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Jimenez, A.; UMSNH, Morelia, Mexico; Garcia, N.

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Voltage Unbalance Analysis of Distribution Systems Using a Three-Phase Power Flow ans a Genetic Algorithm for PEV Fleets Scheduling

Alejandra Jiménez, Student Member, IEEE, and Norberto García, Member, IEEE

Abstract—A powerful blend based on a three-phase distribution power flow method and a Genetic Algorithm for plug-in electric vehicular fleets scheduling is proposed in this paper. The Genetic Algorithm optimizes the number of charging and discharging plug-in electric vehicles in order to efficiently manage voltage unbalances and power losses. The plug-in electric vehicle based on a voltage controlled representation is incorporated into a power flow formulation suitable for radial and unbalance distribution network. The PEV model comprises a voltage source converter (VSC) and a battery pack. While active power is regulated at the storage device according to the charging and discharging status of battery, the voltage magnitude at the point of common coupling is regulated by the VSC. Furthermore, a comprehensive VSC-based PEV equivalent model that accurately reflects the behavior of a distributed vehicular fleet is proposed in this work to carry-out efficient steady-state analyses. The impact of a plug-in vehicular fleet in the voltage unbalance of the IEEE 13-node test feeder is optimized with a multiobjective genetic algorithm, where each PEV is modeled as a Tesla Roadster EV with a lithium-ion battery pack.

Index Terms—plug-in electric vehicle, voltage source converter, distribution power flow, voltage unbalance, genetic algorithm.

I. INTRODUCTION

WITH the depletion of fossil fuels, researches around the world are looking for more efficient and renewable transportation alternatives. Grid connected electric vehicles have been identified as an alternative solution to conventional fuel-based vehicles with benefits beyond just transportation. However, overloaded national grid due of lack of new investments during the past decades is now looming as an impediment to grid connected vehicles. In addition, important factors to be considered include harmonic generation at the PEV battery charger, reactive power demand, battery charge rates and control, sub-harmonic signal generation, distribution transformer loading and voltage regulation in the distribution system [1] [2].

In order to evaluate the impact of PEVs on distribution systems, a reliable PEV model is needed to be incorporated in a three-phase power flow algorithm. For this purpose, several mathematical models have been put forward in the open literature. These PEV models employ an active power injection approach to be included in conventional power flow program. In a recent contribution [3], PEVs are modeled as PQ bus using a stochastic real and reactive power demand formulation and it is assumed that there is no reactive power control. Nevertheless, PEVs are capable to exchange reactive power by incorporating appropriate power electronic converters [4]. In a recent contribution [5], a novel PEV model based on a VSC converter is proposed in order to exchange not only active power but also reactive power to provide voltage controllability.

In this paper, effects on voltage unbalance are analyzed by incorporating the VSC-based PEV model into a three-phase distribution power flow algorithm. A genetic algorithm is implemented to determine the number of vehicles per phase that minimize the percent of voltage unbalance and power losses. Validation of the results obtained with the VSC-based PEV model is presented for the Tesla Roadster PEV with a lithium-ion battery pack, considering both active and reactive power transfer conditions.

II. DISTRIBUTION POWER FLOW METHOD

A three-phase power flow method, suitable for radial and unbalanced distribution systems, is implemented in this work. This method is based on the development of two basic matrices, which relate the bus injections to branch currents,

\[ \mathbf{i}_b = \mathbf{A}_{BBBC} \cdot \mathbf{i} \]  

and the branch currents to bus voltages [6],

\[ \mathbf{v}_0 - \mathbf{v} = \mathbf{A}_{BBBV} \cdot \mathbf{i}_b \]  

where \( \mathbf{i}_b \) and \( \mathbf{i} \) are vectors of branch currents and bus current injections, respectively. Besides, \( \mathbf{v}_0 \) and \( \mathbf{v} \) are column vectors containing the no-load bus voltages and bus voltages, respectively.

The \( \mathbf{A}_{BBBC} \) matrix is a constant upper triangular matrix with non-zero entries set to 1. For a \( n \)-node and \( m \)-branch distribution system, the dimension of the \( \mathbf{A}_{BBBC} \) matrix is \( m \times (n - 1) \). \( \mathbf{A}_{BBBV} \) is a lower triangular matrix, where the non-zero entries represent the line sections impedance value. For a \( n \)-node and \( m \)-branch distribution system, \( \mathbf{A}_{BBBV} \) is a \((n - 1) \times m\) matrix.

