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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in the most developed countries electricity grid that is used today was designed more than 50 years ago and is becoming outdated.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

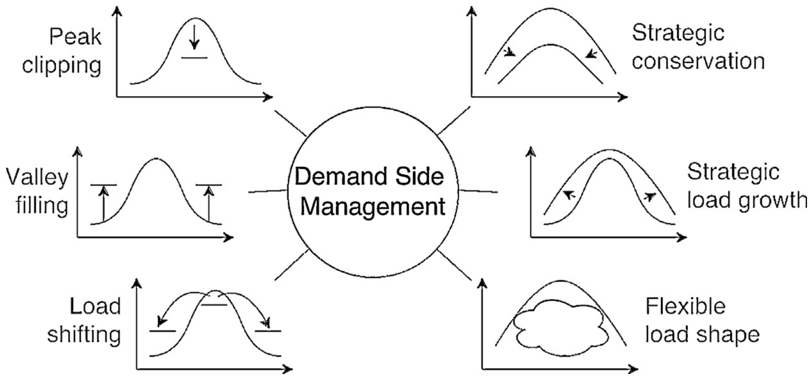
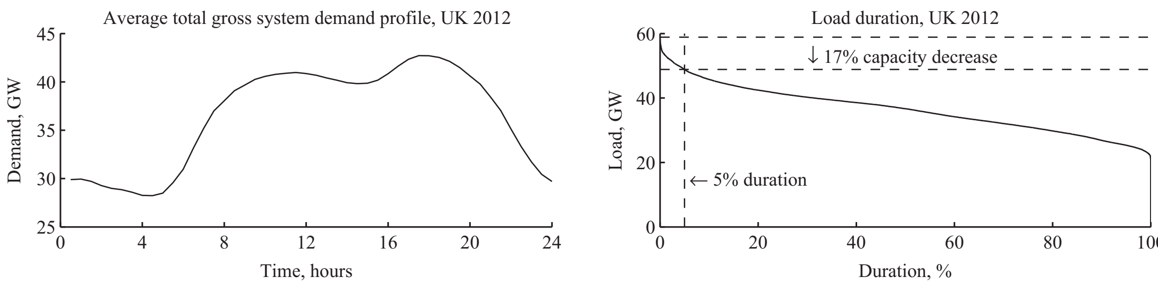


Fig. 1. Basic load shaping techniques (Gellings, 1985).



(a) Average total gross system demand (b) Load duration

Fig. 2. System load in UK 2012. (a) Average total gross system demand. (b) Load duration.

for customers to react to the real-time market price of electricity. If real-time pricing was implemented, the price would become elastic on the demand side opposed to fixed price tariff. On the other hand, increased number of renewable would also reshape the supply curve. During the times when green energy is scarce, the price for the same amount of energy would increase, shifting the curve up. That happens because renewable energy, like wind or solar, has very low running costs. All in all, demand response techniques would allow customers to participate both saving money and being more environmentally friendly.

Payback of investment in assets is another big consideration when planning system expansion. DSM would play a key role in increasing return of investment by increasing utilization of assets and making electricity sector more attractive to investors. As the designed useful lifetime of UK electricity grid comes to an end, there should be some consideration on the strategy for infrastructure replacement and investment in new technologies.

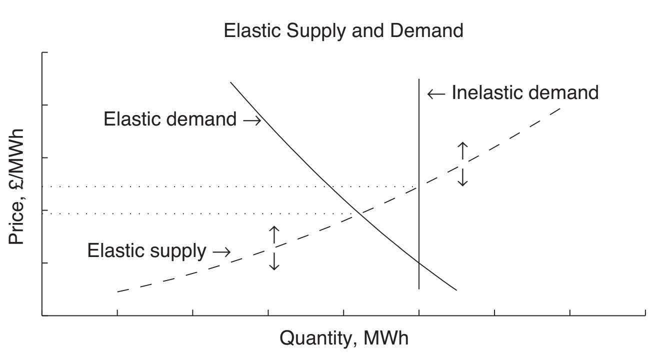


Fig. 3. Supply and demand of electricity.

