FORECASTING AND CONTROL IN ENERGY SYSTEMS

EERA SP2 Workshop

DTU - Lyngby

02/11/2016 E. Crisostomi - University of Pisa

OUTLINE

- Introduction
- Forecasting
  - Load forecasting
  - Wind/Sun power forecasts
  - Electrical energy price forecasting
- Optimised power control in a microgrid
- A case study: DR in a fleet of EVs and PHEVs
- Conclusions

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INTRODUCTION

- I shall mainly present our research activity on forecasting and control, carried out at the University of Pisa;

- We have not used laboratory infrastructures, but in most cases we have used real data from DSOs/Energy companies/SMEs with whom we work in close collaboration;

- We have used realistic simulators at some points (OpenDSS, DOME, SUMO).

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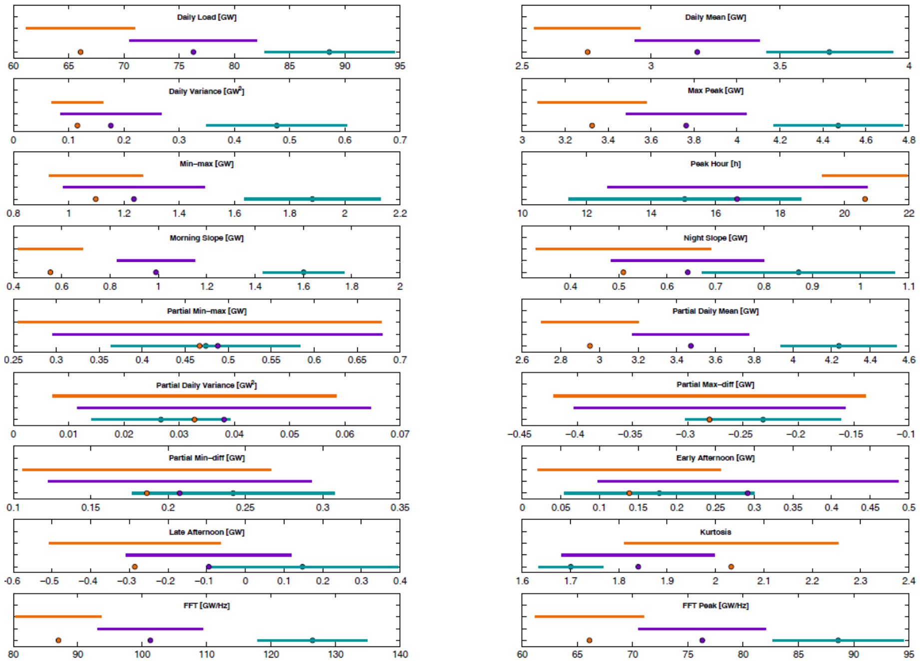
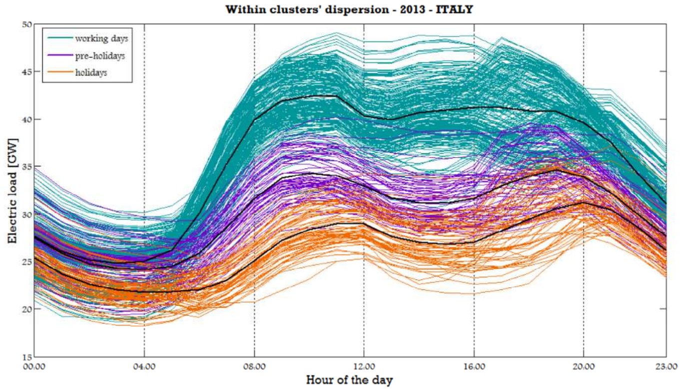
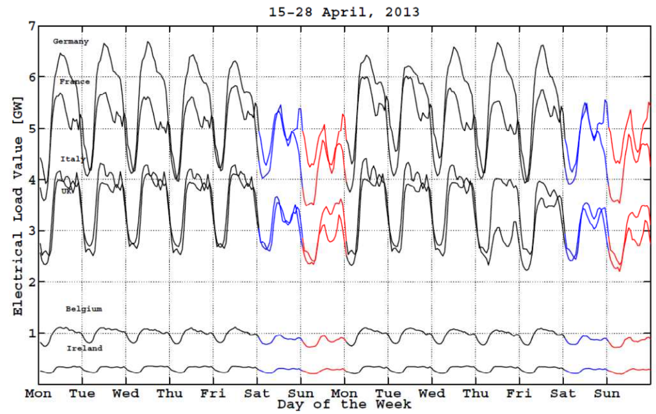
LOAD FORECASTING

- We are interested in aggregated national loads;
- We have carried out an extensive clustering analysis to infer daily/weekly/seasonal patterns;
- We have developed multi-objective forecasting algorithms to maximize the accuracy and the reliability of the short term (24h) forecasts;
- We have tested and compared our results in many different European countries.

