Greening the Azores Islands:
The Key Role of Dynamic Monitoring and Decision Systems (DYMONDS)

©Marija Ilic
ECE and EPP Professor, CMU; milic@ece.cmu.edu
Director of SRC SGRC http://www.src.org/program/eri/
Honorary Chaired Professor for Control of Future Electricity Network Operations
Faculty of Technology, Policy and Management
Delft University of Technology

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TU Delft
Delft University of Technology

Outline

- Summary of a Draft Report on Greening the Azores Islands [1]
- The rationale for DYMONDS [2]; the key idea pursued at CMU's SRC Smart Grid Research Center http://www.src.org/program/eri/sgrc/
- Toward a DYMONDS-based simulator for Azores Islands [1,3]
- DYMONDS-based simulations to illustrate potential of using this approach for deploying large amounts of wind, solar, EVs without increasing cost [1]
- Key preliminary findings and recommendations for next steps
- Acknowledgments
- Disclaimer: Emphasis on a possible approach; the actual numerical findings require further discussions with EDA

Summary of Draft Report [1]

- Introduce the objectives of greening the islands and relating these to the planning and operating utility practice; careful definition of ``cost”

- Describe the basics of one possible IT-enabled technical and economic approach (DYMONDS)

- Illustrate using our rudimentary DYMONDS-based simulator the key role of embedding sensing, and decision making tools into the existing and new resources and the demand;

- Illustrate using our rudimentary DYMONDS-based simulator the key role of grid management for loss minimization, ensuring quality of electricity services (frequency and voltage) and reliability in systems with high presence of variable resources.

Some key performance metrics relevant for making islands green—Many contributors to ``cost”

- Annual variable (fuel) cost
- Annual emissions cost
- Annual T&D energy loss cost
- Cost of wear-and-tear (regulation) cost
- Cost of un-served load
- Cost of poor quality of electricity
- Capital cost for new investments and sunk cost of the existing assets

- ***The objective of greening the electric energy system must be posed in terms of reducing these costs**

The need for integrated cost management

- Performance in operations function of predictions, dispatch and grid operations methods
- Effectiveness of system planning function of coordination between planners and operators; selection of sub-objectives and their coordination; methods of managing risk
- In practice, it is impossible to model or solve this problem effectively as a single problem
- A direct consequence: Today's industry practice—lack of coordination; reliability at the expense of efficiency and emissions