2.1. Demand response (DR)

Demand response is a specific tariff or program to motivate end-use customers respond to changes in price or availability of electricity over time by changing their normal patterns of electricity use. It can also be defined as incentive payment program to reduce usage of electricity when grid reliability is jeopardised (U.S. Department of Energy, 2006).

There are three actions a customer can take in response. Customers can reduce load only during critical peak time and maintain normal load pattern during off-peak time. This induces a decrease in customers comfort as they are forced to curtail electricity usage at certain times but reduces the overall consumption thus reducing electricity bill even further. The second action that could be taken in order to respond to high electricity prices or low availability is to offset electricity use from peak to off-peak time. This method would flatten the load shape by both decreasing the peak load and filling low consumption valleys. It does not reduce the average amount of energy used by the end users, but increases the transmission and distribution efficiency as the system operates in more stable mode. Finally, customers can use on site generation to reduce demand seen by the utility. This would increase user autonomy, further decentralise generation and decrease average load on distribution and transmission grids. On the other hand, it would maximise system complexity.

To accomplish load shaping, deferrable load appliances are needed. Ramchurn, Vytelingum, Rogers, and Jennings (2011) suggest to divide all residential loads into four groups: wet, cold, water heating and space heating. Devices from these categories behave very differently. These four device types can be further categorised as thermal loads and shiftable static loads (SSL), for example wet types should be classified as SSL because they usually run at a set period of time and consume a certain amount of energy, whereas thermal loads are more dependent on external factors such as usage and surrounding temperatures. Ramchurn et al. (2011) also state that currently penetration of electrical heating is around 7% in the population of UK and SSLs take about 20% of total energy consumption. It is also expected that electricity usage for heating increases significantly, thus giving more room for DSM to maximise efficiency.

Hardware implementation is needed for users to respond rapidly. Energy Management Units (EMU) can communicate with all residential smart appliances in order to coordinate their consumption. The communication from utility to end user might include various types of information. There are four control strategies that can be established between the customer and the utility – passive, active, interactive and transactive (Charles River Associates, 2005; Fuller, Schneider, & Chassin, 2011; Global Smart Energy, 2008).

Many different DSM and DR methods are overviewed in Strbac (2008) and Albadi and El-Saadany (2007) to accomplish these tasks. These methods can be divided into two main groups: incentive based programs and price based programs. Incentive based programs could be further classified as classical or market based. Using classical incentive based program the end user is involved in load shaping by agreeing to either give-up control of certain appliances (direct load control) or to react by limiting the total use of electricity (load limiter or interruptible program). Users who agree to participate but do not respond would face penalties according to the program terms and conditions. Market based programs would allow users in various incentive based load reduction programs where users could bid load reductions and Buyback electricity, participate in emergency DR, etc. (U.S. Department of Energy, 2006). The price-based programs (PBP) would operate using dynamic electricity pricing rates that would reflect price and availability of electricity in real time. The simplest form of PBP is time of use (TOU) and consists of peak and off-peak rates (Gellings & Chamberlin, 1988). It is already widely implemented due to the fact that it needs least enabling technologies. In addition to TOU extreme peak pricing can be used to shave of peaks during extreme situations. The most complex (both hardware and ICT) method is real time pricing (RTP). It controls price in real time to shape end-use load. Information about implementation and experiment results of DR programs can be found in Charles River Associates (2005). Real Time Pricing is the most promising DR technique. It follows standard economic rules. Opposed to other incentive based programs it does not directly limit users consumption, thus users always have a choice of their load patterns. It would not raise huge policy issues, as RTP does not involve any intervention from utility side to customers promises opposed to incentive based programs.

Demand response is challenging from both technical and policy perspective. Most of the DSM techniques require a reliable and high bandwidth connection in order to have two-way communications between users and utilities to transmit price signals, bid data, etc. Also DR is hardware intensive. Participating users would have to install home energy management units and smart appliances to be able to respond on time without human interaction. DSM and DR will benefit both users and utilities as well as make the overall system more secure and maximise social welfare.

