance increase power loss, decrease voltage profile and decrease hosting capacity in LV distribution grids.

With increase in number of PEVs and DGR in the system, the phase imbalance increases considerably. Minimising the phase imbalance problem, achieving system reliability and effective power flow to customers is hence essential which induces the balance in the system. PSO algorithm technique has been proved to be very effective for finding the optimal solutions in constrained environment. Formulation of an objective function for minimisation of the phase imbalance and cost reduction in smart grid is proposed. An attempt is made to apply PSO algorithm for addressing an optimal solution for the phase imbalance problem and cost reduction issue in Smart grid due to the PEVs and DGRs in smart grids with their corresponding optimisation functions. This work compares the performance of Game theoretical Approach (GA) and Particle Swarm Optimization (PSO) algorithms on the application of phase balancing.

Keywords—Phase balancing, plug-in electric vehicles, Particle Swarm Optimization, Smart grid

Introduction

In practice, the three phases of the distribution network have an unevenly distributed single phase loads [2]. It causes an unequal distribution of loads, which has a negative influence on the system's performance as well as the equipment linked to it [3]. Due to higher current flows in some phases and in the neutral, imbalanced operation produces a rise in copper losses and overheating of equipment, leading to circuit breaker tripping as a measure of over

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load protection for the feeder [4]. The imbalanced condition among the three phases is becoming more problematic as the number of dispersed power sources and interconnected electric cars to the grid grows. It can also reduce the amount of electricity accessible in the feeds [5]. To improve system dependability and effective power delivery to customers, several academics have focused on decreasing the phase unbalance problem.

Reassigning load to various phases has traditionally been used to correct phase imbalances. To arrive at the best option on this load reassignment, a mixed integer programming approach is used [6]. It has been suggested that the influence of demand-side uncertainty be taken into account [7]. The cost and voltage drop have been presented as multi objective mineralization functions in the reassignment approach [8]. [9] Discusses the use of the particle swarm optimization technique to investigate a rephrasing strategy from a cost perspective. All of these methods, because they are carried out manually, are likely to induce service disruptions for clients. As a result, study has been concentrated on tackling the problem of dynamic phase balancing, which is necessary in a micro grid setting. A static transfer switch is used to facilitate the dynamic transfer of residential consumer loads from one phase to another [10]. The automated re-assignment of loads to different phases with the assistance of switches is presented in [11]. It is important to remember that these approaches need additional infrastructure. The unbalances that exist in the three stages are defined as a mixture of two types of unbalances: systematic and random unbalances. Rephrasing can successfully address systemic unbalances, while random unbalances require further emphasis [12].

Several researches have been published on how to use the available resources on the demand side to reduce unbalances. This research looked at ways to make the most of these resources' flexibility when it comes to generation and consumption patterns. The inverters and chargers of electric cars are used to transfer loads from a heavily loaded phase to a lightly loaded phase in the three-phase architecture [13]. In [14], proper charge and discharge timing schedule, as well as phase balance, were accomplished.

Investigation of the data centers' accessible data has been utilized to initiate suitable management activity to mitigate the unbalances [15]. There is occasionally an excess of electricity present at demand side resources. At the same time, the system may be experiencing phase unbalance. [16] Shows how proper coordination allows extra power to be used to correct for phase unbalances via a single phase inverter.

The problem of phase balance was also handled by changing the quantity of reactive power generated [17]. [18] Describes the tying up of the DC side of inverters that are side by side with chargers of electric cars placed in various phases to accomplish phase balancing. The thermostatic effect was used to regulate the loads and achieve phase balance [19].

The use of game theory for phase balancing has been used to utilize artificial intelligence approach for phase balancing by offering incentives to electric car owners who participate to solving the phase imbalance as stated [5] in. The PSO method has been shown to be an effective tool for solving optimization issues. It is proposed to formulate an optimization problem for decreasing phase imbalance in smart grids. The use of a PSO algorithm to discover an ideal solution for the phase imbalance problem that arises in smart grids as a result of PEVs and DERs is attempted.

Phase Balancing Using PSO Algorithm

In the Fig. 1 depicted beneath, which is a sample smart distribution system, clean and green power sources and electric cars are connected at one load bus. The power supply to the system is intermittent due to intermittent power generation from clean and green power sources. Furthermore, in all three phases, the dispersed generation may or may not be linked. Transformers may be severely damaged of the phase imbalance in the system and induction motors. In order to decrease the unbalance in a three-phase distribution system [5], PEVs can be used, and the entire optimization method is carried out using the PSO algorithm. Fig.2 depicts the flow chart of PSO.

