Energy Management Methods in Scalable Smart Grid

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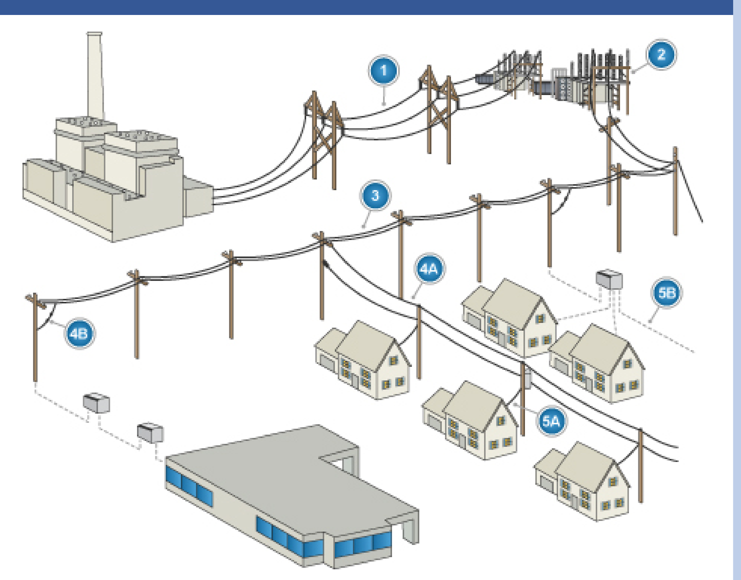
Introduction

Supply-demand balancing act in electricity grids is a very demanding task. It requires constant monitoring of the network and very fast response to system changes. Poor regulation might lead to brownouts or even blackouts of the whole country. At the same time, increasing number of renewables add another layer of complexity due to their inherent variability in power output. Luckily, recent advancement in communication and sensing technologies enable the advancement of Smart Grid. It will supply utilities and grid managers with additional set of tools for maintaining system balance and stability.
A novel method is being developed at Lancaster University, which focuses on Demand Side Management (DSM) technique using real-time pricing (RPT). It proposes to use state of the art machine learning techniques - Artificial Neural Networks (ANN) - to control the total consumption using pricing signal, which is sent to residential Energy Management Units (EMU). It is expected that increased number of smart appliances and intelligent Heating Ventilation and Air Conditioning (HVAC) system will contribute in reacting to the state of electricity network. The main research challenge in this novel technique is to be able to shed the load without creating even bigger peaks of energy consumption at other times.

Electricity grid today vs. Smart Grid

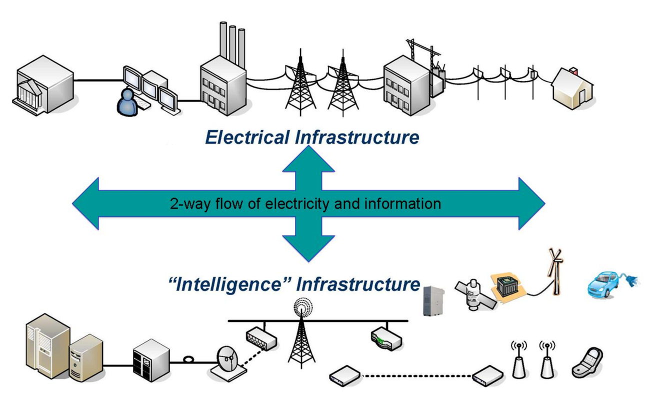
Today's electricity grid

- Electricity grid is outdated
- Designed for one-way flow
- Centralised generation
- Difficult to balance demand with supply
- Cross-subsidies between users