2.2. Distributed energy resource (DER)

Decentralised energy resources are small, modular energy resources and storage technologies that provide electric energy where it is needed. It can range from utility-scale to residential size electricity supply. The world is gradually transitioning from large centralised power plants towards small-scale distributed generation ones. CO_2 emission reduction programs play key role in increasing distributed generation (DG) as large portion of renewable are small-scale plants. There are many incentive programs for small-scale solar power plants throughout the Europe. The buy-up price sometimes reach four times the retail price of electricity. Developing countries show high increase in distributed generation in the last 20 years.

There are many benefits of distributed generation. Firstly, it would decrease overall power flow on transmission and distribution networks, thus decrease the associated losses and assets cost. Secondly, technologies like micro-CHP make use of huge amounts of heat generated locally, which can be used for space and water heating. Finally, DER allows islanding which is an important topic when talking about reliability and security of the system. On the other hand, DER faces a lot of challenges. Renewable introduce uncertainty on the generation side, which will require increased amount of reserves. It is usually provided by the standing reserve. When part-loaded, thermal units run less efficiently, with an efficiency loss of about 10–20%. So if unmanaged, DG will have some negative implications. Also, distributed generation power plants tend to be more expensive in terms of investment per capacity.

2.3. Storage technologies and electric vehicles (EV)

Electric energy is volatile. It needs to be used at the exact same time as it is generated unless converted and stored in some form. Thus it is clear that it is not possible to fully control the demand to meet uncontrollable renewable generation so energy storage is needed. To some extent, energy storage technologies decouple generation and consumption. It would help a lot in the balancing process, which is the biggest challenge in power grids.

There are many possible storage technologies in the market. According to Electric Power Research Institute (EPRI) pumped water power plants account for about 99% of the bulk storage capacity worldwide. Power output of such technology can reach up to 3 GW in a very short period of time typically 15 s, i.e. plants are very responsive. It is popular for high capacity, good responsiveness, high power output and high efficiency (varies between 70% and 80%). Having high capacity and fast response this technology is good for long-term electricity supply and helps increasing system stability.

Other less popular storage technologies are electric batteries, compressed air, flywheels, hydrogen, superconducting magnetic energy, thermal and liquid air. Each of these technologies has many variations with their advantages and disadvantages. Most of them can only provide short-term electricity supply due to low capacity as well as high cost per MWh. Thus storing large amounts of electricity has not yet been put to general use.

The advancement of battery storage promises an increased number in electric vehicles in the nearest future. It will increase consumption of electricity dramatically. If unmanaged, it might dramatically increase the evening peaks. On the other hand, thousands or even millions of electric vehicles might serve as huge distributed energy storage device.

3. Demand side management techniques

Loganthiran, Srinivasan, and Shun (2012) present demand side management strategy for load shifting based on heuristic optimisation. The proposed optimisation algorithm aims to shape the final load curve as close as possible to the desired load curve. The restriction of this strategy is compliance in the number of shiftable loads in the system, which users are willing to use at a different time. From the user point of view, this implies to a dramatic loss of comfort. Minimisation technique formulated below is used to reach the desired goal

$$\text{Minimise} \sum_{t=1}^{N} (\text{PLoad}(t) - \text{Objective}(t))^2 \tag{1}$$

where Objective(t) and PLoad(t) are the desired load and actual load curves respectively. As linear and dynamic programming cannot handle large numbers of controllable devices, a heuristic evolutionary algorithm is used (Loganthiran et al., 2012). The evolutionary algorithm achieves the best fitness for the next day, which is calculated as follows:

$$\text{Fittness} = \frac{1}{1 + \sum_{t=1}^{24} (\text{PLoad}(t) - \text{Objective}(t))^2} \quad (2)$$

The results of this strategy are positive and show 5–10% operational cost reduction and 14.2–18.3% peak demand reduction.

Similar DSM technique is proposed by Ramchurn et al. (2011). It explains a novel model for Decentralised Demand Side Management (DDSM) mechanism that allows agents to coordinate in decentralise manner. Agents control load by adapting the deferment of loads according to prices sent by the utility. The goal of the agent is to optimise the heating so as to minimise cost paid by the user. This alone can cause peaks to be shifted opposed to load shape being flattened. To overcome this problem agents reoptimise their thermal loads on any particular day with a small probability, i.e. only small portion of agents recalculate load curve at the same time. It allows total load curve to converge to optimal load factor. This technique manages to reach very high results by reducing the peaks of domestic consumers load profiles by 17% and thus reducing carbon emissions by up to 6%.