Consider a group of PEVs represented by $\zeta = \{1,2,3, \ldots,n\}$ and each $PEV_x \in \zeta$, in three phase distribution contains three subgroups i.e, $\zeta = U_j \in \zeta_j$, here $\Theta = \{1, 2, 3\}$.

Assume $PEV_x \in \zeta$. Constraint on state of charge:

$$0 \le D_x \le 1 \quad (1)$$

And time $\tau = \{1, 2, 3, \ldots, T\}$, here $t \in T$.

The charging constraint of PEV based on time slot is:

$$D_x B_x \le D_x^0 B_x + \sum_{t=1}^{T} C_t^x \le B_x \quad (2)$$

And charging rate is given by

$$0 \le C_t^x \le C_{max}^x \quad (3)$$

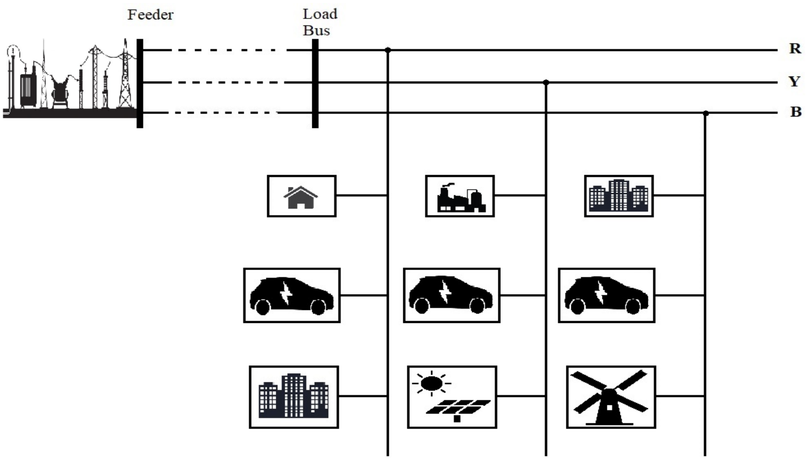

Fig. 1. Block diagram of the three phase distribution system

ISSN NO:1934-7197

As renewable energy generators (REGs can be regarded as negative loads, inflexible load X_t^j on phase j in time slot t is defined as the conventional power load less the REG power generation. Note that the conventional power load here excludes the flexible PEV loads committed to phase balancing PB. Hence, the total inflexible load X_t^j is the sum of inflexible loads on three phases, i.e.$X_t' = \sum_{j\in\Theta} X_t^j$ similarly, the total load X_t is defined as, $X_t = X_t' + \sum_{x\in\zeta} C_t^x$ i.e., the sum of inflexible loads and PEV loads. Assume the inflexible loads are known or can be predicted accurately, i.e., X_t' is a deterministic parameter.

The electricity price $p_t(X_t)$ in time slot t is a non-decreasing twice differentiable convex function of X_t. Therefore, the charging cost of each PEV x over τ is

In order to encourage PEV owner's participation in phase balancing, financial incentives must be provided to them. From the definition of phase imbalance PI_t can be expressed as

$$PI_t = \max_{j\in\Theta} \{ \left(X_t^j - \frac{X_t}{3}\right)^2 \} \tag{4}$$

Where $X_t/3$ is average total load of each phase

To summarize, PEV owner x solves the following problem:

$$\min_{Cx\in\Omega x} \sum_{t=1}^{T} (p_t(X_t) C_t^x + k_t . \frac{PI_t}{N}) \tag{5}$$

Where k_t is pricing coefficient for PEVs and PI_t

Therefore, the feasible charging rates $(C^x = (C_1^x, \dots, C_T^x)^T$ of PEV x can be described by a set *x*:

$$\Omega_x = \{C^x \in R^T : D_x B_x \le S_x^0 B_x + \sum_{t=1}^{T} C_t^x \le B_x, 0 \le C_t^x \le C_{max}^x, \forall t\tau\} \tag{6}$$

Where C_{max}^x is PEV_x's maximum charging rate?