The automatic generation of matrices \( \mathbf{A}_{BBBC} \) and \( \mathbf{A}_{BBBV} \) for large-scale distribution networks is accomplished with the pseudocode presented in Figure 1. Consider that the line sections data is stored in three column vectors. Vector \( z \) contains...
begin Matrices\_procedure
set \( m, z, a_i, a_j, h = 0 \)
repeat
\( h = h + 1 \)
\( i = a_i(h); j = a_j(h) \)
set \( A_{BIBC}(i,j) = A_{BIBC}(i,j) \)
set \( A_{BIBC}(h,j) = 1 \)
set \( A_{BCBV}(i,:) = A_{BCBV}(i,:) \)
set \( A_{BCBV}(j,h) = z(h) \)
until \( (h = m) \)
end Matrices\_procedure

Figure 1. Pseudocode for automatic generation of matrices \( A_{BIBC} \) and \( A_{BCBV} \).

the impedance values associated to each line section, while vectors \( a_i \) and \( a_j \) include the sending and receiving-end node for each line section, respectively. It can be appreciated that after an initialization section, matrices \( A_{BIBC} \) and \( A_{BCBV} \) are computed by a sequential process by columns and rows, respectively. First, column vector \( A_{BIBC}(; i) \) is stored in the location \( A_{BIBC}(; j) \) and then location \( A_{BIBC}(h, j) \) is set to 1, for \( h = 1, 2, \ldots, m \). Similarly, matrix \( A_{BCBV} \) is assembled by copying column vector \( A_{BCBV}(i,:) \) to \( A_{BCBV}(j,:) \) and setting \( A_{BCBV}(j, h) \) equal to \( z(h) \).

The mismatches at the bus voltages caused by the variations at current injections are obtained by combining (1) and (2),

\[
\Delta v = A_{BIBC} \cdot A_{BCBV} \cdot i = A_{DLF} \cdot i
\]

The distribution power flow iterative process is given by,

\[
\Delta v^{k+1} = A_{DLF} \cdot i^k
\]

with

\[
v^{k+1} = v_0 + \Delta v^{k+1}
\]

\[
i^k = \left( \frac{P_i + jQ_i}{V_i^k} \right)^* \]

where \( k \) is the iteration number, \( P_i \) and \( Q_i \) are the specified active and reactive powers at node \( i \).

III. VSC-BASED PEV MODEL

The schematic diagram and equivalent circuit of the VSC-based PEV for reactive power control in power flow studies are presented in Figure 2. The VSC-based PEV comprises a battery system, a power converter and coupling impedance. It can be appreciated that the VSC-based PEV equivalent circuit for power flow studies can be represented as a complex voltage source \( V_{usc} \) behind the transformer impedance \( Z_{usc} \) \[7\] (see Figure 2(b)).

The complex voltage source generated at the AC side of the VSC is defined as,

\[
V_{usc} = |V_{usc}| \angle \delta_{usc}
\]

where \( |V_{usc}| \) is the voltage magnitude and \( \delta_{usc} \) is the angle of the complex voltage.

The nodal power flow equations at node \( EV \) are,

\[
P_{EV} = |V_{EV}|^2 G_{usc} - |V_{EV}| V_{usc} \cdot \\
\left\{ G_{usc} \cos (\theta_{EV} - \delta_{usc}) + B_{usc} \sin (\theta_{EV} - \delta_{usc}) \right\}
\]

\[
Q_{EV} = -|V_{EV}|^2 B_{usc} - |V_{usc}| V_{EV} \cdot \\
\left\{ G_{usc} \sin (\theta_{EV} - \delta_{usc}) + B_{usc} \cos (\theta_{EV} - \delta_{usc}) \right\}
\]

where \( Z_{usc}^{-1} = G_{usc} + jB_{usc} \).

