A Genetic Algorithm for Flattening Cumulated Household Load Curves

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1 Introduction

In recent years the electricity industry has been undergoing a deep mutation. On the one hand, the emergence of decentralized production makes a radical change in the grid management landscape, setting new problems, especially in term of irregular electrical production of photovoltaic panels and wind turbines. On the other hand, new electricity usages (such as fully-electric or hybrid cars) lend to a difficult modeling of consumer behavior. As a result, grid operators face a new challenge, namely take advantage of Information and Communication Technology (ICT) in order to optimally operate the grid. This is the well-known concept of smart grids. In this framework, one of the main issues is the problem of load-balancing between on-peak and off-peak periods. By no means is this a new issue, but ICT tools included in recent electricity meters provide new possibility to tackle the problem.

2 Context

During past decades, time-of-use tariffs have been used in France in order to balance the consumption load between on-peak periods (ONPP) and off-peak periods (OFFPP). In order to encourage the consumer to use its electrical appliances when the electrical system is not overloaded (typically at night), he is offered cheap prices during these periods. Traditionally, two such periods of the day where defined, the first one located between noon and five PM (Day Off-Peak Period, or DOPP), the second one between 8 PM and 8 AM the next day (Night Off-Peak Period, or NOPP). On the contrary, consuming electricity the rest of the day will be done at higher costs. So far, each consumer that chose this kind of pricing was provided a cluster of (one or two) off-peak periods in the day, randomly drawn from a set of 4 fixed clusters, and depending of the primary substation at which he/she is connected. Although this is an effective strategy, it has a drawback: the lack of flexibility. One striking example is due to the servo-control included in some electrical appliances (e.g. hot water tank): these appliances start operating when receiving a signal sent on the grid at a given frequency. Since numerous customers appliances located on the same network may react simultaneously at the signal, a consumption peak sometimes appears over a short period at night (typically at 11 PM). A way to avoid these risks would be to assign different off-peak periods, starting at different moment, to customers connected on the same network. The work described in this paper aims at investigating the possibility of flattening the cumulated load curve of a given part of the grid by determining peculiar OFFPPs for each customer connected to that network.

3 The problem

For a set of customers for whom we aim at determining new OFFPPs possibly different from the current ones, we are given two household load curves for a typical day, made up of 144 points (a consumption level for each time step of 10 mn). The first curve, that we call the “off-peak extra

consumption" curve, is related to the servo-controlled appliances. The second curve, that we call the "natural" curve, represents the remainder of the household consumption. When summed, these two curves constitute the "total consumption" curve of the customer. Now, consider a set of n customers connected to the same sub-network. If we add their total consumption curves, we get a cumulated curve, which represents the total load on the sub-network. Our goal is to assign to each customer a particular moment for starting OFFPP, so as to flatten as much as possible the cumulated curve. The constraints that must be fulfilled state that OFFPP must be entirely set in DOPP and/or NOPP. They also state that the total duration of OFFPP must be equal to 8 hours. They finally state that the number of OFFPP per day should remain the same for each customer in the new setting. As for the objective function, the flattening is assessed through the computation of the Euclidian distance between the cumulated curve and a horizontal line.

4 The resolution method

The number of customers in a data set may amount to up to several thousands. Moreover, the number of possibilities for starting an OFFPP may be as big as 60. Facing such a huge search space with a quadratic objective function, we considered the use of meta-heuristics from the very beginning of our study. So, in order to solve efficiently this problem, we designed a genetic algorithm. In our case, an individual is made up of the whole set of customers, each one being assigned a peculiar set of one or two OFFPPs with initial starting points. We manage a fixed size population through the successive generations. In order to insure diversity, an elimination process is carried out each hundred generations, so that only one occurrence of duplicate individuals is kept in the population. Then the population is enriched with randomly created individuals to reach again its constant size. There are two mutation processes: *normal* mutation consists of mutating 5 genes of the individual, *close* mutation consists of mutating only 3 genes, in turns the corresponding starting moment of OFFPP is at most delayed or brought forward by 20 minutes. As for crossover, we use a conventional one-point technique. Finally, the selection step uses a stochastic tournament.

5 Results

Experiments have been carried out on a standard PC with 4GBytes of memory and a 2.5 GHz Intel Core i5-2520M processor. Running times are satisfactory, ranging from 40 sec. for a small data set with 63 customers, up to 28 min for a set of 4000 customers. We give below an example of initial cumulated curve and optimized cumulated curve (for some confidentiality reasons, the data is made of 100 simulated prototypical customers, representative of a real-life situation).

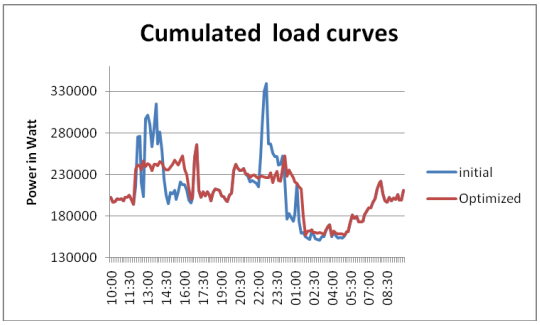

Fig. 1 comparison of initial and optimized load curves

The GA has proved to be effective in solving instances of our problem. The prototype has been delivered to the Distributor System Operator which will carry out further experiments aiming at checking scaling capabilities, as well as assessing the commercial soundness of the provided solutions.

References

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