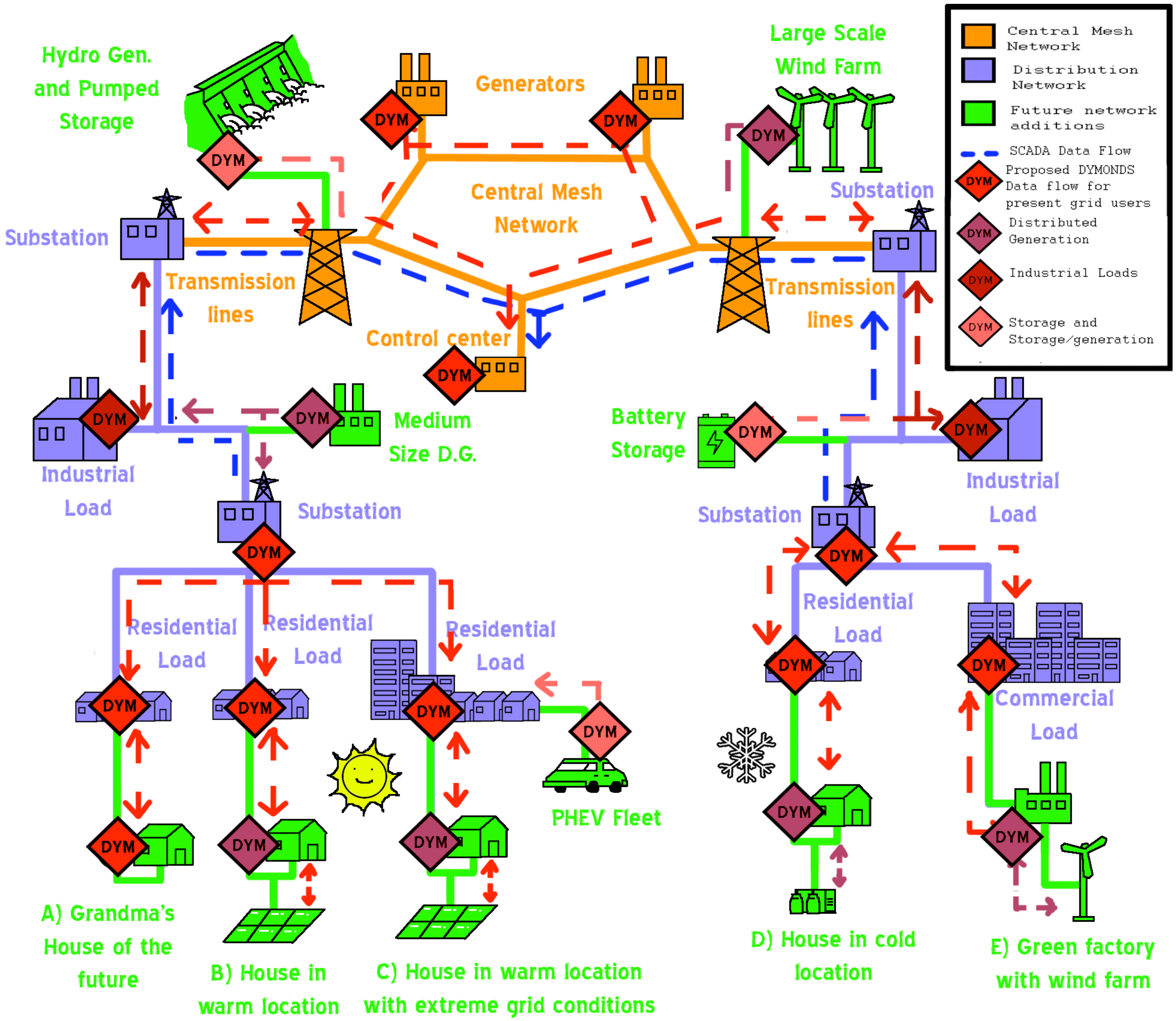
Our IT-enabled interactive cost management: DYMONDS framework [2]

- A modeling and decision making framework for supporting an IT-enabled platform for interactive information exchange between
  - system planners and operators (temporal interactions)
  - grid planners and resource planners (key to investing in reliable and efficient assets)
  - between the candidate investors in new resources and the central planner (key to reconciling trade-offs between stakeholders)
  - between the grid assets willing to produce/consume and the system operators (key to utilizing existing assets efficiently and reliably)

Some key observations on DYMONDS

- Nobody has perfect information
- System state dependent on what system users are doing over time
- Impossible to plan highly variable resources without relying on multi-directional information exchange (temporal, spatial, contextual)
- Possible to improve key performance metrics of interest and control their trade-offs; high dependence on how well are the interactions known and managed (just-in-time, just-in-place)
- Feasible IT-enabled coordination/integration of unconventional resources for near-optimal performance at choice.

DYMONDS-enabled Physical Grid [2,3]



Toward an Interactive Framework for Planning and Operating Azores as Green Islands

- An interactive energy planning framework (IEPF) for deploying clean energy resources at value [2]
- An interactive energy dispatching framework (IEDF) for dispatching existing and new energy resources at value [3]
- An interactive grid planning framework (IGPF) for locating the new resources within the existing grid [4]
- An interactive grid operations framework (IGOF) for operating the grid with new resources [6]
- POTENTIALLY IMPLEMENTABLE BY:

  -embedding look head, predictive decisions into resources and minimally coordinating temporal and spatial interactions (this is DYMONDS)

