RECHARGING PROCESS OF PLUG IN VEHICLES BY USING ARTIFICIAL IMMUNE SYSTEM AND TANGENT VECTOR

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ABSTRACT

This work deals with the application of Artificial Immune Systems (AIS) in distribution systems. Based on natural immune systems, these systems present some important characteristics that may be useful in optimization of power systems operation and planning. In this paper, such a technique is enhanced by tangent vector to help the search solution, so the optimization process is accelerated. The tests are obtained by using the IEEE 34-bus distribution system.

INTRODUCTION

Ensuring desirable operating conditions is one of the main goals of system planners and operators around the globe. By desirable, in this sense, one may think as voltage stable [1], [2], reliable [3] and dynamically stable [4]. Additional features, like good power quality [5] are also pursued. If all these conditions are applied, further actions to enhance the system operating conditions may be taken. In this sense, loss reduction [6] may be the focus, since this tends to improve the voltage level and the reactive power control.

Loss reduction may be obtained by a sort of different meanings. Traditional optimization techniques, like interior points method [7] may be effectively applied. Evolutionary techniques, as Particle Swarm Optimization, may also be applied, as described in [8]. Genetic Algorithms (GA) are also used as optimization tool in losses minimization problems.

Another tool of analysis for the purpose of loss reduction is the Artificial Immune System (AIS). Such a system is meant to emulate the natural immune system, which is a complex of cells, molecules and organs that represent an identification mechanism capable of perceiving and combating dysfunction from our own cells and the action of exogenous infectious microorganisms. It recognizes an almost limitless variety of infectious foreign cells and substances (nonself-elements), distinguishing them from those native noninfectious cells (self-molecules).

The AIS searching process is quite different from GA, for example. While GA operators guide the population towards its fittest members, AIS searches for optimal solutions locally and in different regions of space shape at the same time. These features contributed for choosing AIS as the optimization tool in this paper. The search process is enhanced by employing tangent vector as a tool of help. Such a vector converges to the zero-right eigenvector and provides the sensitivity of the state variables with respect to a system parameter [1]. Using tangent vector to identify the most critical buses with respect to voltage collapse creates a search direction for AIS that tends to produce better results in a reduced computational effort. This is the core of this paper, so the next sections are devoted to describe the methodology employed and to present the results obtained with the help of the IEEE 34-bus distribution system.

TANGENT VECTOR FEATURES

Tangent vector used to identify the most critical buses in a system is briefly described, so the reader may become familiar with the theory employed. Tangent vector is given by

$$TV = \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \frac{1}{\Delta\lambda} = J^{-1} \begin{bmatrix} P_o \\ Q_o \end{bmatrix} \qquad (1)$$

where J is the load flow Jacobian, θ and V the state variables (angle phase and voltage magnitude, respectively), and P_o and Q_o are the net active and reactive powers connected to each bus. TV is the shortage for tangent vector.

ARTIFICIAL IMMUNE SYSTEMS

The artificial immune system is used here because they present the following characteristics [9], [10]:

- Uniqueness: each individual possesses its own immune system with its particular vulnerabilities and capabilities;
- Recognition of foreigners: the harmful molecules that are not native to the body are recognized and eliminated by the immune system;
- Anomaly detection: the immune system can detect and react to pathogens that the body has never encountered before. This is possible due to mechanisms like somatic hypermutation and receptors editing, which creates a repertoire diversity;
- Distributed detection: the cells of the system are distributed all over the body and, most importantly, are not subject to any centralized control;
- Imperfect detection (noise tolerance): an absolute recognition of the pathogens is not required, hence the system is flexible;
- Reinforcement learning and memory: the system can “learn” the structures of pathogens, so that future responses to the same pathogens are faster and stronger;
- Pattern recognition: the immune system recognizes some antigens, even if it has never faced them.

In this paper, this technique is applied to the charging coordination of plug-in hybrid electric vehicles. Results already obtained render (AIS) as appealing for this sake. An improvement in the search process is proposed here, since tangent vector [1] is used as a tool to form the initial antibodies to be considered in the optimization process. Recall that an antibody, in this context, is the solution which satisfies the objective function. For example, if loss reduction is pursued by capacitor placement, an antibody represents the node set where capacitors are installed. Using tangent vector may reduce the computational burden, since a better search direction is provided. The idea is tested in an academic test-system, so the results may be reproduced.

METHODOLOGY

The optimized recharging scheme is described in this section. At the beginning, the PHEV models are randomly chosen and connected to the nodes according to the quantities established previously. The vehicles' battery State of Charge (SOC) is randomly chosen, but it's restricted to be higher than the minimum SOC for each model.

Then for each node load, P_{node} and Q_{node}, are evaluated considering residential customers, P_{res} and Q_{res}, and vehicles' recharging power, P_{veh} and Q_{veh}, according to Equations (2) and (3).

$$P_{node} = P_{res} + n.P_{veh} \tag{2}$$

$$Q_{node} = Q_{res} + n.Q_{veh} \tag{3}$$

Max P_{node} = 60 kW;
Max Q_{node} = 45 kVAr;
Max P_{veh} = 4 kW;
n: number of vehicles connected to node.

