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Demand side management in smart grid: A review and proposals for future direction

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ABSTRACT

This paper mainly focuses on demand side management and demand response, including drivers and benefits, shiftable load scheduling methods and peak shaving techniques. Demand side management techniques found in literature are overviewed and a novel electricity demand control technique using real-time pricing is proposed. Currently users have no means to change their power consumption to benefit the whole system. The proposed method consists of modern system identification and control that would enable user side load control. This would potentially balance demand side with supply side more effectively and would also reduce peak demand and make the whole system more efficient.

Contents

1. Introduction

Even in the most developed countries electricity grid that is used today was designed more than 50 years ago and is becoming outdated. By modernising electricity grids it is possible to increase the efficiency of electricity production and the use of grid assets, to decrease carbon footprint and to make the whole power network more reliable and secure. New technologies are currently being developed that will enable so called smart grid. Although smart grid does not have a single clear definition, the European Technology Platform (European Commission, 2006) defines it as follows: “A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies.”

The idea of a smart grid has been around for a while and recent technological advancement in communications and sensing areas enables the development of smart grid. The traditional power grid landscape consists of centralised generation, where energy is

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pushed one-way through transmission and distribution networks to the end users. Currently this paradigm evolves by adding distributed renewable energy generation, distributed energy storage, utility scale renewable, utility scale energy storage, etc. It is also converting from radial networks to mesh networks with the possibility to reconfigure and self-heal. On top of the existing power network layer there will be a new communications layer for information exchange and control. The whole landscape is dramatically changing from what it has been historically.

From the global perspective, main drivers behind smart grid are capacity, efficiency, reliability, sustainability and customer engagement. Higher capacity electricity grid is needed in most developing countries. At the same time electric vehicles will also demand some changes on the grid in most developed countries. Electricity throughput can be increased by enhancing efficiency. At the same time the virtual capacity would be increased using peak-shaving techniques (Zhuo, Gao, & Li, 2008). Reliability is another big issue. Most of the system failures that lead to outages occur as a result of problems in the distribution system. Information from advanced sensors through supervisory control and data acquisition (SCADA) system might help to prevent accidents or react to the fault more rapid. Smart grid also looks at sustainability problem, where one of the major elements is the interconnection of renewable generation and how that generation is managed in order to meet the demand. Finally, residential customer engagement would enable demand side management to reduce the peak load, thus decreasing the required capacity and cost as well as increasing the overall efficiency.

Two main elements when considering efficiency are losses in the system and how the assets are deployed/used. Losses often depend on the load shape in the system, for example partially loaded transformers are less efficient, so it is desired that system operates at near capacity level. Utilization of system is a major factor when considering investment in system assets. Optimal planning of how system assets should be deployed and used (energy management) plays a key role when considering overall system efficiency.

Smart grid technologies mainly focus on advancements in distribution side of electricity network. Many people associate smart grid term to smart meters placed at the end users. The main goal of this paper is to overview demand side management technologies focusing on demand response (DR) and user engagement techniques.

2. Demand side management (DSM)

Demand side management is the planning, implementation and monitoring of utility activities that are designed to influence customer use of electricity. As a result, it changes the time pattern and magnitude of utility's load. Usually, the main objective of demand side management is to encourage users to consume less power during peak times or to shift energy use to off-peak hours to flatten the demand curve. Sometimes instead of flattening the curve it is more desirable to follow the generation pattern. In each case, there is a need of control over customer energy use.

Reliable operation of power grid is primarily dependent on perfect balance between supply and load at each given time (Kothari & Nagrath, 2009). It is not an easy task to maintain balance, assuming there is very little control on the demand side (generation side can be controlled according to the load). It gets even harder when distributed energy generation increases. Renewable generation varies with weather conditions and it is not generally easy or desirable to modulate the output of renewable in order to follow a particular load shape (Strbac, 2008). Also, peaks in renewable generation do not necessarily coincide with peak in demand so energy needs to be either artificially consumed or stored for later. The system could continue to rely on fossil fuels during peaks, but due to increased variability in generation, utilities would be forced to keep bigger margins of reserve, which would dramatically increase the total cost of electricity. The alternative of maintaining the balance is to use new methods and technologies, mainly the ones that are based on user engagement. To sum up, the classical approach is to supply all the required demand whenever it occurs, but the new strategy states that the demand should be controlled by engaging users as well to respond to current state of the system.

Demand response will indeed play a key role in electricity balancing act in the future. Currently consumers have no means of receiving information that would reflect the state of the grid thus cannot react to reach the balance and increase efficiency. Due to the nature of renewable, it is not possible to control or request power when it is needed. The main objectives of DR techniques are reduction of peak load and the ability to control consumption according to generation (Palensky & Dietrich, 2011). In other words, there should be a way for end-use appliances to know and react when cheap renewable energy is available and when there is a shortage of electricity.

There is a significant scope for DSM to contribute in increasing the efficiency and use of system assets. Demand side management has been considered since the early 1980s. It can be used as a tool to accomplish different load shaping objectives, such as peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape (Gellings, 1985) (Fig. 1). The combination of the mentioned techniques enables the load shape to follow generation as close as possible. It could decrease the amount of assets needed to fulfill current demand using existing methods of power generation (mostly fossil-fuel) and would significantly increase the load factor (Strbac, 2008).

Utilization of assets has the biggest influence over the price of electricity. Generation, transmission and distribution assets need to be built to meet peak demands, thus high peaks contribute to the biggest portion of electricity price. Electricity system in the UK has relatively low utilization of generation and network assets – about 50% (Strbac, 2008). Fig. 2(a) shows recent average demand in the UK and Fig. 2(b) shows average load duration in the UK. It can be seen that if the demand was controlled during critical 5% of the time, there would be a huge decrease in the required asset and even more dramatic decrease in electricity generation cost.

The UK Climate Change Programme aims to decrease carbon emission. According to Climate Change Act 2008, UK has to cut 80% of carbon emissions by 2050 (compared to 1990 levels). Energy sector is a major contributor to carbon footprint. In particular, electricity system is expected to make significant contribution in decreasing pollution that is originating from fossil-fuelled power plants. The deployment of low carbon renewable energy generation has already been started and is expected to increase in the future. The introduced inherent variability of renewable sources could be managed by matching the demand to supply, which is where DSM might come into play.

Another driver for modernising distribution system is to be able to charge customers with real time price of electricity. The way electricity is sold now does not meet modern market principles (Schuler, 2004). When the good is scarce, prices rise, suppliers want to sell more and consumers decrease their consumption. Due to the fact that electricity is a very short-term commodity and economically non-storable, i.e. it has to be consumed the moment it is produced, markets constantly experience short-term changes as capacity fluctuations from surplus to scarcity due to the hourly and daily fluctuation in demand. Fixed electricity tariff is simply very archaic and introduces cross-subsidies between customers. There is simply no incentive for customer to contribute in making the system more efficient (Tiptipakorn & Lee, 2007). Fig. 3 shows how price based incentives and increased number of renewable change price elasticity. Vertical demand curve represents inability