Similarly, the power flow equations at node \( vsc \) are,

\[
P_{vsc} = |V_{vsc}|^2 G_{vsc} - |V_{vsc}| V_{vsc} \cdot \\
\left\{ G_{vsc} \cos (\delta_{vsc} - \theta_{vsc}) + B_{vsc} \sin (\delta_{vsc} - \theta_{vsc}) \right\}
\]

\[
Q_{vsc} = -|V_{vsc}|^2 B_{vsc} - |V_{vsc}| V_{vsc} \cdot \\
\left\{ G_{vsc} \sin (\delta_{vsc} - \theta_{vsc}) + B_{vsc} \cos (\delta_{vsc} - \theta_{vsc}) \right\}
\]

By assuming a lossless VSC, the active power supplied by the PEV battery system equals the active power exchange with the grid,

\[
P_{EV,s} = P_{vsc}
\]

A. PEV Active Power

The active power \( P_{EV,s} \) is derived from the instantaneous states of charge and discharge using exponential functions over the time \[3\]-\[8\],

\[
P_{EV,ch}(t) = P_{EV,\text{max}} \left( 1 - e^{-\frac{t}{\alpha t_{\text{max}}}}} \right) + P_{EV,0} \]

\[
P_{EV,\text{dis}}(t) = P_{EV,0} \cdot e^{-\frac{t}{\alpha t_{\text{max}}}}
\]

where \( P_{EV,\text{max}} \) is the battery maximum power output, \( P_{EV,0} \) is the battery initial state of charge, \( t_{\text{max}} \) is the maximum charging time and \( \alpha \) is a constant parameter that allows charging the battery system from a fully discharged state to 97% of maximum power capacity in one third of \( t_{\text{max}} \).

In order to calculate the PEV active power demand it is necessary to assume that \( t_d \) hours are needed to charge the battery system. As a result, \( P_{EV} \) is defined as,
\[ P_{EVdem} = P_{EVmax} \left( 1 - e^{-\frac{t_d}{t_{max}}} \right) \]  
(15)

On the other hand, the active power supplied by the EV assuming that \( t_s \) hours are required to fully discharge the battery system is,

\[ P_{EVs} = P_{EVmax} \cdot e^{-\alpha} \cdot e^{-\frac{t_s}{t_{max}}} \]  
(16)

where \( t_s = t_{max} - t_d \).

**B. One-PEV Equivalent Model.**

Assuming that the vehicles have similar characteristics, the transformation of a group of PEVs into a one-PEV equivalent relies on the computation of an equivalent active power flow and equivalent internal impedance as follows,

1) The equivalent active power of the fleet is the sum of the active power of each vehicle. Since all vehicles are identical, then the active power is computed as,

\[ P_{EV, fleet} = n_{EV} \cdot P_{EVs} \]  
(17)

where \( n_{EV} \) is the number of PEV within the vehicular fleet.

2) The internal equivalent impedance of the one-PEV equivalent is the sum of the impedance of each device,

\[ Z_{usc, fleet} = n_{EV} \cdot Z_{usc} \]  
(18)

The impedance of the recharge center transformer is maintained constant since the total capability of the center does not change.

**C. Incorporation of PEV to distribution power flow.**

The PEV model presented in this paper is based on a controlled voltage formulation. This model allows active power exchange and regulation of bus voltage magnitude. However, the three-phase distribution power flow method implemented in this work requires the system components to be modeled as current injections. Therefore, the PEV model must be adequate in order to be incorporated to a three-phase power flow solution.

Figure 3 resumes the unbalanced three-phase power flow algorithm. It relies on a double-loop algorithm to integrate the PEV model. While the outer loop performs the main power flow analysis, the inner loop determines the reactive power required to maintain constant the bus voltage magnitude. The inner loop iterates until the \( \Delta Q_{EV}^{k,l} \) is smaller than a predefined tolerance.

Assuming \( \bar{V}_{EV} \) is the desired voltage at PEV controlled voltage node, then the voltage mismatch is defined as,

\[ \Delta V_{EV} = \left| \bar{V}_{EV} \right|^2 - \left| V_{EV}^{k,l} \right|^2 \]  
(19)

where \( \Delta V_{EV} \) is the variation of the PEV bus voltage for the \( k \)th outer iteration and the \( l \)th inner iteration.