The challenge of ``optimal" design and operations for sustainable energy systems

- **An ``optimal investment" –any investment whose capital cost makes up for cumulative lack of performance in operations***
- CRITICAL WHEN MANAGING VARIABLE RESOURCES (THE VALUE OF FLEXIBLE OPERATIONS IN OFF-SETTING INVESTMENT NEEDS ---JIT AND JIP)
- Truly optimal performance requires knowledge about:

  - performance during operations and capital cost of candidate investments;

  -trade-offs between resource characteristics, system users preferences and systems objectives

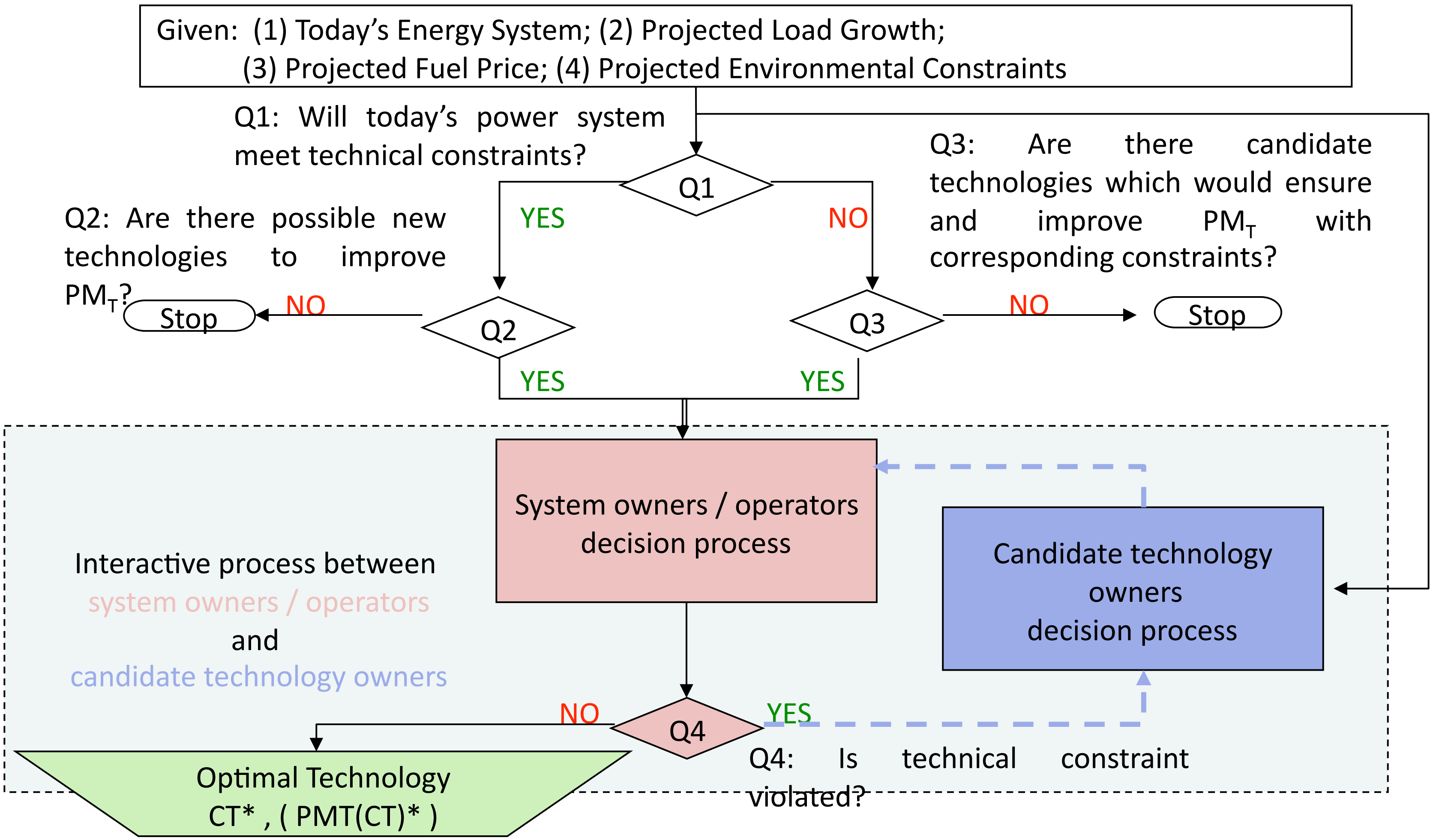
An interactive energy planning framework (IEPF) for deploying new resources in the Azores