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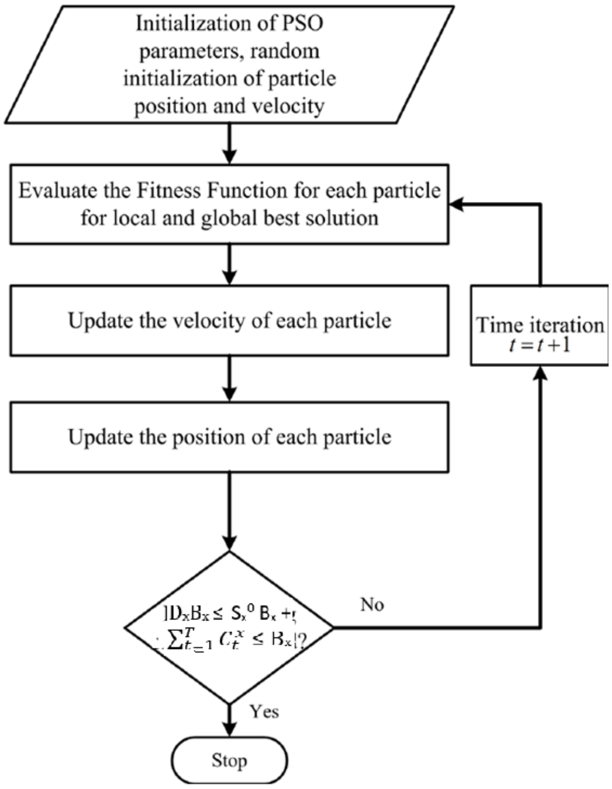

Fig: 2. Flow chart for PSO for phase balancing

Remuneration to the PEV owners depends on their contribution to reduction in the phase imbalance in each phase. Every PEV owner's aims at reducing the charging cost and increasing the remuneration they receive for participating in phase balancing. It is to be noted that the participation of PEV owner in phase balancing is the choice which the PEV owner can opt and it is not mandatory.

RESULTS

A test system like the one depicted in Fig. 3 has been explored to evaluate the suggested algorithm's efficacy. It's challenging to predict electricity output and consumption over three phases due to the inconsistency and unpredictability that characterises weather conditions and consumer demand. Electric loads and regulators are installed to bus number 846, but all other loads remain unaltered. The loads on Bus 846 are considered to be very imbalanced and unstable [5]. This is a three-phase, four-wire feeder with an isolated neutral (without ground conductor). This work does not take into account multi-ground.

ISSN NO:1934-7197

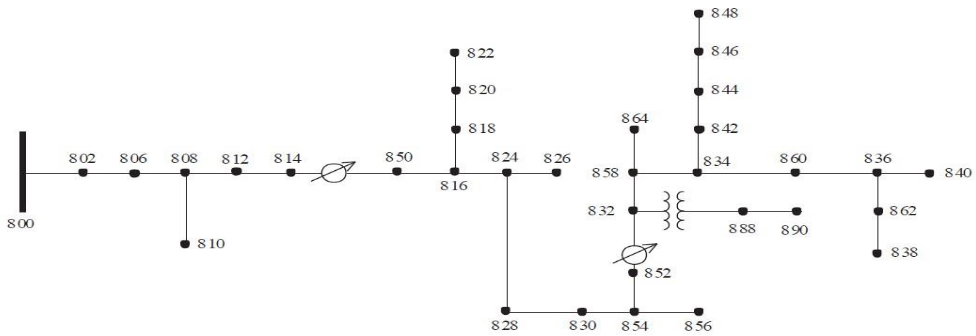

Fig: 3. IEEE 34 bus test feeder

In our model, a Gaussian distribution test is used to create 100 sets of unbalance load data at random. The total number of PEVs=15 i.e., n_1=1, 5 PEVs, n_2=6, 10 PEVs, n_3=11, 15 PEVs are regarded distribution system over three phases. When a pricing function, such as a linear equation, is addressed, $p_t(X_t)=aX_t + b$. The imbalance phase loads mean in different time slots is shown in table 1.

Table: 1. At bus 846 mean imbalance loads (kw)

Time slot	Phase a	Phase b	Phase c
1 – 4	150	50	250
5 – 8	150	250	50

Table 2 depicts the imbalance loads with different price functions.

Table: 2. At bus 846 imbalance loads when different pricing function (kw)

Time slot	Phase a	Phase b	Phase c
1 – 4	150	50	250
5 – 8	100	150	50

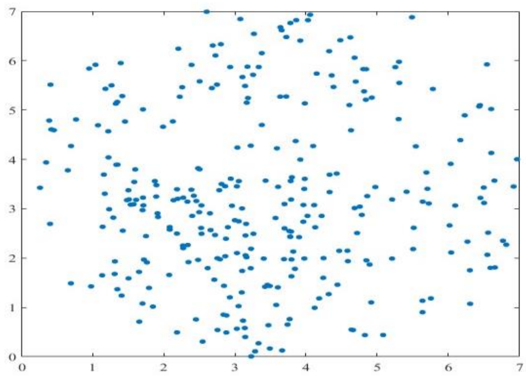

Fig: 4. Node movement of PEVs

ISSN NO:1934-7197

The pattern of electric vehicle motion is depicted in Fig. 4 using the PSO algorithm. A total of two hours is divided into fifteen minute time periods. Thus the time set is expressed as τ= {1, 2, and .8}.