Then the reactive power error in terms of the voltage mismatch is given by [9],

\[ \Delta Q_{EV}^{k,l} = \frac{\Delta V_{EV}}{2X_{EV}} \]  
(20)

where

\[ X_{EV} = \text{im} \left( A_{BCBV}(i,:) \cdot A_{BCBC}(i,:) \right) \]  
(21)

If the reactive power mismatch is not smaller than tolerance \( tol_{Q} \), then PEV power and bus voltage at the \( (k + 1) \)th outer iteration and \( (l + 1) \)th inner iteration are calculated.
IV. GENETIC ALGORITHM

Genetic Algorithms (GA) are systematic methods for solving search problems applying a biological evolution scheme: population-based selection, reproduction and mutation. After describing the problem in a number of variables \((x_1, x_2, \ldots, x_n)\), the solutions are encoded in a chromosome. All operators used by a GA are applied on these chromosomes or populations derived from these chromosomes. GAs have been applied to solve combinatorial optimization problems, that usually involves a huge number of possible solutions. Some examples of combinatorial problems on power systems are economic and reactive dispatch, optimal power flow and planning and expansion of power systems [10].

In this work a multiobjective GA is applied in order to find the number of PEVs per phase that minimizes the percent of voltage unbalance at the bus where the PEVs recharge center is connected and total power losses of a distribution feeder.

The Multiobjective Optimization Problem (MOP) is devoted to find a vector of decision variables which satisfies constrains and to optimize the vector function whose elements represent the objective functions. These functions form a mathematical description of the problem to be optimized, which usually are in conflict with each other. The objective functions are represented as a vector with the form \([f_1, f_2, \ldots, f_o]\).

\[
\bar{f}(\bar{x}) = \begin{bmatrix} f_1(\bar{x}) \\ f_2(\bar{x}) \\ \vdots \\ f_o(\bar{x}) \end{bmatrix}
\]

(22)

where \(o\) is the number of objectives.

When having multiple objectives, the notion of optimum is slightly modified, since the objective functions are opposed. Unlike the mono-objective problems with unique solutions, in MOPs it is desired to find a set of solutions that provide adequate or acceptable values for the objective functions. This set of solutions is known as Pareto Optimal.

In order to find the Pareto Optimal set the Nondominated Sorting Genetic Algorithm II (NSGA-II) is used. The process of sorting based on nondominated solutions is summarized in Figure 4. NSGA-II compares each solution of the population with the rest of them to know which individuals are dominated and which are not dominated. This information is stored in two variables: (1) \(n_p\) is the number of individuals that dominate the solution \(p\), and (2) \(S_p\) is the set of individuals dominated by the solution \(p\). The solutions that belong to the Pareto Optimal set will have \(n_p = 0\).

V. STUDY CASES

A test case based on the IEEE 13-node test feeder and a vehicular fleet is presented in this section. The PEV recharge center has space and current limits for 60 units uniformly distributed in the three phases (20 units per phase). Each PEV is modeled as a Tesla Roadster EV [6], where the lithium-ion battery pack requires 3.5 hours for full charge using a 240 V and 70 A single-phase power supply. The VSC internal impedance is 6% and the constant parameter \(\alpha\) is 10.14. The reactive power limits of the VSC are set for a power factor of 0.9. All transformers have a grounded wye-grounded wye configuration.

The proposed optimization problem consists in finding the number of electric vehicles per phase in the recharge center connected at node 671 of the IEEE 13-node test feeder. It minimizes the percent of voltage unbalance in the node where the recharge center is located \((%K_V)\) and the power losses \(P_{loss}\) of a distribution feeder. Then,

\[
\min \left\{ \frac{K_V}{P_{loss}} \right\}
\]

\text{s.t. } 0 \leq eV_{a,b,c} \leq 20

where \(eV_{a,b,c}\) is the number of PEVs connected in phases \(a\), \(b\) and \(c\).

A number of simulations are carried out in order to find the parameters needed for genetic operators. The parameters that give the best results are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>100</td>
</tr>
<tr>
<td>Number of offsprings</td>
<td>75</td>
</tr>
<tr>
<td>Mutation probability</td>
<td>0.5</td>
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</table>

Figure 4. Flux diagram of the sorting process based on nondominated solutions.

Table 1
PARAMETERS USED FOR GENETIC OPERATORS.
A. Charging from the grid

The equivalent vehicular fleet is defined as a voltage-controlled node demanding active power from the grid in order to charge the battery pack within the PEVs. The percent of voltage unbalance in the three-phase distribution system is analyzed for three operating scenarios:

- Base Case: The IEEE 13-node test feeder operates without a vehicular fleet.
- Case A: A vehicular fleet at node 671 is defined as an active power load without bus voltage control.
- Case B: A vehicular fleet is operated as an active power load with bus voltage control at node 671.