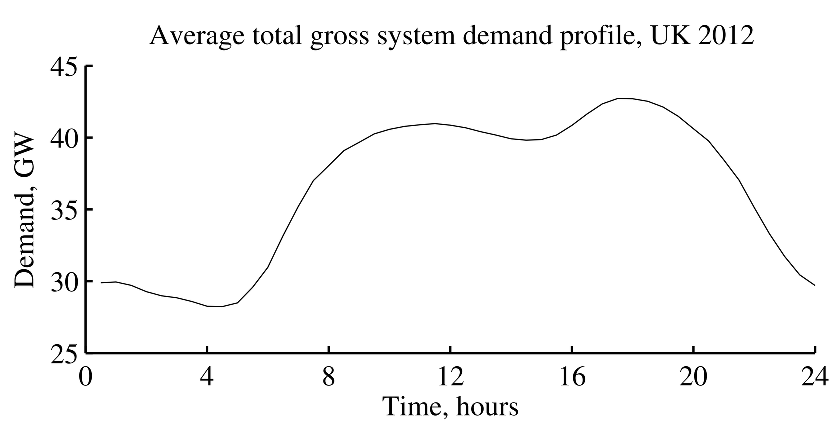
What's new in Smart Grid

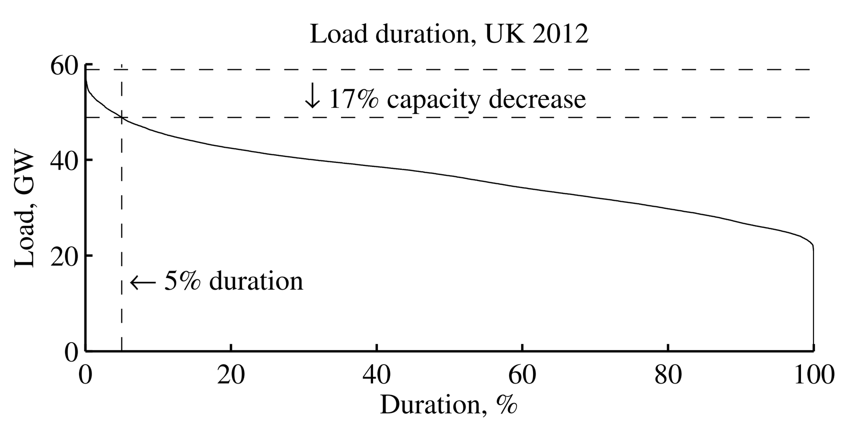
- Current grid needs complete makeover
- ICT layer on top of electricity grid
- T&D automation
- Distributed energy resource integration
- Smart meters along with EMU's
- Smart electricity consumption
- Customer enablement

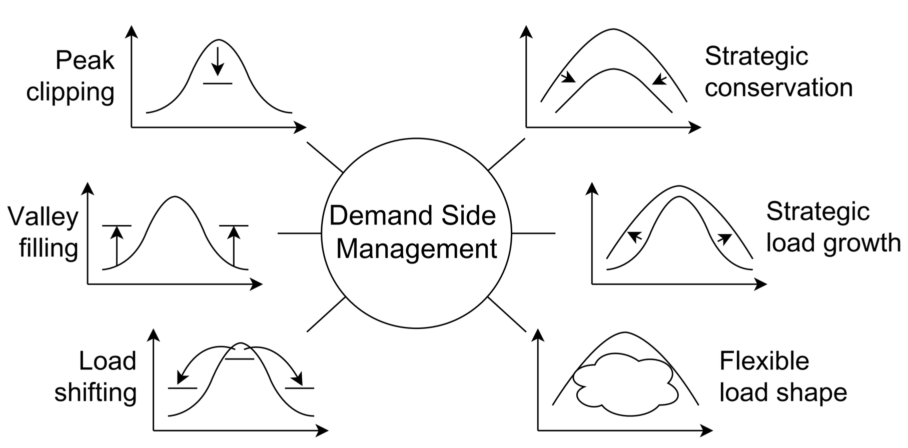


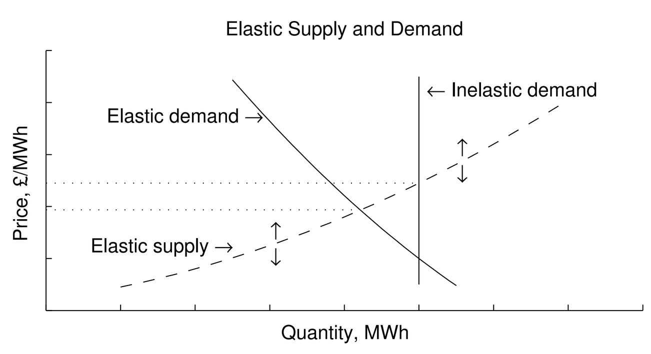
Drivers and benefits of Smart Grid

- Power quality and security
  - Outages and blackouts
  - Self-healing
  - Early fault sensing
- Renewable power integrity
  - Manage renewable energy output
  - Distributed energy integration
  - Manage back-up energy assets
- Enabling technologies
  - Information and Communication technologies
  - Sensing
  - Advancement in artificial intelligence
- Efficiency
  - Increased "virtual" capacity
  - EV as storage devices
  - Energy monitoring and control
  - Decrease carbon emissions
- Demand response programs
  - Incentive based - direct load control
  - Price based - real-time pricing