LOAD FORECASTING: CLUSTERING

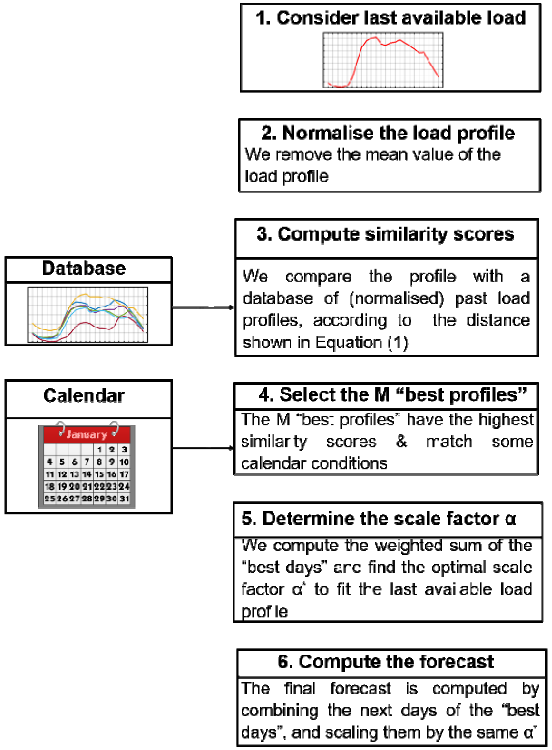


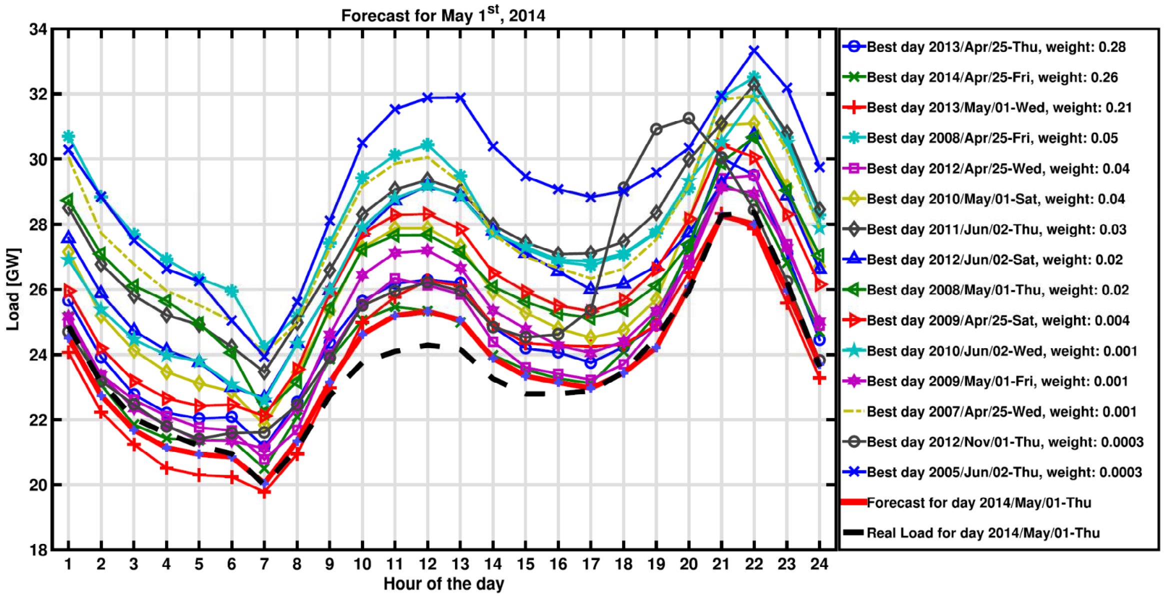




P. Ferraro, E. Crisostomi, M. Tucci and M. Raugi, "*Comparison and clustering analysis of the daily electrical load in eight European countries*", Elsevier Electric Power Systems Research, vol. 141, pp. 114-123, 2016.

LOAD FORECASTING: K-NN ALGORITHM





Parameters are chosen to maximize a multi-objective criterion (accuracy and reliability of the forecast)

M. Tucci, E. Crisostomi, G. Giunta and M. Raugi, "*A Multi-Objective Method for Short-Term Load Forecasting in European Countries*", IEEE Transactions on Power Systems, vol. 31, no. 5, pp. 3537-3547, 2016.