Figure 5 summarizes the percent of voltage unbalance at each node of the IEEE 13-node test feeder for base case and case A with three scenarios: (i) - the recharge center operates at full capacity (i.e. 20 PEVs each phase), (ii) - 6, 16 and 0 vehicles are plugged at phases $a$, $b$ and $c$ according with the distribution given by the GA to minimize the percent of voltage unbalance at node 671, and (iii) - 3, 13 and 0 vehicles are plugged at phases $a$, $b$ and $c$ according with the distribution determined by the GA that minimizes the power losses in the system.

It can be appreciated high unbalanced voltages up to 50% at nodes 645, 646 and 684, while 100% of voltage unbalance for nodes 611 and 652. These high levels are associated to voltage nodes with only one or two phases. The percent of voltage unbalance detected in the rest of the bus voltages for the base case are $K_V = \{1.38, 1.40, 1.57, 3.017, 3.017, 3.19, 3.017\}$, for nodes 632, 633, 634, 671, 692, 675 and 680, respectively.

The corresponding percent of unbalance for case A scenario (i) are $K_V = \{1.69, 1.71, 1.91, 3.68, 3.68, 3.88, 3.68\}$, for scenario (ii) $K_V = \{1.14, 1.15, 1.32, 2.51, 2.51, 2.69, 2.51\}$, while $K_V = \{1.1, 1.20, 1.35, 2.51, 2.51, 2.77, 2.51\}$ for case A scenario (iii). It can be seen that the percent of unbalance increases 1.18 for scenario (i), whilst for scenarios (ii) and (iii) the percent of unbalance decreases 5.66 and 3.83% average with respect to base case.

Figure 6 summarizes the percent of voltage unbalance at each node of the IEEE 13-node test feeder for base case and case B with three operating scenarios: (i) - the recharge center feeds 20 PEVs at each phase, (ii) - 17, 17 and 0 vehicles are plugged at phases $a$, $b$ and $c$ according with a GA that minimizes the percent of voltage unbalance at node 671, and (iii) 0, 16 and 3 vehicles are scheduled for minimizing the power losses in the system.

Unbalanced voltages up to 50% at nodes 645, 646 and 684, while 100% of voltage unbalances for nodes 611 and 652. For nodes 632, 633, 634, 671, 692, 675 and 680 the corresponding percent of voltage unbalance for case B(i) are $K_V = \{1.57, 1.58, 1.79, 3.44, 3.44, 3.63, 3.44\}$, $K_V = \{1.01, 1.03, 1.26, 2.30, 2.30, 2.49, 2.30\}$ for scenario B(ii) and $K_V = \{1.41, 1.42, 1.55, 2.99, 2.98, 3.16, 2.98\}$ for case B scenario (iii). It can be seen that the percent of unbalance increases 1.14 and 1.04 times for scenarios (i) and (ii), whilst the percent decreases 9.79% for scenario (ii) with respect to base case. Table 2 summarizes the power flow results for base case, case A and case B with the PEVs distributed accordingly with the results given by the GA.

B. Discharging to the grid

The equivalent vehicular fleet is defined as a voltage-controlled node providing active power to the grid. The percent of unbalance voltage in the distribution system is analyzed for three operating scenarios:

- Base Case: IEEE 13-node test system with no vehicular fleet.
- Case C: A vehicular fleet is connected at node 671 and supplies active power with no voltage control.
Figure 6. Percent of voltage unbalance for PEV fleet demanding active power with voltage control.

Table II

<table>
<thead>
<tr>
<th>Base Case</th>
<th>Case A</th>
<th>Case B</th>
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<tr>
<td>PEVs</td>
<td></td>
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<tr>
<td>a</td>
<td>0</td>
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<tr>
<td>b</td>
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</tr>
<tr>
<td>c</td>
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<td>20</td>
</tr>
<tr>
<td>%K_V</td>
<td>2.75</td>
<td>3.68</td>
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<tr>
<td>Power losses</td>
<td>61.82 kW</td>
<td>125.62 kW</td>
</tr>
</tbody>
</table>

Case D: A vehicular fleet is connected at node 671 supplying active power and providing voltage controllability. Figure 7 summarizes the percent of voltage unbalance at each node of the IEEE 13-node test feeder for base case and case C with three scenarios: (i) - the recharge center is full capacity with 20 PEVs per phase, (ii) - 16, 1 and 20 vehicles are plugged at phases a, b and c using the GA to minimize the percent of voltage unbalance at node 671, and (iii) - 20, 15 and 20 vehicles are plugged at phases a, b and c according to the results generated by the GA to minimize the power losses in the system.

