Intelligent Control for Efficient Demand Response in Smart Grids

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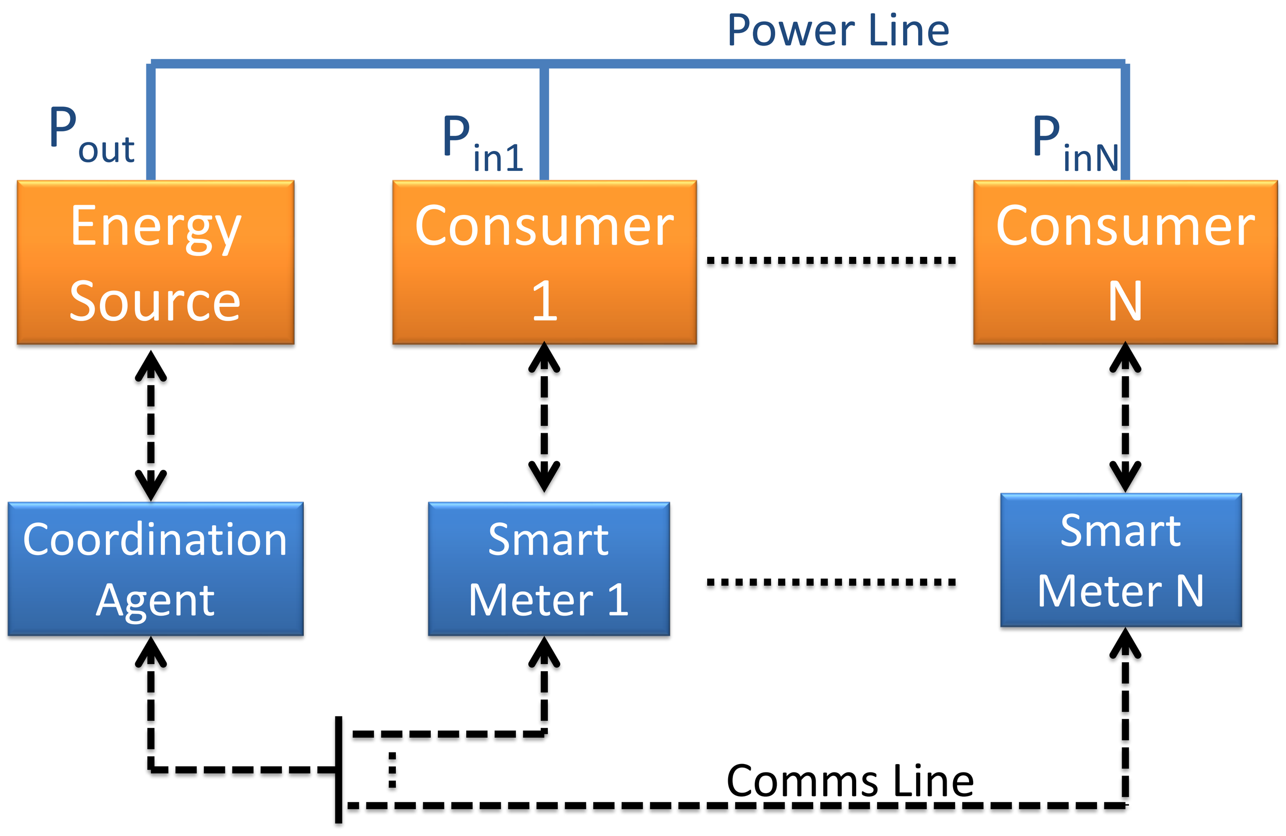
Introduction

- In future power grids, it is envisioned that certain loads, such as electric vehicles and heating devices, will be controllable, via Smart Meters (SMs) or Building Energy Management Systems. Demand Response (DR) algorithms can be used to automate the process of controlling these loads in order to fulfil objectives such as peak lopping, valley filling, minimisation of CO_2 emissions, load balancing, etc.
- If accurate predictions of the base load in the power system can be made several hours in advance, then it is possible to schedule the predicted controllable loads over the same time period, such that they can be postponed to off-peak times while still fulfilling consumer objectives, such as comfort level, total energy delivered, etc.
- It is natural then to frame this problem as a predictive constrained optimisation problem. Centralised implementations of these algorithms may not always be possible, however, due to privacy and scalability issues. Techniques from the intelligent control literature, the Model Predictive Control literature in particular, can be used to address these issues.