- Assess economic, emission and technical performance of the island's electric energy system; Identify major opportunities for improvement (initial conditions)
- Creating long-run marginal cost (LRMC) curves by the candidate technologies
- Consider key candidate energy technologies for improving the existing performance and select the best combination of new resources (EDA; system planner)

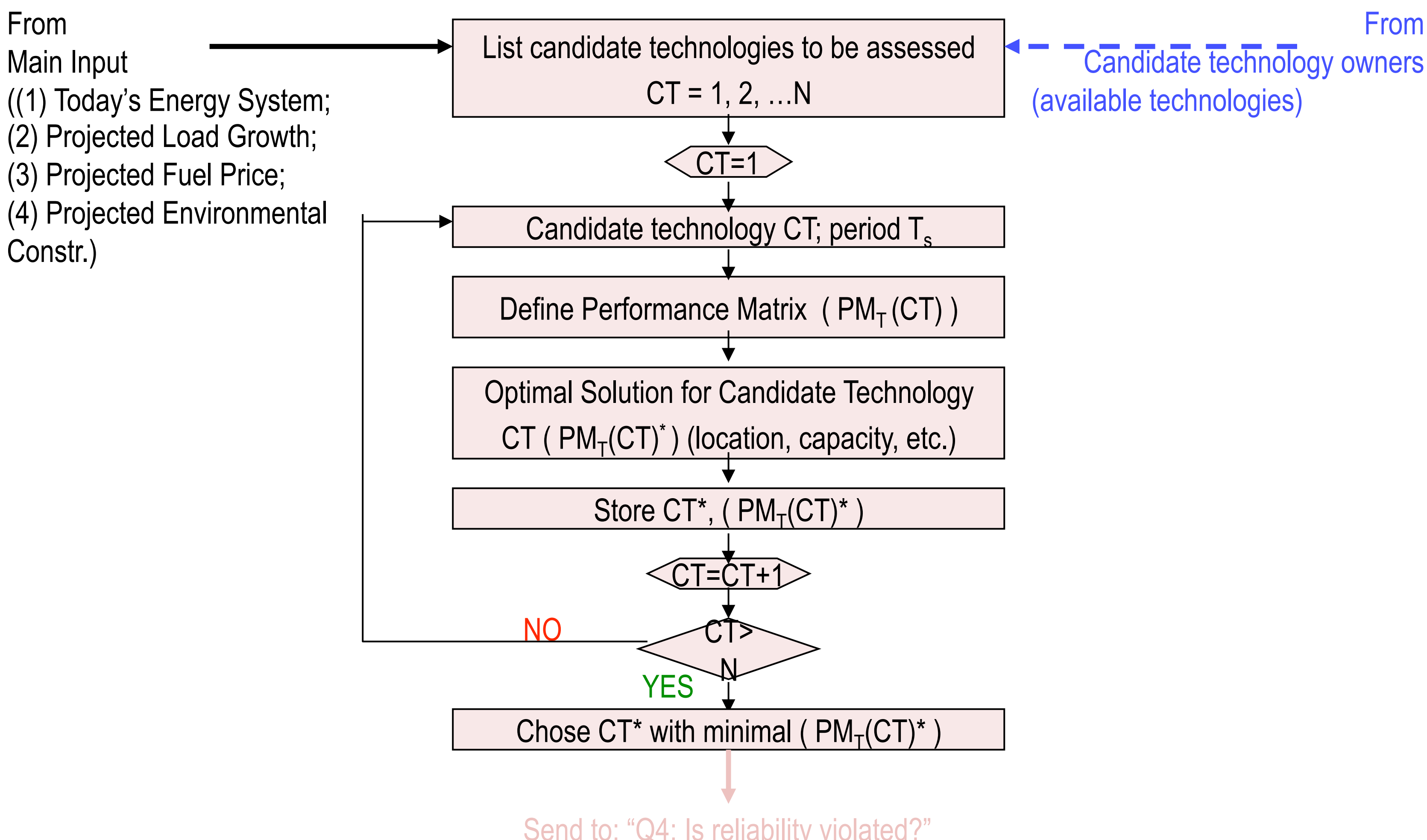
Assessing candidate technologies

- Annual variable (fuel) cost
- Annual emissions cost
- Annual T&D energy loss cost
- Cost of wear-and-tear (regulation) cost
- Cost of un-served load
- Capital cost of new investments
- Sunk cost of the existing investments

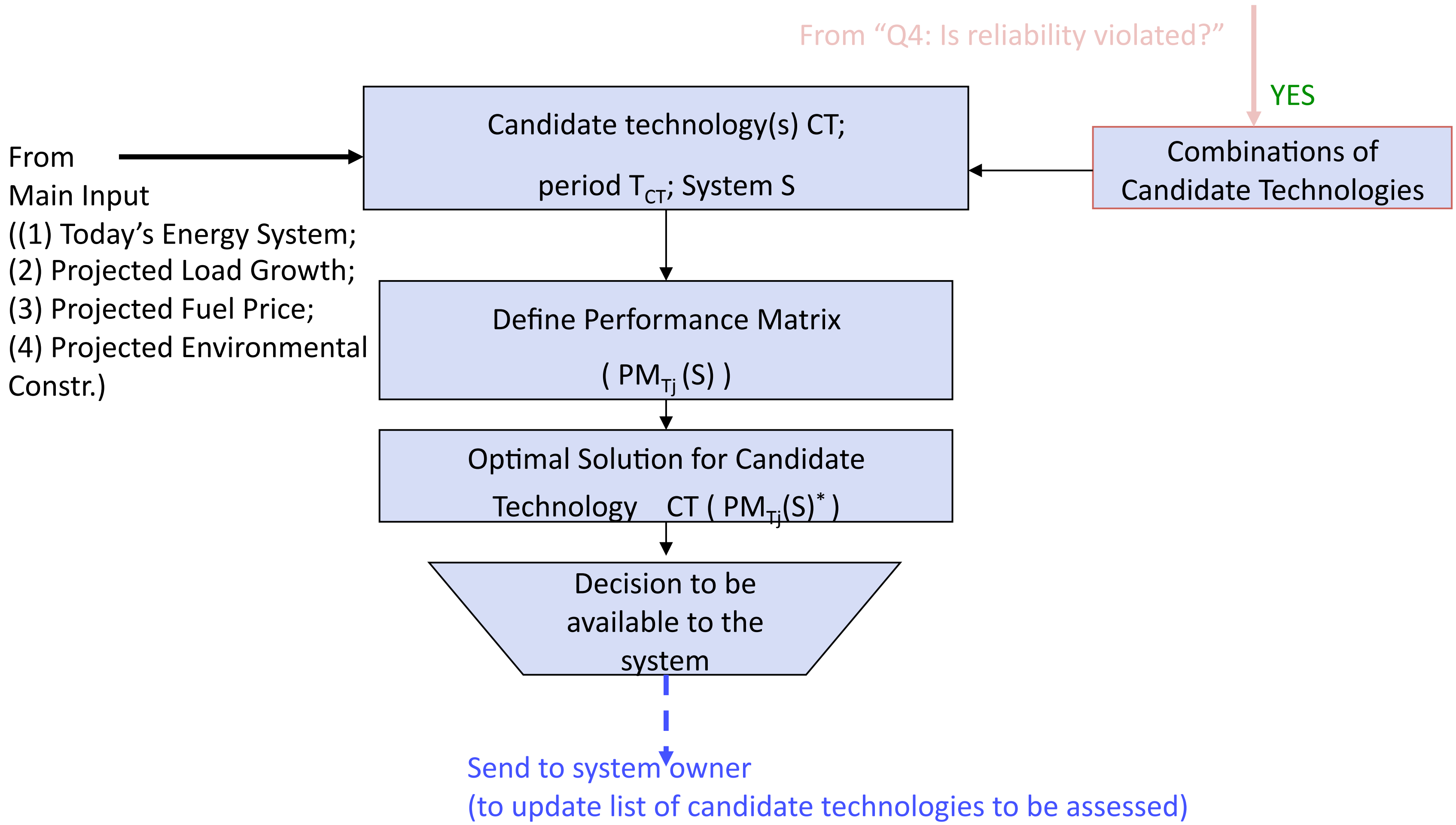
Interactive planning framework (IPF) [4,5]