Financial effects of phase balancing:

The cost of charging for electric car owners and the distribution system operator's operational costs determine the financial elements of phase balancing. It's worth noting that when calculating the cost of charging an electric car, the incentive offered to owners is taken into account in the other direction.

Energy loss: Assume a group of distribution lines given by $\mathcal{L}$. The energy loss in terms of the magnitude of current $I_{l,t}$ flowing at any time t in the line l and R_l – resistance of line $l$as $E_{loss} = \sum_{t\in\mathcal{T}} \sum_{l\in\mathcal{L}} I_l^2 R_l$; [1].

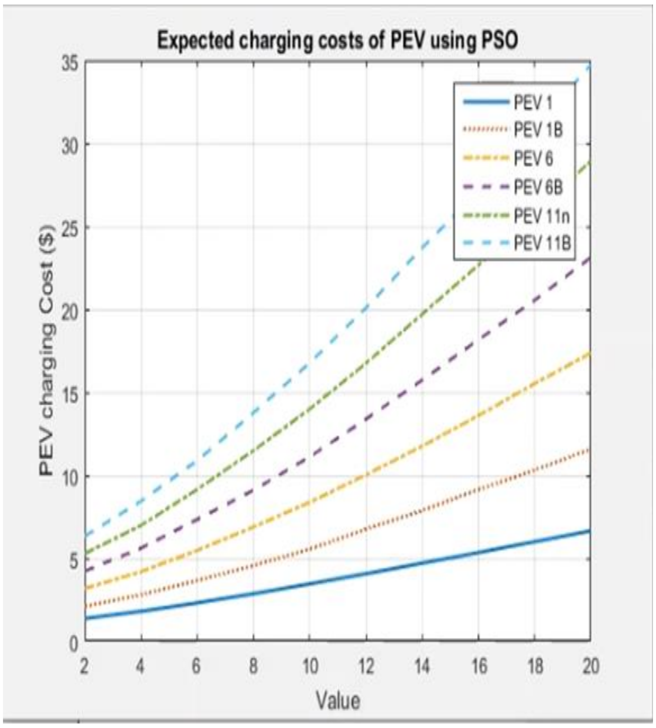

Fig: 5. charging cost expectation of PEV owners

Three electric vehicles (1, 6, and 11) from three distinct phases were chosen as a generic case study for demonstrative purposes.

The charge cost excluding incentives is used as the benchmark data for comparison. Based on the charging selections made by all electric car owners, a vehicle owner can employ battery charging flexibility while having in mind unpredictable loads. Figure 5 depicts the cost expectations of owners when it comes to charging.

ISSN NO:1934-7197

The payment offered to electric car owners for aiding in phase balancing might be regarded as providing a chance for vehicle owners to take use of the versatility in their charging time. It also led to an increase in income for the distribution system operator.