Cheng (2012) describes the control principles, particularly agent-based control and event-based control is presented. The agent-based control enables to settle the price in auction-based market using standard economics rules. This requires consumers and generators to send their quantity vs. price bids to access the responsible party (ARP). The event-based control, on the other hand, only responds to the price that is received by the smart meter. The author also introduces virtual agents to optimise power flow in power distribution networks. Agent-based and event-based controls alone do not take into account distribution system operation parameters (maximum capacity optimal flow, efficiency). Therefore distribution system operator is given responsibility to act upon virtual agent to offset price that market settles. It takes care of constraints associated with power quality and loss minimisation. The author notes that ICT technologies introduce noticeable delay so short term fluctuations should be handled separately. Super-capacitor storage is suggested to overcome this problem. The evaluation results show that the average power flow in case of the integration of renewable energy sources and fluctuating loads can be optimised using proposed methods.

Double-auction electricity market is discussed by Fuller et al. (2011). It uses transactive controllers to send bids to the central market. Price is cleared after all bids from users and generators are received. Supply and demand curves determine the actual price for upcoming period of time. Controllers adjust settings for appliances to respond to varying price after the end user receives price signal. Even though the aim of Fuller et al. (2011) was to demonstrate the level of details needed to perform analysis on smart grid, it proved that DR using price signals give positive results.

There are some drawbacks of using double-auction and heating, ventilation and air conditioning (HVAC) control method. First of all, bids received from users and generators are not reliable. It is impossible for renewable generators to predict their output with high certainty. There could also be fake bids from the user side that would distort price cleared by the market. It would induce reasonably big challenges for policy makers. Another drawback is the high communications requirement. There might be situations where user would like to submit a set of price/amount bids. Communication technologies would be challenged to transmit the increased amounts of data and largely increase the overall complexity of the system. Finally, a rebound of energy use after high price signal is a big issue. It could lead to even bigger peaks thus creating another vulnerability problem.

4. Proposed DSM strategy and method

The proposed demand side management strategy is based on advanced control theory. It involves system identification and model design to achieve the desired load. Fig. 4 shows block diagram of the proposed system created using MATLAB Simulink.

The block diagram consists of four major subsystems namely generation, weather and time information, controller and the system (also referred as the plant). Each of these parts plays a distinguished role that is explained in the following section.

4.1. System (plant)

This control problem was approached by designing a system model that represents the electricity use behaviour of the population relevant to price level. To predict user response to price changes, GridLab-D simulation software was used. Simulations have been carried to collect statistical information and evaluate the feasibility of DR (see Section 5). Representation of population behaviour (system) was assumed to be accurate enough for the purpose of the proposed model to respond similarly in a real world situation.

The diagram in Fig. 5 represents the proposed architecture for modeling the system. It includes price, weather and time information as inputs. The output is the predicted demand. The size and number of hidden layers might be adjusted dependent on how well the neural network is trained for a particular area.

System identification step needs to be repeated over time for the model to adapt to the changes in distribution side of the network. It is important to have a model that is as accurate as possible in order to avoid creation of even higher peaks in demand.

4.2. Generation

Generation side supplies information about the desired load. It is the sum of all generator outputs that are currently connected to the grid. Generators connect and disconnect from the grid depending on the real-time tariff which is calculated using the feedback real-time price from the controller. When the price increases, more generators connect to the grid to sell electricity but on the other side customers shed their loads due to high price. Thus a balance is settled between generation and consumption where both ends actively participate in this process.

4.3. Weather and time information

System behaviour (consumption of electricity) is dependent on many external factors. Most important ones for HVAC is weather. Weather can be described as a combination of temperature, humidity, wind speed, solar irradiation and other measurements. This information is fed to the controller where it is processed and appropriate price signal is computed.