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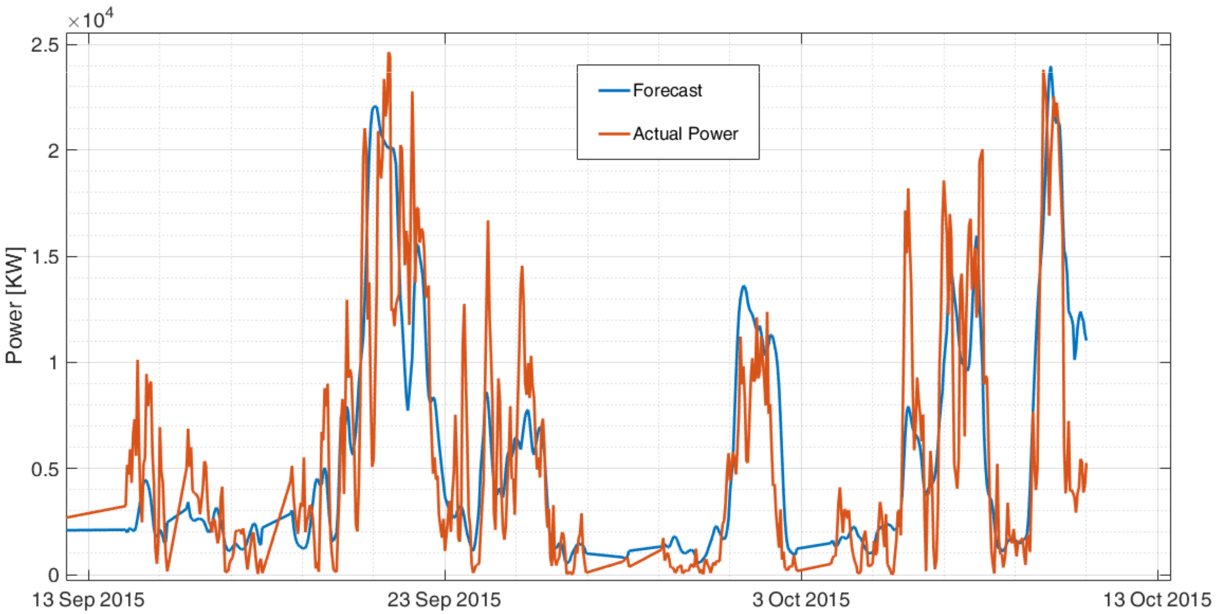
Wind/Sun Power Forecasts

- We have a historical data-base of weather forecasts and measurements from some providers;
- We have developed a number of algorithms to forecast power generation from renewables;
- We receive updated 24-h ahead weather forecasts, and use them to make 24-h ahead power forecasts;
- Parameters of the algorithms are updated every month.

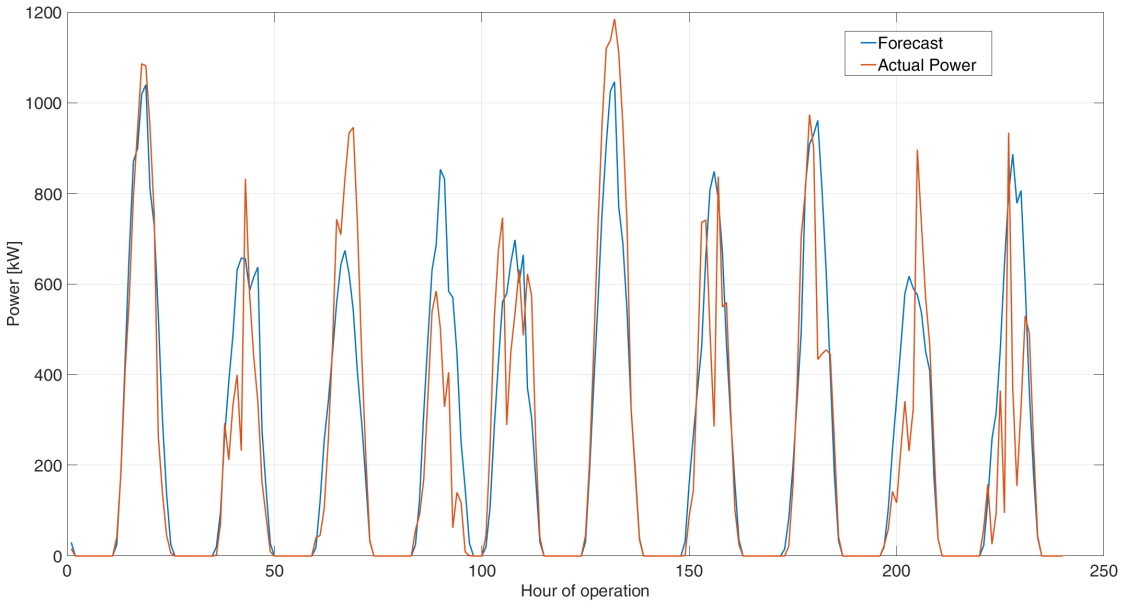
WIND POWER FORECASTS

- We are currently providing wind forecasts every day for 4 wind plants (20 to 60 MW nominal power);
- We are still employing a k-NN-based algorithm.