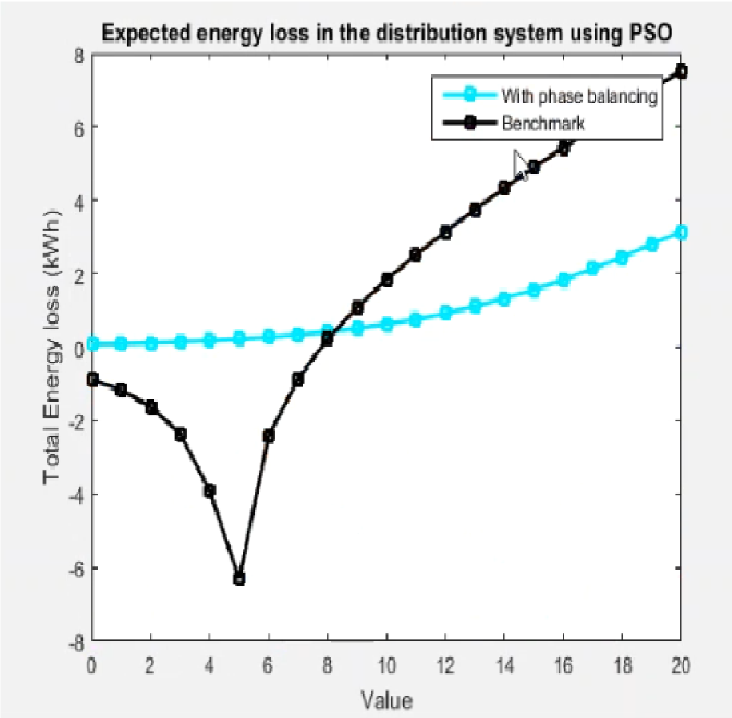

Fig: 6. over the 2 – hours time the distribution system energy loss expectation

The drop in energy loss as a result of phase balancing is seen in Fig. 6. Conducting power flow on the changed system and estimating the losses can be used to determine the energy loss. Comparison to the energy loss calculated from the original network's power flow study.

Phase balancing impacts of Power quality:

$$\text{Voltage imbalance} = \frac{\text{Max}\left(|V_A - V_{avg}|, |V_B - V_{avg}|, |V_C - V_{avg}|\right)}{V_{avg}}$$

Where V_A, V_B and V_C

- Voltages of three different phases; V_{avg} - average voltage of three phases

Fig. 7 presents magnitude of imbalance in voltage present at bus 846. It is clear that the voltage imbalance is a function of the value of ‘k’. Electric vehicle owners will readily come forward for helping in phase balancing with increase in value of ‘k’ which also reduces the voltage imbalance.

ISSN NO:1934-7197

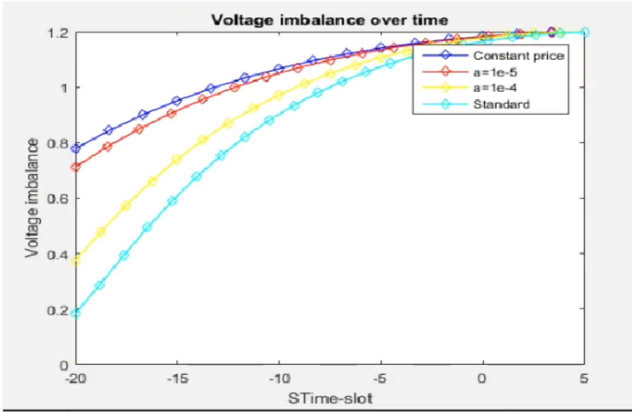

Fig: 7. at bus 846 voltage imbalance over a time

The vertical axis indicates voltage unbalance, whereas the horizontal axis shows time slot. When rises in this diagram, the voltage imbalance diminishes. The reason for this is because as the PEV fleet grows in size, owners are increasingly ready to assist in lowering the phase unbalance. We may infer that our suggested scheme is capable of reducing the voltage unbalance to the safe zone because the maximum permitted VU of electric supply systems is 3%.

COMPARISION ANALYSIS:

Table: 3. Cost attained for PEV 1

PRICING COEEFICIENT (*10^-4)	EXPECTED COST($)	BECHMARK COST($)
2	2.1	1.5
8	4.6	3
14	8	4.8

Table: 4. Cost attained for PEV 6

PRICING COEEFICIENT (*10^-4)	EXPECTED COST($)	BECHMARK COST($)
2	4.5	3.5
8	9	7
14	15.9	11.5

Table: 5. Cost attained for PEV 11

PRICING COEEFICIENT (*10^-4)	EXPECTED COST($)	BECHMARK COST($)
2	6.2	5.5
8	13.9	12
14	23.5	20

CONCLUSIONS

A plug-in electric vehicle (PEV) employed phase balancing arrangement based on particle swarm optimization (PSO) algorithm is proposed. Payment mode to the PEVs for assisting in reducing the imbalance helps the DSO to decrease the problem of phase unbalancing. With the expanding distributed energy assets and plug in electric vehicles usage in the smart grid environment, the issue of unevenness in three phase distribution system turns out to be seriously difficult. Limiting the unevenness issue, accomplishing system dependability has been expressed as an optimization problem and an attempt is made to apply PSO algorithm to find the most feasible solution. It has been observed that efficient planning of using the PEVs charging and discharging schedules to compensate for the differences that arise in the generation in the three phases of a distribution system equipped with distributed generation resources. Finally, the efficacy of these algorithms are evaluated for the proposed unbalance improvement technique, and it is found that the proposed technique using PSO algorithm can reduce a significant amount of unbalance at all the buses of the distribution grid with less computational effort.

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