4.4. Controller

A controller is designed to control the price signal. The concept design of the controller is based on neural network predictive control. Fig. 6 shows a block diagram and basic principles of operation. The controller optimises future price signal for the modeled demand to match the desired generation. Next time step only the first control input is used and the process repeats. Its major task is to compute the right price for the total load to become as close as

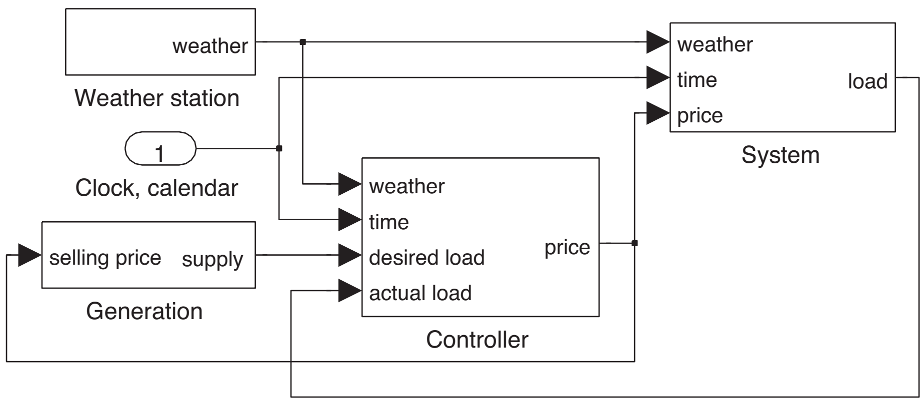


Fig. 4. System block diagram.

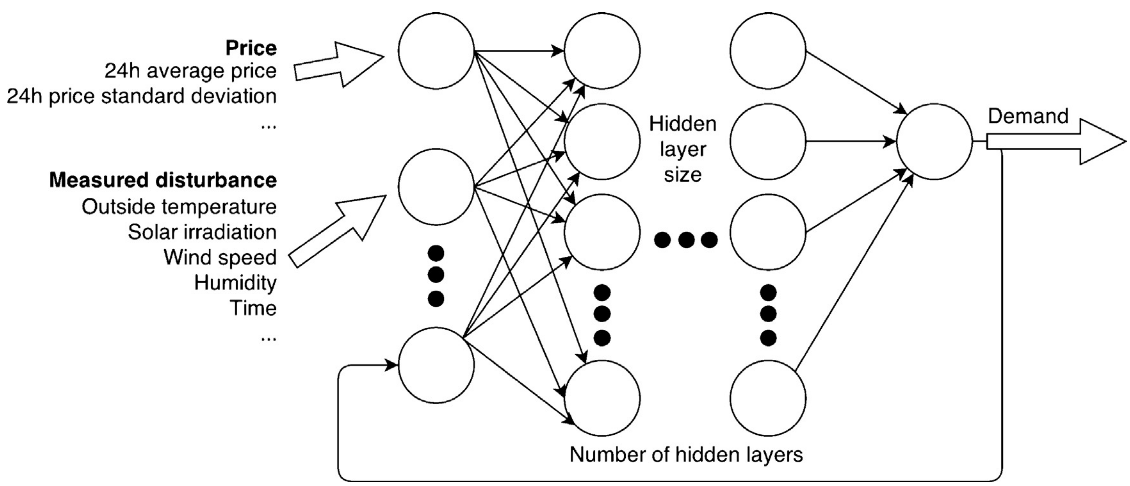


Fig. 5. Neural network model of the system.

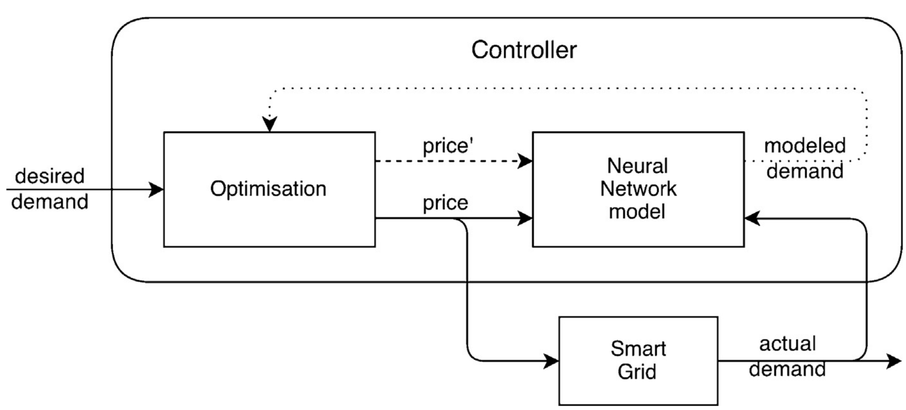


Fig. 6. Neural network predictive controller.