SUN POWER FORECASTS

- We are currently providing sun power forecasts every day for 32 PV plants (0.5 to 10 MW nominal power);
- We are using a combination of algorithms (k-NN, neural networks, physical models).



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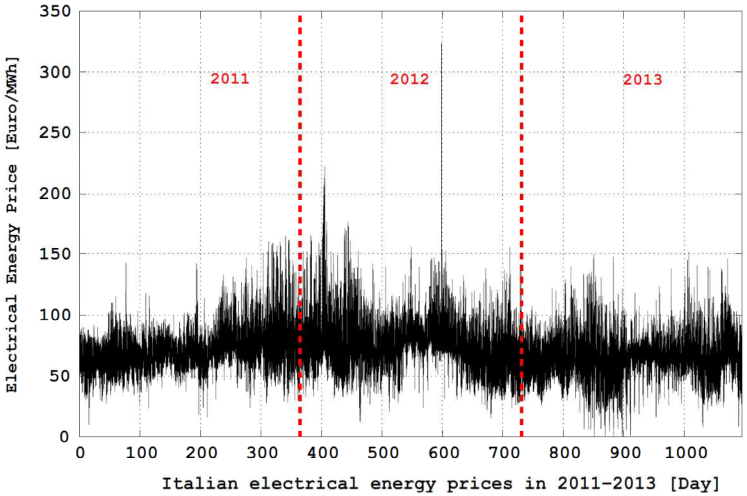
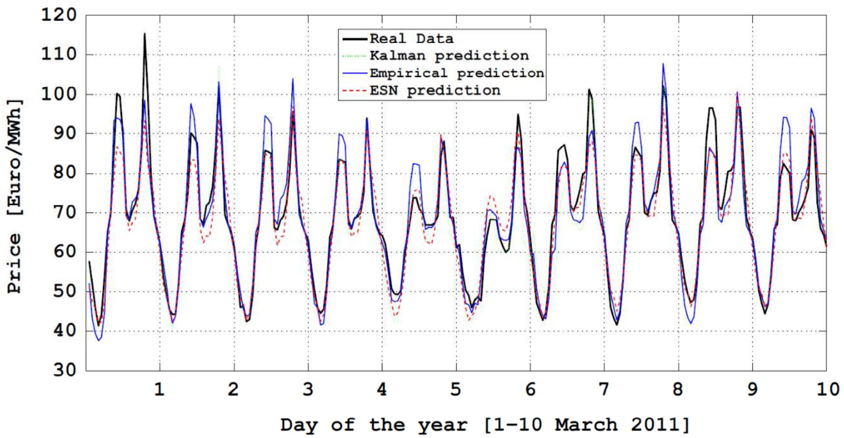
Price Forecast





	Predictive model											
	Day before			EA			KF			ESN		
	MAE	RMSE	MAPE	MAE	RMSE	MAPE	MAE	RMSE	MAPE	MAE	RMSE	MAPE
2011	6.83	10.28	9.49	5.67	8.34	7.86	6.27	9.15	8.71	5.25	7.57	7.30
2012	9.55	14.81	13.05	7.99	12.01	10.85	8.54	12.75	11.59	7.59	11.59	10.3
2013	8.94	13.92	15.05	6.87	10.00	11.47	7.71	11.33	12.99	6.51	9.25	10.99
2011–2013	8.44	13.15	12.53	6.84	10.23	10.06	7.51	11.18	11.1	6.45	9.61	9.53

E. Crisostomi, C. Gallicchio, A. Micheli, M. Raugi, M. Tucci, "*Prediction of the Italian Electricity Price for Smart Grid Applications*", Elsevier Neurocomputing, vol. 170, pp. 286-295, 2015.

