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Electric load management approaches for peak load reduction: A systematic literature review and state of the art

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ABSTRACT

This paper proposes a review of the scientific literature on electric load management (ELM). Relevant topics include the smart grid, demand-side management, demand-response methods, and peak load reduction. The evaluation is performed by a systematic literature review (SLR) and an evaluation of the recent advances in the state of the art. The analysis is based on the classification of 200+ papers, considering the covered topics/problems, assumptions, constraints, and the proposed methods. Statistical results show a growing interest in ELM in the last few years, and a fast obsolescence of older results. A lack of common benchmarking frameworks has been detected.

Contents

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1. Introduction

The balance of the power demand is one of the main challenges in power delivery systems. The problem is that the electric power generation has to steadily match the consumption to avoid performance losses in the network. This problem is exacerbated by the increasing penetration of the distributed generation associated to renewable sources, due to their intermittent and partially unpredictable behavior. As a result, coping with a highly variable power demand is a critical and challenging issue for the utilities.

As an example of the impact of the power demand on the efficiency of global cities, we can consider that a big city such as New York annually consumes a total amount of around 54 TWh of energy (New York Independent System Operator, 2014) each year in the period 2010–2014. This is equal to 33% of the total energy consumption of the whole New York state, which consumes around 163 TWh per year (New York Independent System Operator, 2014) in the same period. Global cities thus have a huge impact on the energy/power usage in their territory. On the other hand, there are historical data about the peak-to-average power consumption at state level. For instance, EIA (2015) reports several statistics related to power consumption in various US areas, including peak-to-average evaluation. We report a representative example of a typical trend of the peak-to-average behavior, considering the yearly trend in New England (Fig. 1), which shows the steadily increasing trend of this parameter. The distribution power grid in global cities is thus a relevant component of the city itself. By reducing the peak-to-average power usage, the power grid is affected by less

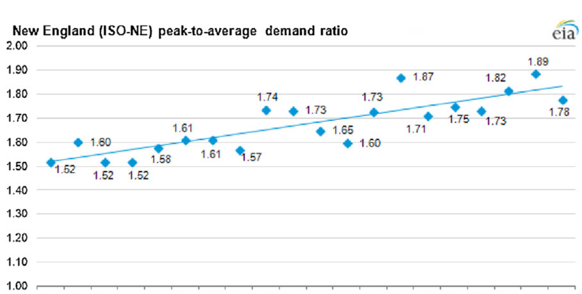

Fig. 1. Yearly peak-to-average trend in New England (US).

stress and can provide a more reliable and adequate quality of service.

These issues have generated lot of interest in many energy providers and companies operating in the electricity market. Several programs and projects have been started by these companies. Some relevant examples include the Demand-Response program started by the Office of Electricity Delivery & Energy Reliability (U.S. Department of Energy, 2015), the Demand-Response project ran by Consolidated Edison (2015) and PowerOn™ Precision management system proposed by General Electrics (2015). The success of these programs, and many other similar ones, will be also related to the exploitation of technologies and solutions covered by our review.

A common solution adopted by energy providers is to control the activity of power plants to match as much as possible the requested electric power. However, this approach has several disadvantages. An important problem is that traditional power plants (e.g., thermal power plants) are more expensive to start/stop than plants based on renewable sources. For example, starting/stopping a gas turbine is more challenging with reference to a hydroelectric generation unit. Moreover, they cannot be turned on/off at an arbitrary frequency, since the switch may require a relatively long time. As a side effect, power plants based on renewable sources are not exploited at their full capacity, since it is more convenient to reduce the power generated from such plants instead of dealing with more complex traditional plants. For this reason, an increasing penetration of renewable energy generation technologies will require a growth in the use of automatic power load management techniques. Moreover, a higher elasticity in the power demand enabled by the technologies discussed in this paper, will allow the on-site consumption of the energy generated by distributed renewable sources, thus reducing the impact of the variability of renewable energy generation. Another issue arises from the sizing of the power distribution infrastructure, which must be tailored to tolerate peak load conditions. For example, the size of the cables needs to be large enough to support the peak power, and since the peak occurs during a fraction of the life time of the system, cables don't operate at full capacity in the majority of the time. The same rule applies to other electrical equipment, such as transformers, switches, etc. Eventually, the end-user pays for these disadvantages, for example when critical-peak tariffs are adopted (Newsham & Bowker, 2010).