possible to the desired load from the generation side. Model predictive control (MPC) is suitable for this application because inputs are constrained, disturbances are measured (not shown in the diagram) and time constants are large enough for MPC to perform calculations.

The actual load will respond to price fluctuations. Controller is tuned so that actual load matches the generation pattern as close as possible. In order to demonstrate positive results using this technique, users need to be equipped with residential energy management units (EMUs) that respond to control input (price signal). This technology would enable customers to immediately respond to price fluctuations by adjusting temperature set point as described by Fuller et al. (2011).

5. Demand response simulation results

5.1. Simplified one house simulation

In the first case, the simulations were simplified to a single house and only the price signal was fluctuating. Fig. 7 shows the results of single residential HVAC load response to price change including temperature information. The outside temperature was set to

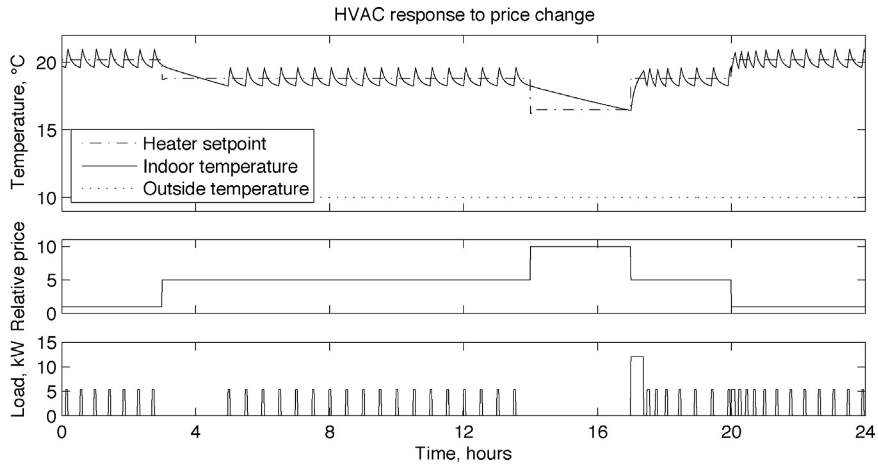


Fig. 7. Simulation of HVAC response to price change.

a constant 10 °C and other values of the climate object were set to default. Attributes like HVAC comfortability settings, default temperature set point, house size, window to wall ratio, etc. define the transient and steady state responses to change in price signal. In particular, the interest is focused on how the total HVAC demand is related to change in price. A series of simulations were completed to collect data.

As it can be seen from the graph, price change directly influence heater operation. HVAC controller adjusts the temperature set point whenever the price changes. When the price increases, the HVAC controller lowers the indoor temperature set point according to the comfortability setting (Fuller et al., 2011). This results to heater shut-off until the house cools down to the new set point. After that the steady state resumes. A different transient response occurs when price decreases. When that happens, the HVAC controller increases the indoor temperature set point due to low price, thus turning on the heater to full power to raise the temperature to a new set point.

5.2. Demand response simulation of a population

In the second case, a population of 629 houses was simulated. The purpose of this simulation was to ascertain the possibility of controlling HVAC and water heater loads of a group of residential houses using price signal.