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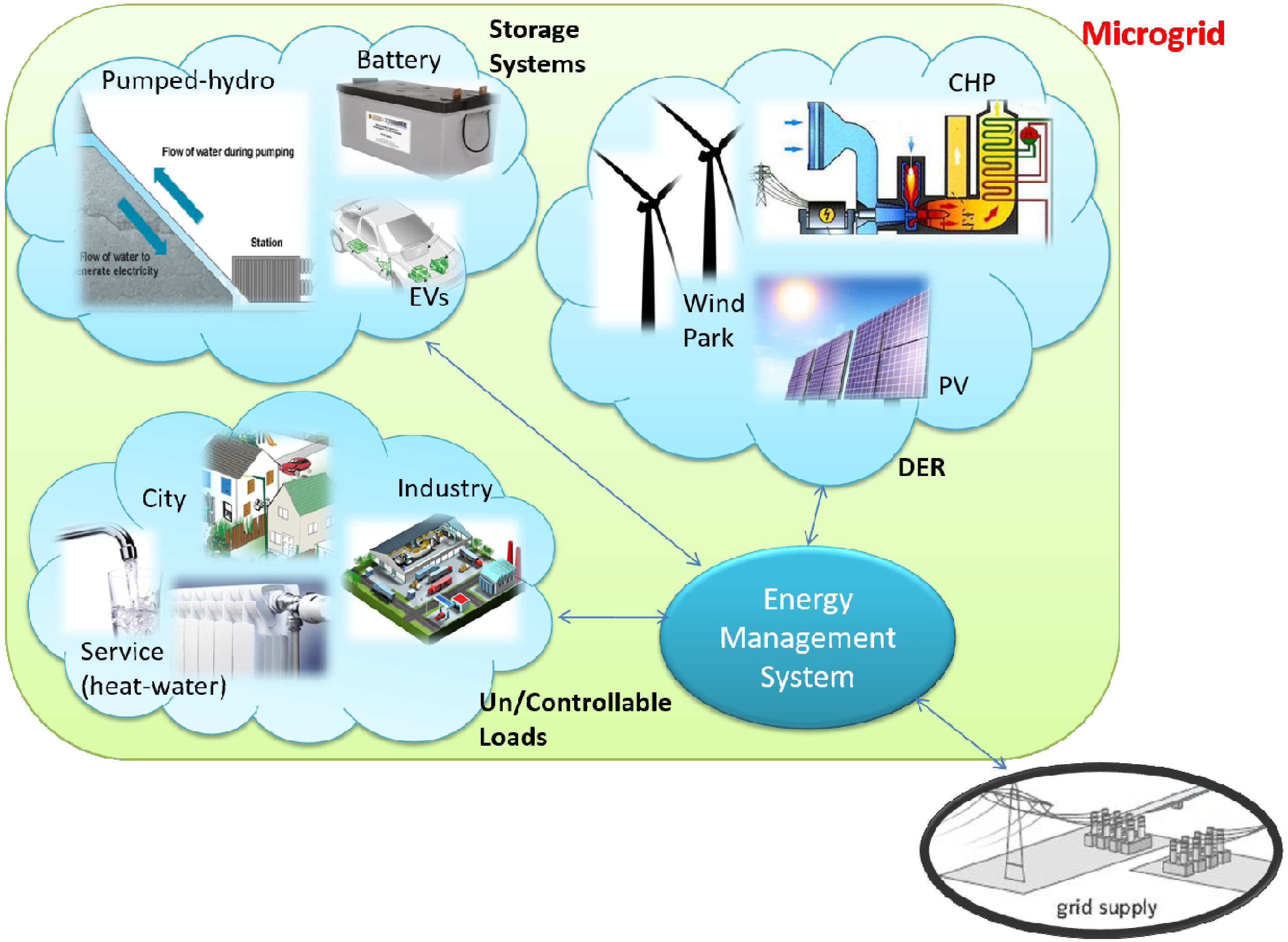
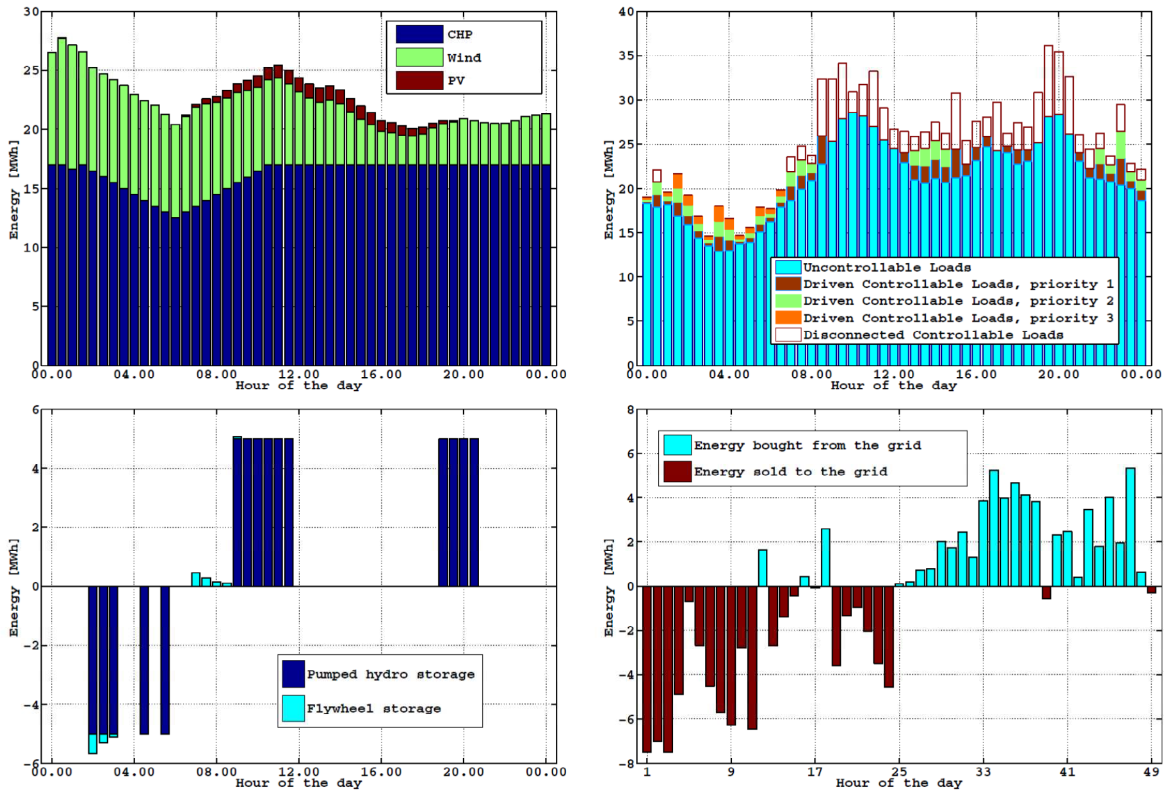
Optimised Power Control (I)