Problem

- Increasing number of renewables pose threat to system balance
- Growing demand increases peaks & requires greater capacity
- Fixed price creates cross-subsidies between users
- Currently users have no means of knowing about system state
- Demand and price varies hourly and this is expected to worsen in the future

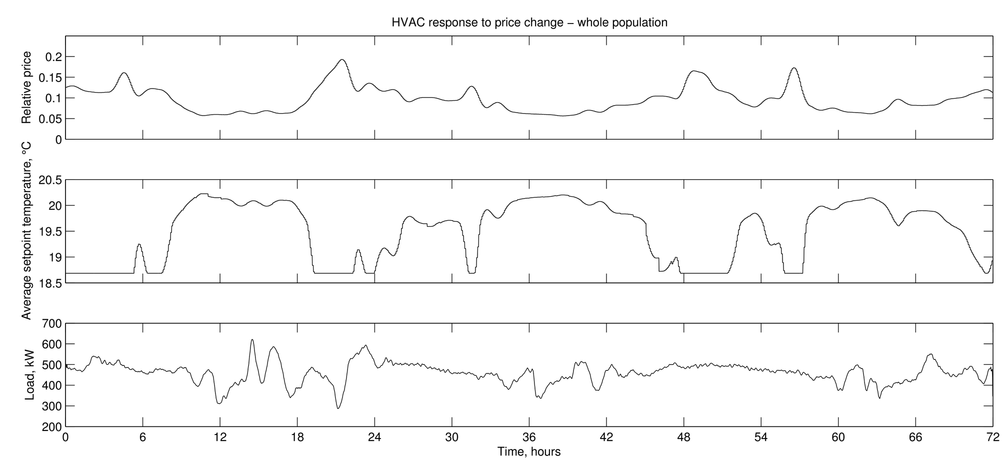
Proposed solution

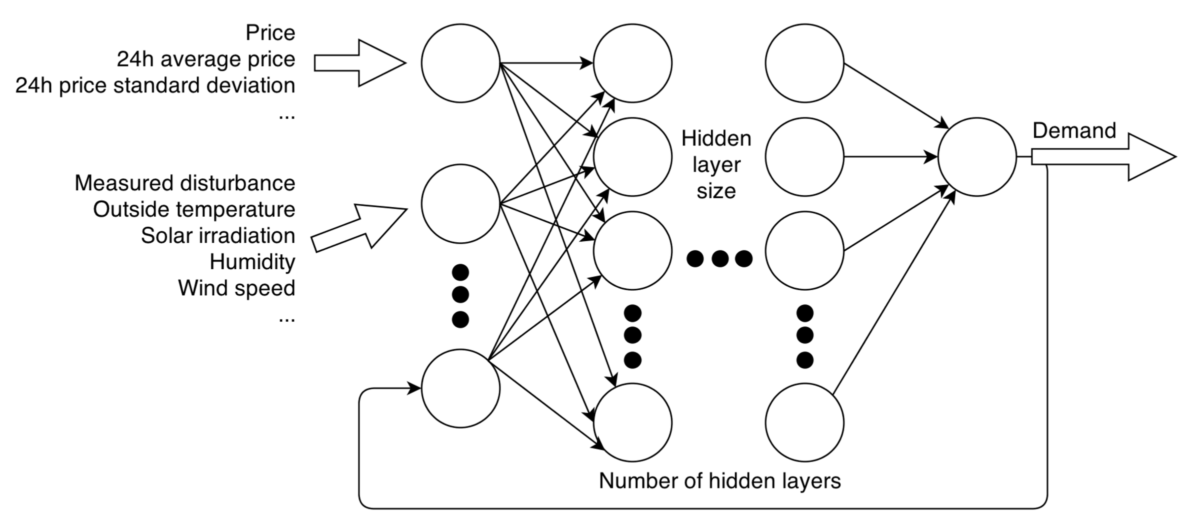
- Implement real-time pricing - this solves cross-subsidies problem and creates control input to the system.
- Model the relationship between real-time price and electricity demand using Artificial Neural Networks. Ultimately it should include measured disturbance variables like weather temperature, humidity, wind speed, etc.
- Implement Neural Network Predictive controller to optimize control inputs (price) for load balance.