Objective:

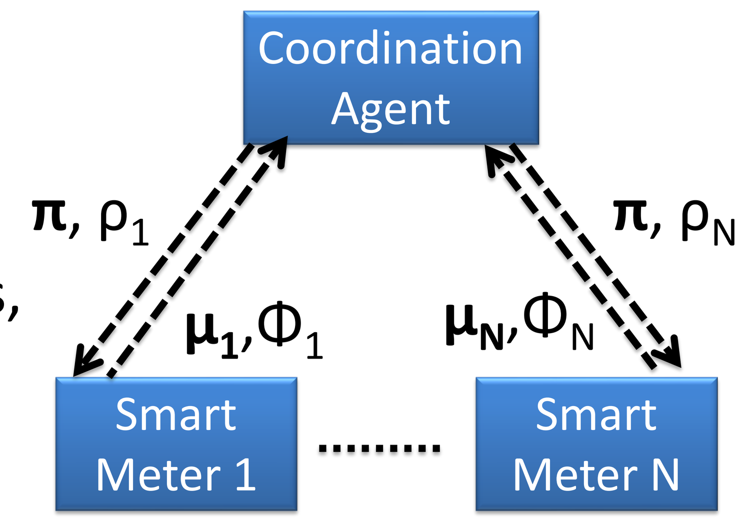
➢ **Improve the efficiency and scalability of Demand response (DR) algorithms using Intelligent Control techniques.**

Methodology



The above communications architecture is used to control the system. This can accommodate a centralised or hierarchical predictive control approach. Predictions on the base load, based on Smart Meter information, and the predicted consumed power by each device are used to enact the peak load minimisation objective. The first controller considered is a hierarchical Dantzig-Wolfe Decomposition (DWD) based controller. The second centralised controller is based on the use of Laguerre networks. These are briefly introduced next.

Dantzig-Wolfe decomposition for PARR



- DWD achieves a centralised optimisation performance in a hierarchical fashion. Here the Coordination Agent (CA) handles global constraints, and coordinates the actions of the Smart Meters' local sub-problems. The approach maintains the privacy between the CA and sub-problems.
- The master problem passes coordinating Lagrange multipliers, $\boldsymbol{\pi}$ and $\boldsymbol{\rho}$. Sub-problem *i* updates the Coordination Agent Problem with column vectors $\boldsymbol{\mu}_i$ corresponding to new solutions, and function evaluations Φ_i which help determine convergence.
- DWD is used to implement **Peak to Average Ratio Reduction** (PARR). This is implemented as a centralised linear programme given by:

$$\min_{x_1 \ldots x_N} \max[P_{total}(k) \ldots P_{total}(k+H)]$$

subject to subsystem constraints. The effect of this is to minimise the peak power consumption over the course of the next *H* hours.

Laguerre Networks for Demand Response

- DR can also be formulated as a centralised quadratic programme:

$$\min_{x_1 \ldots x_N} P_{total}^2(k) + \ldots + P_{total}^2(k+H)$$

subject to subsystem constraints. As *H* can become very large it means that the size of the optimisation vector can become very large very quickly too.

- Laguerre functions can be used to parameterise the predicted inputs to the system. The idea is that rather than specifying every input over the full prediction horizon, the input trajectories are parameterised. Then instead of optimising for the individual inputs at every step of the prediction horizon, the coefficients of the Laguerre network are optimised instead.