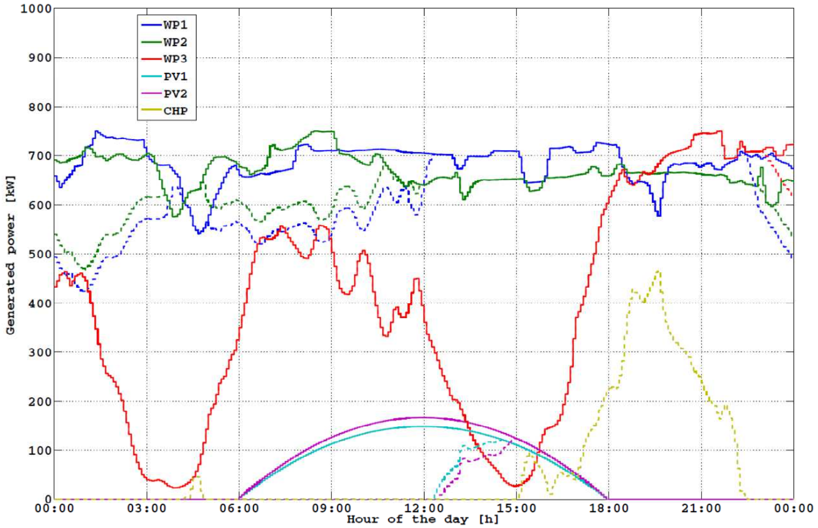
OPTIMISED POWER CONTROL (II)

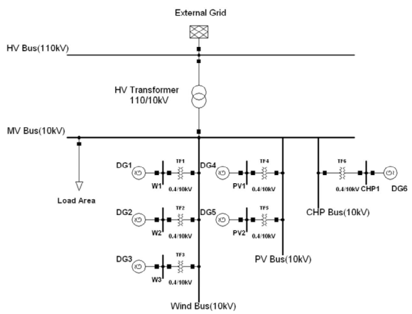


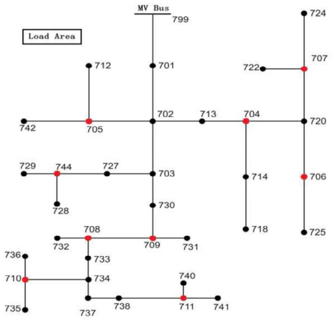
D. Aloini, E. Crisostomi, M. Raugi, R. Rizzo, "*Optimal Power Scheduling in a Virtual Power Plant*", Innovative Smart Grid Technologies (ISGT) Europe, Manchester, UK, 2011.