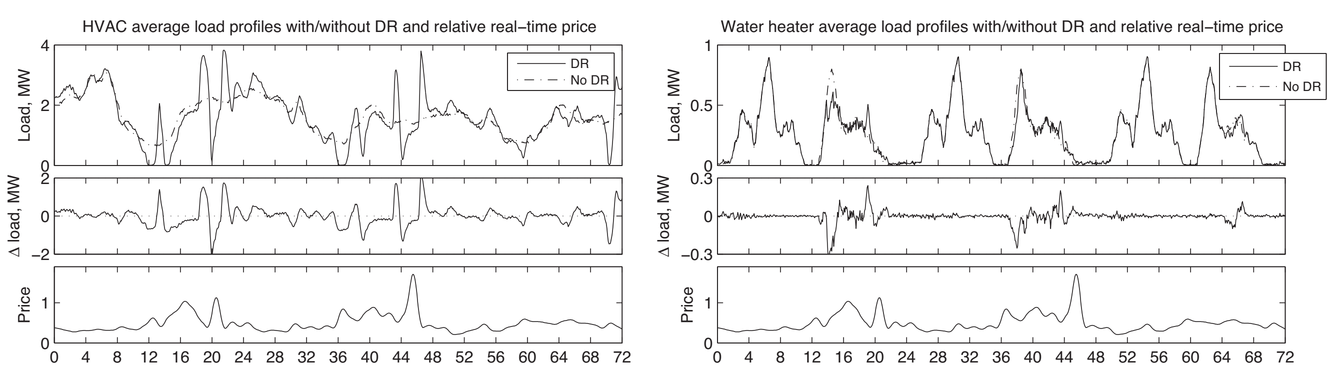
Each house was equipped with either a gas heater, a heat pump or a resistive electric heater. The penetration level of each type was set to 135 (22%), 235 (37%) and 259 (41%) respectively. High level of electric heaters were intentionally chosen to emphasise future dependency on green energy. The average floor area was 195 m^2 with a standard deviation of 27 m^2.

A passive controller that react to real-time price were used to control air heating, cooling and water heaters. HVAC controller was used in ramp mode and settings that describe comfort level were set to same value for every house (Fuller et al., 2011). In particular lower and upper offset from desired heating temperature limits were set to −1.389 and 0.833 °C, respectively. Controllers' lower and upper ramp gradients were 0.8 and 1.33. Cooling controllers' absolute values were the same, except signs were adjusted.

Typical meteorological year for Seattle (Washington, USA) was used for weather information input. The average outside temperature from the 2nd to the 5th of January was recorded to be 7.6 °C with a standard deviation of 8.4 °C. Fig. 9 shows outside temperature graph.

Mainly tree end consumer appliance groups were used – HVACs, water heaters and other electronic devices such as lights that were modeled as ZIP loads. Table 1 shows statistics for each group – average load, average load with DR, mean absolute error (MAE) and modified mean absolute percentage error (MAPE). The modification of MAPE was done because of division by zero at some time steps. Eq. (3) was used to calculate modified MAPE. Fig. 8 shows time series load profiles for HVACs and water heaters respectively. A base consumption schedules were used for each of the groups. Other non-responsive loads are out of the area of interest

$$\mathrm{MAPE} = \frac{\overline{\mathrm{MAE}}}{\overline{\mathrm{load}}} \times 100\% \tag{3}$$



(a) HVAC simulation data (b) Water heater simulation data

Fig. 8. Responsive appliance load profiles (upper), change in load profiles (middle) and real-time price (lower). (a) HVAC simulation data. (b) Water heater simulation data.

Table 1
Average load by appliance group.

	Average load, kW (%)	Average load with DR, kW (%)	MAE, kW (MAPE, %)
HVACs	1639 (70%)	1641 (70%)	341 (21%)
Water heaters	257 (11%)	254 (11%)	23 (9%)
Other	488 (19%)	228 (19%)	0 (0%)
Total	2342	2341	349 (15%)

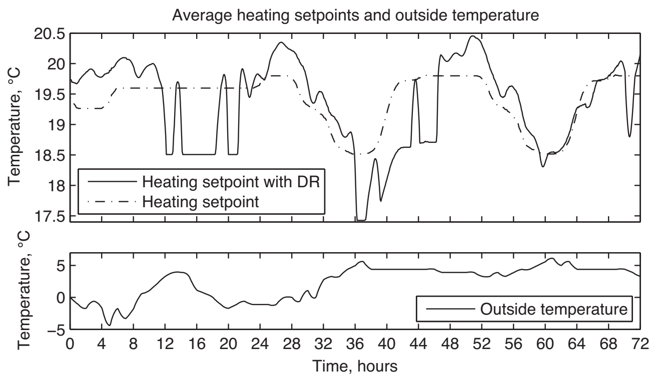


Fig. 9. Heating set points and outside temperature.