Important unbalanced voltages can be appreciated at nodes 645, 646, 684, 611 and 652 which are due to the presence of only one or two phases. These high levels are associated to voltage nodes where one or two phases are missing. The percent of voltage unbalance detected in the rest of the bus voltages nodes 632, 633, 634, 671, 692, 675 and 680 for case C scenario (i) are %K_V = \{1.15, 1.61, 1.31, 2.48, 2.48, 2.65, 2.48\}, %K_V = \{0.97, 0.96, 1.05, 2.01, 2.01, 2.17, 2.01\} for case C scenario (ii) and %K_V = \{1.11, 1.12, 1.24, 2.37, 2.37, 2.54, 2.37\} for case C scenario (iii). It can be seen that the percent of unbalance decreases 5.89%, 15.85 and 8.15% with respect to base case for scenarios (i), (ii) and (iii).

On the other hand, Figure 8 summarizes the percent of voltage unbalance at each node of the IEEE 13-node test feeder for base case and case D with three operating scenarios: (i) - 20 PEVS per phase, (ii) - 20, 0 and 20 vehicles are connected to phases a, b and c as a result of minimizing the percent of voltage unbalance at node 671 with the GA, and (iii) - 20, 9 and 20 vehicles are plugged at phases a, b and c determined by the GA to minimize the power losses in the system.

It can be seen important voltage unbalances up to 100% at nodes where there exist only one or tow phases (see voltage nodes 645, 646, ). The corresponding percents of voltage unbalance at nodes 632, 633, 634, 671, 692, 675 and 680 for case D scenario (i) are %K_V = \{0.98, 0.99, 1.15, 2.19, 2.19, 2.35, 2.19\}, %K_V = \{0.70, 0.69, 0.75, 1.47, 1.47, 1.62, 1.47\} for case D scenario (ii) and %K_V = \{0.87, 0.87, 0.98, 1.87, 1.87, 2.03, 1.87\} for case D scenario (iii). It can be seen that the percent of unbalance for scenarios (i), (ii) and (iii) decreases 12.33, 27.40 and 18.89% with respect to base case. Table 3 summarizes the power flow results for the distribution test case with PEVS discharging to the grid and applying a GA to optimize the number of PEVS per phase.

VI. CONCLUSION

A power flow blend based on a distribution three-phase power flow and a GA for the analysis of voltage unbalance has been presented in this work. The GA is applied to optimize the number of PEVS allocate per phase in order to reduce the percent of voltage unbalances. The PEV is modeled as a voltage controlled node, which allows not only active
power exchange but also reactive power for voltage support. The effect of the vehicular fleet on the unbalance voltage is analyzed using a genetic algorithm, the results show that the presence of the vehicular fleet increases the percent of unbalance in the bus voltages in the system when it acts as a load. On the other hand, the percent of unbalance in the bus voltages can be effectively reduced with respect to the base case with the application of a GA approach.

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REFERENCES

Table III
POWER FLOW RESULTS FOR PEVS DISCHARGING TO THE GRID.

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<th>Base Case</th>
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<td></td>
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<td>20</td>
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<tr>
<td>%Kv</td>
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<td>3.68</td>
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<td>21.55 kW</td>
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<tr>
<td></td>
<td>19.27 kW</td>
<td>2.30</td>
<td>2.98</td>
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</tbody>
</table>


Alejandra Jiménez received her degree in electrical engineering from the Instituto Tecnológico de Morelia (ITM), Morelia, México, in 2006. She received her M.Sc. degree from the ITM, Morelia, México, in 2009. Currently, she is carrying out Ph.D. studies in power systems at the Universidad Michoacana de San Nicolas de Hidalgo (UMSNH). Her areas of interest are alternative sources of energy, distribution systems and genetic algorithms applied to power systems.

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