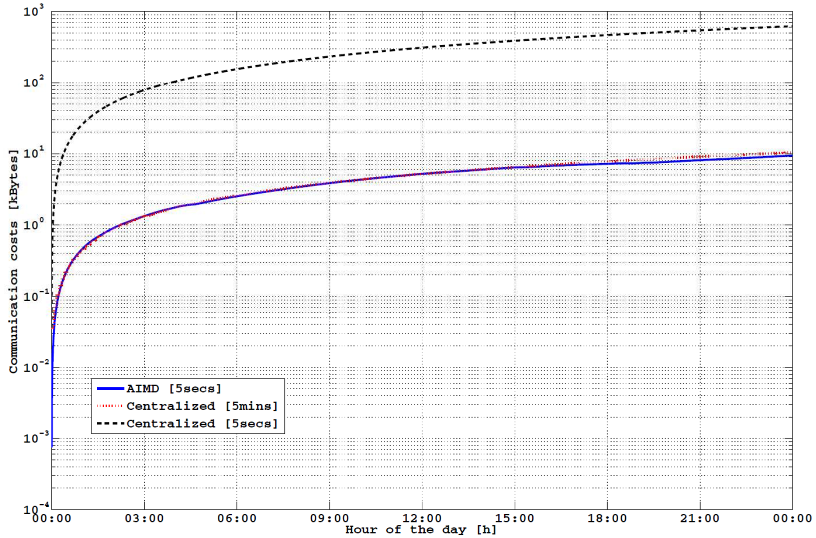
Real-Time Distributed Optimised Power Control

AIMD (Additive Increase Multiplicative Decrease)









E. Crisostomi, M. Liu, M. Raugi and R. Shorten, *"Plug-and-play Distributed Algorithms for Optimised Power Generation in a Microgrid"*, IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 2145-2154, 2014.

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IN SUPREMÆ DIGNITATIS 1343

DR in a fleet of EVs and PHEVs

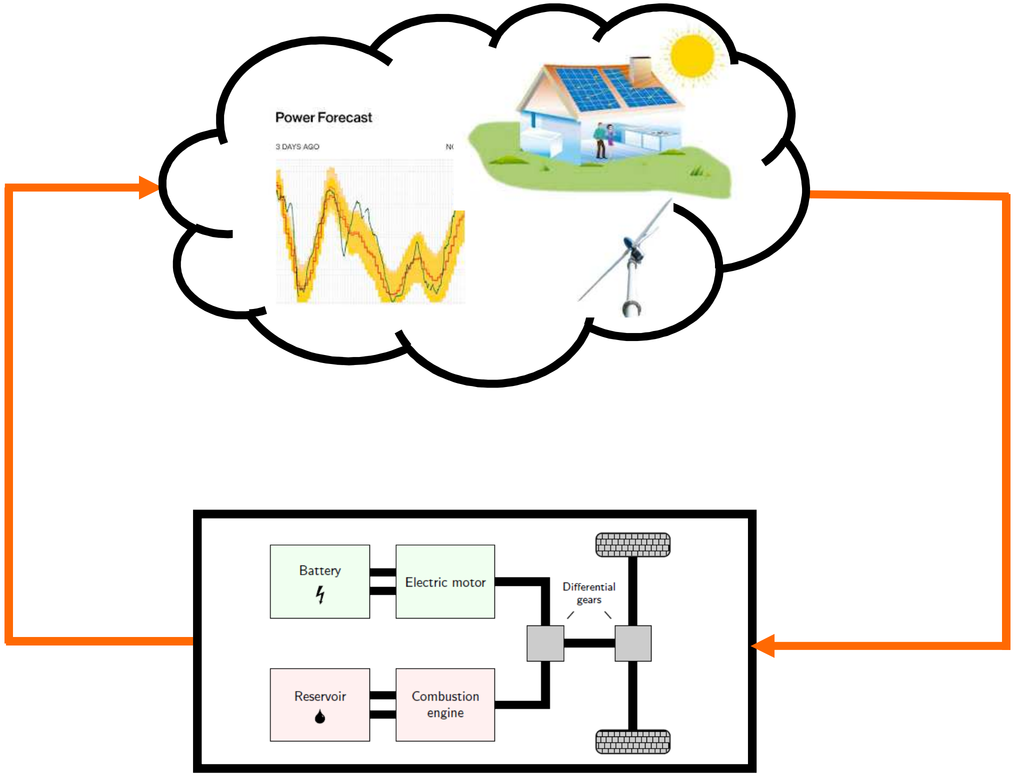
UCD DUBLIN	**Robert Shorten** Wynita Griggs Yingqi Gu
IBM	Sean McKenna Beat Buesser Fabian Wirth Jia Yuan Yu
Technische Universität Berlin	Florian Häusler Ilja Radusch

DR IN A FLEET OF EVS AND PHEVS

- A single EV is an **uncontrollable** load;
- However, a PHEV can be treated as a **controllable** load;
- A fleet of mixed vehicles (EVs, PHEVs, and conventional vehicles) also becomes a **controllable load** as a whole.