Results

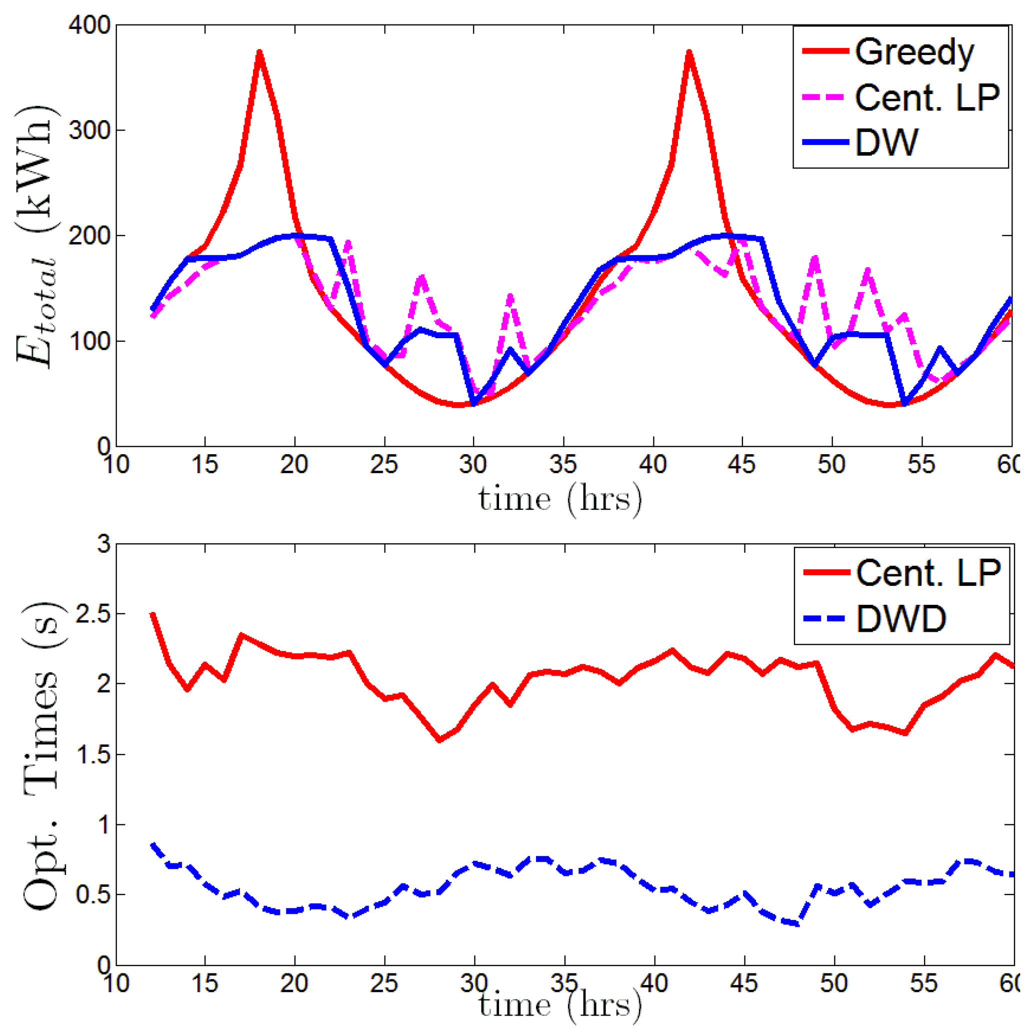


Fig. 1 Results comparing centralised LP and DWD based PARR for 48 controllable loads.