For single-phase nodes Max P_{node} = 12 kW and Max Q_{node} = 9 kVAr. Then a load flow is performed using Equation (4) to backward sweep and Equation (5) for forward sweep. $K_{A,B,C}$ are the incidence matrices for each phase, 'l' represents the load model.

$$I^{A,B,C}_{branch\_ij} = K^{-1}_{A,B,C}\cdot\left[\frac{abs\left(V^{A,B,C}_{node\,i}\right)^{l} \times conj\left(S^{A,B,C}_{load,spec}\right)}{conj\left(V^{A,B,C}_{node\,i}\right)}\right] \tag{4}$$

$$\begin{bmatrix} V_j^A \\ V_j^B \\ V_j^C \end{bmatrix} = \begin{bmatrix} V_i^A \\ V_i^B \\ V_i^C \end{bmatrix} - \begin{bmatrix} Z_{AA} & Z_{AB} & Z_{AC} \\ Z_{BA} & Z_{BB} & Z_{BC} \\ Z_{CA} & Z_{CB} & Z_{CC} \end{bmatrix} \begin{bmatrix} I^A_{branch\_ij} \\ I^B_{branch\_ij} \\ I^C_{branch\_ij} \end{bmatrix} \tag{5}$$

If there are some voltage levels violated, the system's loadability is re-evaluated by rescheduling PHEV's recharging power and a load flow is performed again. This procedure assures that no violations occurs and also an optimal recharging schedule. It's important to emphasize that no residential load switching is considered.

Although this first part assures minimum voltage constraints, the optimization process continues seeking to minimize power losses, described in Equation (6), and improve voltage levels by reactive compensation, reaching better operational conditions.

By using tangent vector, it's possible to reduce the AIS optimization's computational burden. The TV gives the best directions to searching process on the shape space, identifying the most critical nodes with respect to loss minimization.

$$min \sum_{x=1}^{r} Re(S) = Re(Z_{branch\,r}.I^2_{branch\,r}) \tag{6}$$

$$\text{s.t.}\begin{cases} Vmin \leq V_a \leq Vmax; \\ Vmin \leq V_b \leq Vmax\,; \\ Vmin \leq V_c \leq Vmax \\ Vmin = 0.9; Vmax = 1.05; \end{cases}$$

The TV is calculated after the power flow convergence using Equation 1 and capacitors are allocated on the best positions, according to TV's results, forming the antibodies first generation. A new power flow is performed to compare the options, and the best ones are hold. The worst antibodies are deleted.

The TV is calculated again, showing the best positions for second generation antibodies. These new solutions, with two capacitors, are compared according to their power losses, calculated using a power flow. Once more the best antibodies are kept and the worst ones are deleted.

The process is repeated and new antibody generations are calculated until the difference between two generations' power losses is within a limit.

TEST RESULTS

This section describes the results obtained by the proposed methodology. For this sake, the IEEE 34-bus system depicted in Figure 1 is employed.

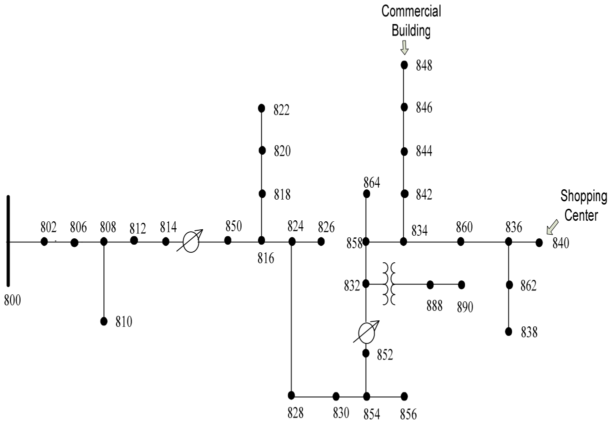

Figure 1 - Test system used in the tests

The solutions obtained by using the methodology described before are better than those ones obtained when a random process is performed. To compare the two approaches their respective results are shown in Table 1 and Table 2.

In Tables 1 and 2, columns 1 to 4 represent the antibody. Each antibody represents the set of nodes where capacitors were installed. Column 5 is associated with the original losses without capacitor installation. Column 6 represents the optimized power losses. Column 7 shows the respective generation of each antibody.

Table 1 - Random process solutions

Pos . 1	**Pos. 2**	**Pos . 3**	**Pos. 4**	**Original Losses**	**Optim. losses**	Gen.
852	864	864	840	0.2136	0.1638	7
862	832	864	864	0.2139	0.1639	8
836	852	812	864	0.2128	0.1744	5
840	820	864	828	0.2019	0.1760	4

Table 2 – Tangent Vector (TV) oriented process solutions

Pos . 1	Pos. 2	Pos . 3	Pos. 4	Original Losses	Optim. losses	Gen.
850	838	810	838	0.2365	0.2068	4
838	818	890	810	0.2372	0.1967	4
818	838	826	826	0.2380	0.1829	4
818	838	810	810	0.2438	0.1731	4

As the results show, the solutions of the TV-oriented optimization process allow a considerable loss reduction with a lower computational burden. This could be observed in the generation column. For the proposed method, all the solutions are from 4th generation. As described before, each generation is created according to TV sensibility.

CONCLUSIONS

This paper dealt with the problem of vehicle recharging policy for a distribution system. For this sake, an Artificial Immune System has been employed to optimize the recharging process, so no system violation is observed. The literature shows this methodology as effective and appealing for a wide range of applications in power systems. In this paper, such a method is enhanced by incorporating tangent vector to help in the search direction. The results obtained render this combination as promising, since the results obtained are in a better computational performance in comparison with the traditional search direction. Further investigation is to be executed by considering larger distribution systems.

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