System Owners / Operators Decision Process



Candidate Technology Owner Decision Process



An illustrative system with new resources

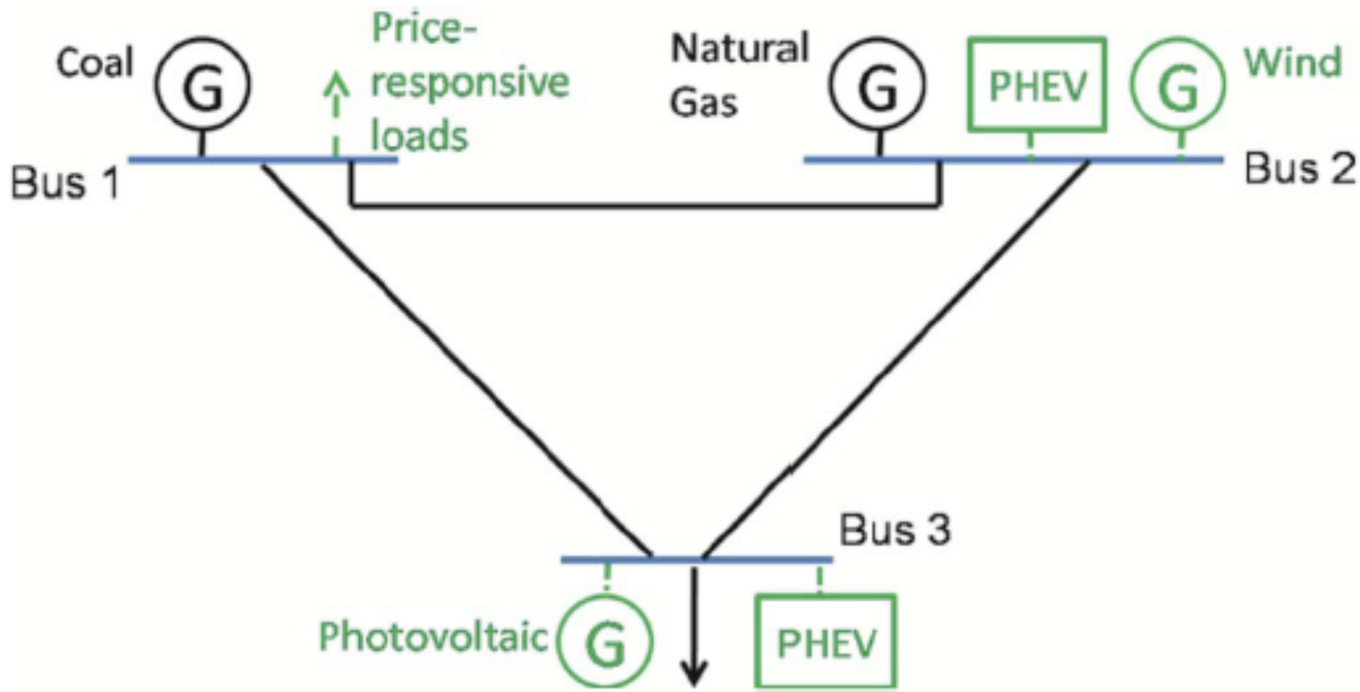
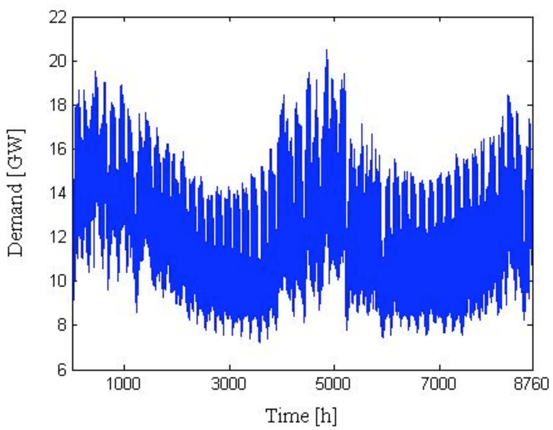