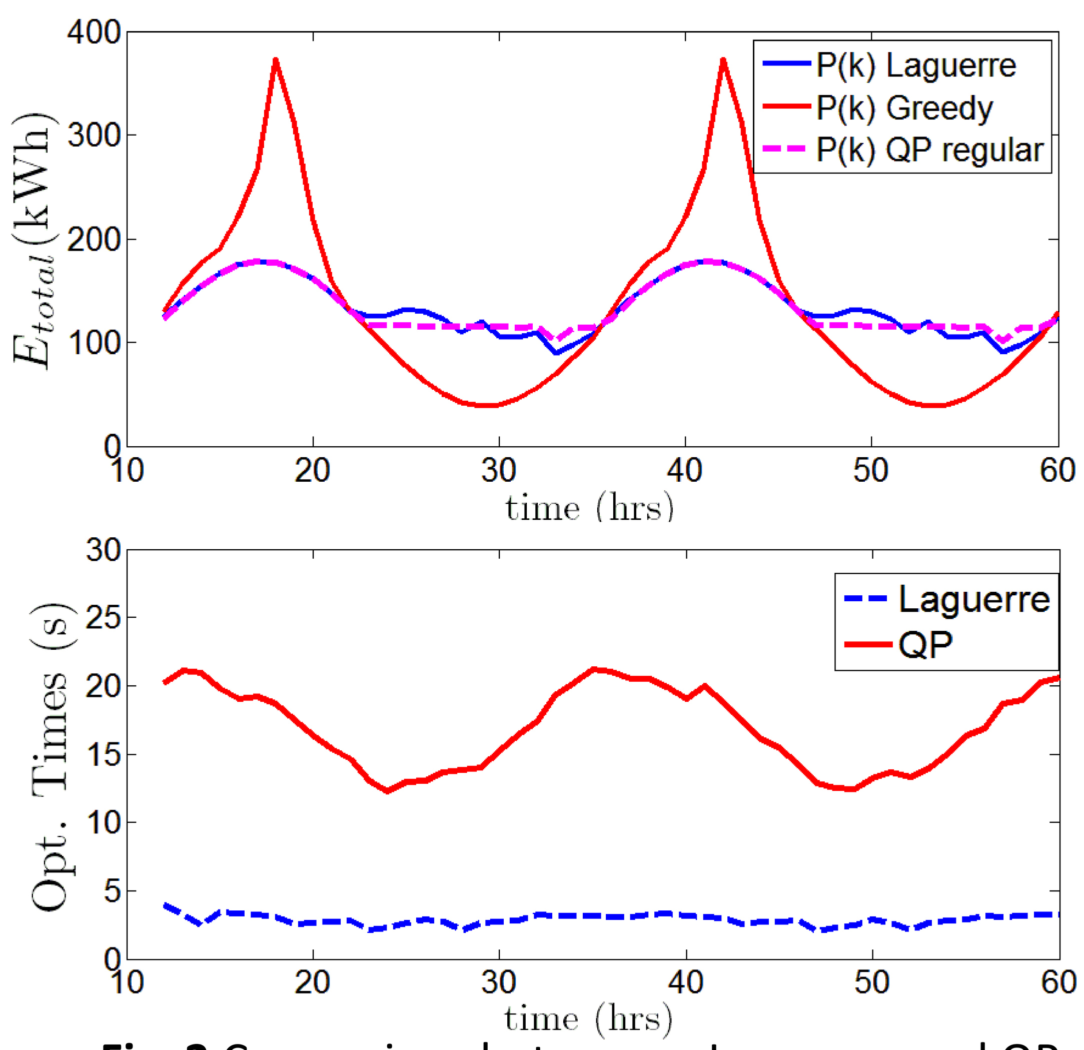


Fig. 2 Comparison between a Laguerre and QP based DR for 48 controllable loads .

Conclusion

Intelligent Control techniques can be used to improve the performance of Demand Response (DR) algorithms. Future work involves the incorporation of system constraints, and testing on large scale power networks.

Acknowledgement

This work was conducted in the Department of Electronic Engineering, NUI Maynooth in collaboration with the Sustainable Electrical Energy Systems (SEES) Cluster and the Electricity Research Centre (ERC).

Paul Mc Namara and Seán McLoone are supported by Science Foundation Ireland under Grant Number SFI/09/SRC/E1780