Evolving Cooperative Behavior in a Power Market

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ABSTRACT

This paper presents an evolutionary algorithm to develop cooperative strategies for power buyers in a deregulated electrical power market. Cooperative strategies are evolved through the collaboration of the buyer with other buyers defined by the different group memberships. The paper explores how buyers can lower their costs by using the algorithm that evolves their group sizes and memberships. The algorithm interfaces with PowerWorld Simulator to include in the technical aspect of a power system network, particularly the effects of the network constraints on the power flow. Simulation tests on an IEEE 14-bus transmission network are conducted and power buyer strategies are observed and analyzed.

Categories and Subject Descriptors

Learning Classifier Systems and Other Genetics-Based Machine Learning

General Terms

Economics, Human Factors.

Keywords

Cooperative behavior, power market, evolutionary algorithm.

1. INTRODUCTION

The power markets in almost all the regions around the world are undergoing deregulation and privatization process to introduce competition and open-market environments to bring about greater value for money, higher grade of service and more efficient allocation of financial resources. Competition is guaranteed by establishing restructured environments or markets in which customers could choose to buy from different suppliers and change suppliers as they wish in order to pay market-based rates. In the deregulated power market, a power exchange (PX) accepts schedules for loads and generation resources. Through an electronic auction, the PX establishes the Market Clearing Price (MCP) for each hour of the following day for trades between buyers (demand) and sellers (supply) of electricity. However, the technical constraints and the safety aspects of the transmission network may cause congestion on the transmission lines [1].

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Congestion pricing is a critical component needed to determine the financial value of transmission congestion to calculate the locational marginal prices (LMPs) based on the allocation of limited transmission capabilities over constrained interfaces, resulting in an increase in the total cost of providing electricity [2].

The variation in price at different locations within the power system is borne by the power buyers. Cooperation among buyers can be a viable solution to reduce the LMPs while at the same time attempting to draw the required amount of power needed from the bus.

2. EVOLVING BIDDING STRATEGIES

The proposed method uses an evolutionary algorithm to evolve cooperative strategies for buyers to lower their costs. Each chromosome represents the twenty buyers and their group membership. A partial illustration is shown in Fig. 1.

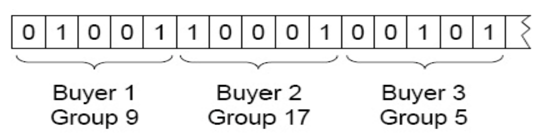

Figure 1. Buyer grouping representation

A heuristic-guided approach has been implemented to model the revaluation of the demand bids of every buyer within the same coalition for each of the 24 hours of the day. The fitness function evaluation of each chromosome is performed using the PowerWorld simulator, which runs a complete power flow program for each chromosome, and ensures that all technical constraints are adhered to. The fitness of the chromosome comprises of twenty fitness values, each representative of each buyer and is determined by comparing the obtained LMPs and power delivered against the base case.

Within the chromosome, genes are ranked accordingly to their individual fitness, and undergo a regeneration process. Tournament selection, adaptive crossover and mutation [3], and elitist replacement processes are used in the regeneration of a new chromosome. Genes with low fitness levels would attempt to change their grouping as it is not rational for them to continue with a group combination which gives them a lower than average fitness value. The regeneration process takes place between genes within a chromosome string instead of between chromosomes. This allows the genes of the particular chromosome to seek out the current groupings which provide high fitness levels to its participants or start new groups. This physically represents buyers evolving to reassess their reward of their current grouping and to attempt to change their grouping to obtain a higher fitness value in the search of finding a better group combination. The regeneration process is then repeated until a predetermined number of cycles have been completed (Figure 2).

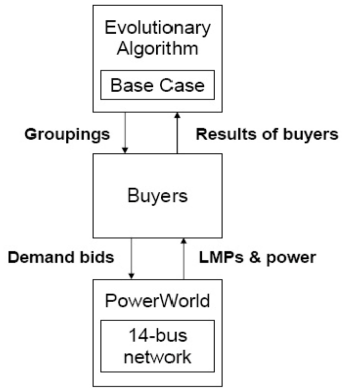

Figure 2. Evolutionary algorithm for evolving bidding strategies

In the base case, the PowerWorld simulator optimal power flow analysis is used without enforcing the transmission line limits. This allows the transmission lines to transmit power above their stated allowed level and all loads to be delivered their requested amount of power. The overloading of the lines by buses is penalized with a corresponding congestion charge.

3. RESULTS

Simulations using the proposed evolutionary approach have been performed on an electricity market with 7 sellers and 20 buyer agents. Through the evolutionary process, the buyer agents learn mutually beneficial strategies to form groups that would result in financial benefits. The developed agent-based model uses PowerWorld simulator to incorporate the traditional physical system characteristics and constraints while evaluating individual agent's behavior, actions and reactions on market dynamics.

3.1 Group Formation

It was observed that for most coalitions with high fitness values for each of the cooperative buyers, the buyers were located within a 2-bus radius. High fitness values are representative of lower costs and small deviations in the power obtained by the buyer relative to the values of the base case.

3.2 Extent of Participation and Group Size

It was observed that there is no correlation between the number of buyers which cooperated, and the average fitness value of the cooperative buyers. Rather, the average group fitness value was found to be mainly dependent on the combination of the buyers in the group.

3.3 Individual Buyers

Generally, individual buyers fared worse as the effects of the revaluation of demand bids by cooperative buyers due to the interconnectedness of the power network meant that the former was exposed to more non-systematic risks.

3.4 Group Dynamics

Using this novel approach to evolve group dynamics in the evolutionary algorithm process, it is possible to allow different buyers to change their grouping without losing pertinent information which might have been lost if a conventional genetic algorithm had been used instead.

Figure 3(a) depicts the population of buyers before the evolutionary regenerative process while Figure 3(b) shows the new population of buyers and their new respective groupings after the evolutionary regenerative fitness-based process.

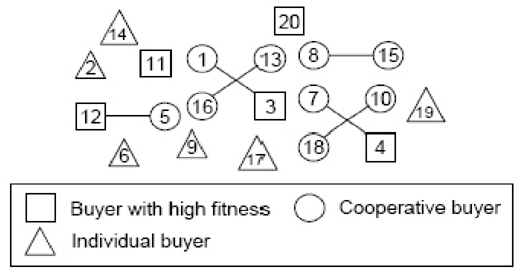

Figure 3(a). A population of buyers and their groupings

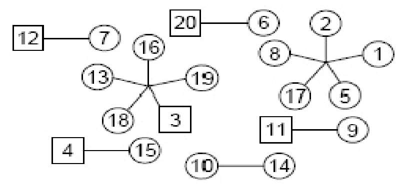

Figure 3(b). The same population of buyers in their new respective groupings after the regeneration process

4. CONCLUSION

By adjusting the demand curve and joining a suitable group, a buyer can achieve substantial cost savings without sacrificing much in desired power consumption. Experimental results using PowerWorld and the IEEE 14-bus network show that buyers on a 2-bus radius stand to benefit from cooperation in general. Buyers at buses with high LMPs due to congestion benefit most from cooperation. The experiments also show that the benefits from forming cooperative groups does not depend on group size but rather on which are the group members.

5. REFERENCES

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