Neural Network Model

We assume that it is possible to find a highly non-linear relationship between real-time price and electricity consumption. In particular HVAC system is the main interest. In general, load profile is highly repetitive and human behaviour tends to form habits. These are two key points that help artificial intelligence (AI) learn from past experience and predict future consumption. **Neural networks match there criteria.**

The goal of the Gridlab-D simulation was to capture dynamic relationship between measurable inputs (electricity price and weather information) and electricity consumption of HVAC loads.



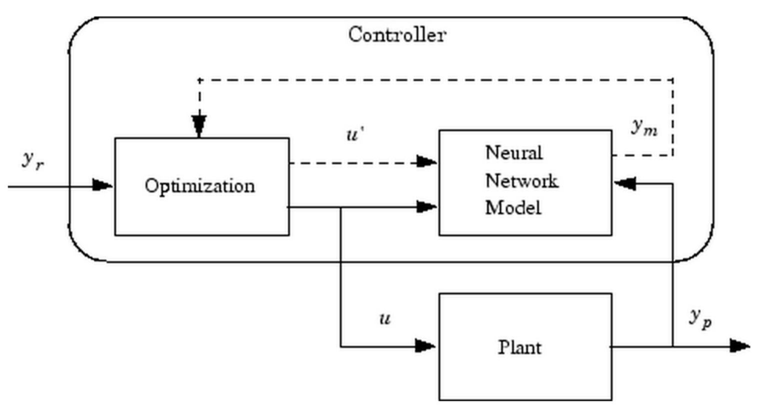


The diagram on the left shows the proposed architecture for NN model. Different parameters to be tested.

Neural Network Predictive Control

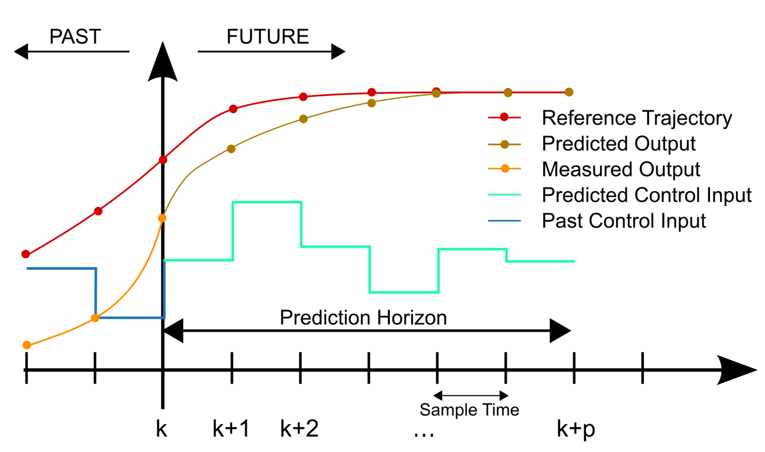
Model predictive control (MPC) is very suitable for this application due to the following HVAC system properties:

- The plant is multi input, multi output system;
- Inputs are constrained;
- Disturbances are measurable (e.g. outdoor temperature);
- Time constants large enough for MPC to perform in time.



The block diagram on the left represents generic NN predictive controller.
yr - desired demand or optimal generation;
u - control input - real-time price;
yp - electricity demand;
u' - optimised control input;
ym - modeled demand.

The graph on the right shows the past and future control inputs and outputs. The reference trajectory in this case is the desired electricity demand. The predicted control input is then calculated while minimising the cost function. In model predictive control strategy, only the first predicted control input is used and the process is repeated for the next step.



Conclusion

- The proposed technique is a new electricity balancing tool for utilities.
- HVAC load shifting incurs minimal customer discomfort. Load control might even be unnoticed as HVAC system usually has high inertia.
- It is easily scalable - different regions can be isolated.
- Follows standard economic rules - varying price of electricity.
- The technique helps to use assets in the most efficient way.
- Does not require critical mass of participants.
- Does not overload communication path as only price signal is sent periodically.
- Design aims to help integrate renewables that have inherently variable output.

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