As we can see from Table 1, the average load maintained at a very similar level with and without DR. This also means that the consumed energy also did not change. On the other hand, high MAE and MAPE values shows that load profiles with DR are significantly different from those without DR. It proves that by fluctuating real-time price in a scenario that is described in this section it is possible to shift about 21% of HVACs' load and 9% of waterheaters' load.

It should be noted that real-time price was chosen with no control strategy (Fig. 8). It was based on heuristics to mime a possible price of electricity during certain periods of the day. Also, some dramatic price jumps were included to imitate extreme scenarios.

Fig. 9 shows how average inside temperature set point changed after DR was applied and the outside temperature profile. The average HVAC temperature set point before DR is shown as a dashed line and the total average is about 19.40 °C. A solid line shows the average temperature set point in 629 houses after DR was applied and the total mean value is about 19.34 °C. Also MAE is about 0.84 °C. These numbers suggest that the comfort was maintained at very high level because the temperature on average deviated only less than a degree and the average temperature stayed virtually the same.

6. Summary

Current electricity grid is outdated and needs a complete makeover. There are many aspects that could be improved but this paper is focused on changes at the user side – demand side management and demand response. Using existing technology and implementing new strategies it is possible to increase grid capacity, efficiency, reliability, power quality, reduce carbon footprint and increase sustainability. Demand side management ideas seen in literature and new proposed strategy was presented. All of the discussed DSM techniques are based on load shifting technique. Most of them use scheduling algorithms to optimise for objective demand profile. Loganthiran et al. (2012) uses heuristic optimisation to defer loads and attempt to follow desired demand. Ramchurn et al. (2011) proposes additional safety mechanism to avoid overly-homogeneous optimised consumption pattern with significant peaks. Price based incentives are used in all reviewed articles and two-way communication is necessary. Also day-ahead planning implemented in Loganthiran et al. (2012) and Ramchurn et al. (2011). This might lead to extremely intensive communication between utility and users as every time step there is an exchange of information about the day-ahead. Fuller et al. (2011) is using a double-auction market technique, which will also require exchange of load/price data pairs. Some of the proposed techniques lack short term easy to see incentives for the users. The benefits usually hide behind the social welfare. The overviewed techniques are mathematically proven, but sometimes it is too difficult to understand for everyday user. So either a less complicated technique is required or there should be more attention taken for user education to promote participation.

Loganthiran et al. (2012) list most popular household appliances as controllable. Shifting devices like kettles might come at a very high comfort cost. In the newly proposed technique, only highly time insensitive devices are assumed to be deferrable. HVAC system has huge thermal capacity and high inertia, which makes it a perfect candidate. The focus of the newly proposed DSM algorithm lies on the utility side. The utility attempts to learn and model customers' response to price chance. It would then know what is the exact control input (price) to send. During normal operation, the price might reflect the wholesale price of electricity, but it can be adjusted to maintain system balance at extreme times. The proposed method is very flexible in many aspects:

- Utility does not need to know the actual control mechanism behind EMUs. User behaviour is estimated using statistical data.
- This strategy is very scalable. Different regions can be isolated and operate separately from each other.
- When divided into regions, it also gives the ability to tune controllers to better accommodate specific response, as it is very likely that different regions have particular habits or preferences of energy use.
- Customers will have the most flexibility and choice controlling their load pattern. Only customer and his willingness to pay certain price at different times define individual load shape.
- Using RTP customers are charged the real price of electricity opposed to the average price that is used now. This eliminated the cross-subsidy between users.
- A minimum amount of communication is required to send only the price information at a fixed intervals.

The biggest danger in this control problem is the creation of even higher peaks in demand at different time. The real-time price should be chosen with caution to induce the desired total demand of electricity at all times. From Fig. 7 it can be seen that decrease in price can create peaks in demand.

Another problem is system model mismatch. For this method to work efficiently, a very accurate representation of system model is needed. This could be done using state of the art Artificial Neural Networks.

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