Demand Response in a PHEV

- Charging at night time;
- During the day travels in EV mode in order to consume the energy that will be available during the night;
- The energy provider tailors tariffs in order to reward virtuous users;



Driving mode

DR: Motivations

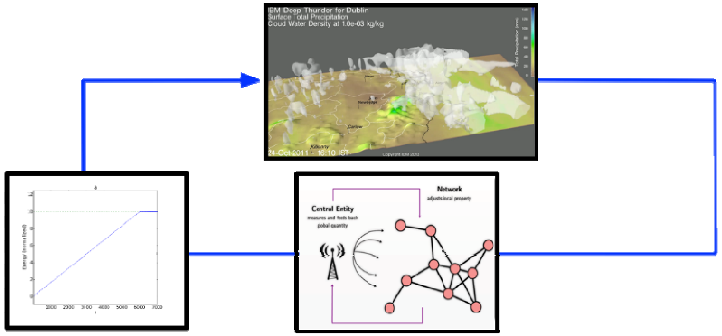
- **Environmental concerns:** *"We find that powering vehicles with corn ethanol or with coal-based or "grid average" electricity increases monetized environmental health impacts by 80% or more relative to using conventional gasoline. Conversely, EVs powered by low-emitting electricity from natural gas, wind, water, or solar power reduce environmental health impacts by 50% or more."* [1]

- **Customer advantages:** Energy from renewable sources is cheaper;

- **Power grid advantages:** PHEVs and EVs may eventually become schedulable and dispatchable loads.

[1] C.W. Tessum, J.D. Hill and J.D. Marshall, *"Life cycle air quality impacts of conventional and alternative lightduty transportation in the United States"*, Proceedings of the National Academy of Sciences (PNAS) of the United States of America, vol. 111, no. 52, pp. 8490–18495, 2014.

Demand Response in a Fleet of (PH)EVs



AIMD

Initialisation: Each agent sets its initial state $x_i(0)$ to an arbitrary value;

while *agent i is active* **do:**

  if $\sum_{i=1}^{n} E_i(k) < C(k)$ **then**

    $x_i(k+1) = x_i(k) + \alpha;$

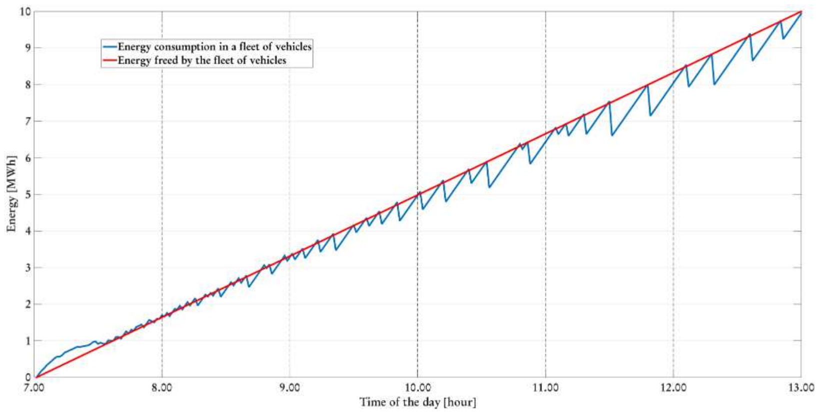
  else

    $x_i(k+1) = \beta \cdot x_i(k)$ *with probability* $\lambda_i = \Gamma \frac{f'(\bar{x}_i(k))}{\bar{x}_i(k)};$

    or $x_i(k+1) = x_i(k) + \alpha$ *otherwise;*

  end

end



Y. Gu, F. Häusler, W. Griggs, E. Crisostomi and R. Shorten, "*Smart Procurement Of Naturally Generated Energy (SPONGE) for PHEVs*", International Journal of Control, vol. 89, no. 7, pp. 1467-1480, 2016.

Demand Response in a Fleet of PHEBs

J. Naoum-Sawaya, E. Crisostomi, M. Liu, Y. Gu and R. Shorten, "*Smart Procurement of Naturally Generated Energy (SPONGE) for Plug-in Hybrid Electric Buses*", under review, 2016.

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CONCLUSIONS

- I have presented our research activity on forecasting and control, carried out at the University of Pisa;

- For any suggestion, interest of collaboration, or other, please do not hesitate to contact me at

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