Fig. 5. Small example of the future electric energy system.

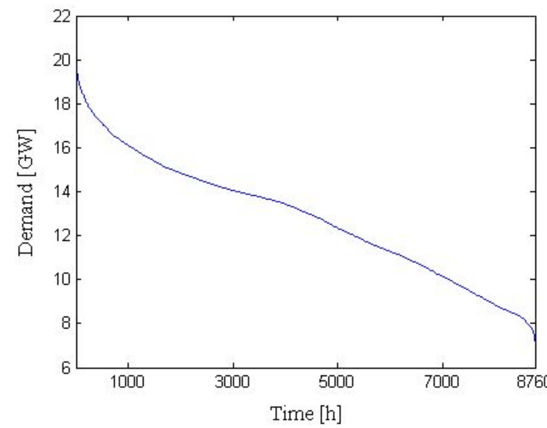
Demand forecast

Annual demand

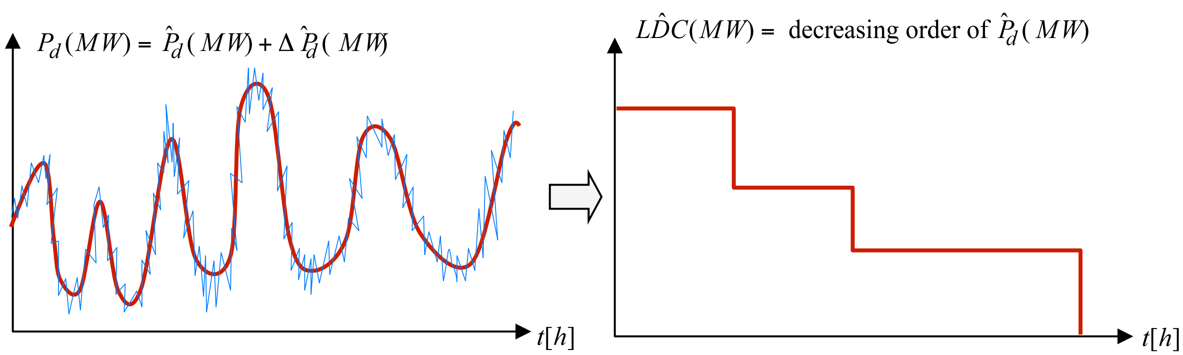


ordering data in descending order of magnitude

Load duration curve



Demand forecast:



IEPF---Interactive energy planning by all: users, resources and planners [3-5]

The main idea:

Consumers who are using a system during capacity scarcity period are responsible for investment into new capacity.

The optimal solution will be reached if investment into new capital investment equals to cumulative operating inefficiency

$$\max_{P_d^{T,t}, P_g^{T,t}, \Delta P_g^T} \sum_{T=1}^{T_H} \rho^{-T} \left[\sum_{t=1}^{n_t} \left\{ U\left(P_d^{T,t}\right) - \sum_{g=1}^{n_g} c_g \left(P_g^{T,t}\right) \right\} \cdot t_{duration}^{t} - \sum_{g=1}^{n_g} C_g \left(\Delta P_g^T\right) \right]$$

Subject to:

$$\sum_{g=1}^{n_g} P_g^{T,t} = P_d^{T,t}$$

$$0 \le P_g^{T,t} \le P_g^{\max} + \Delta P_g^T$$

Key long-term signals for interactive planning

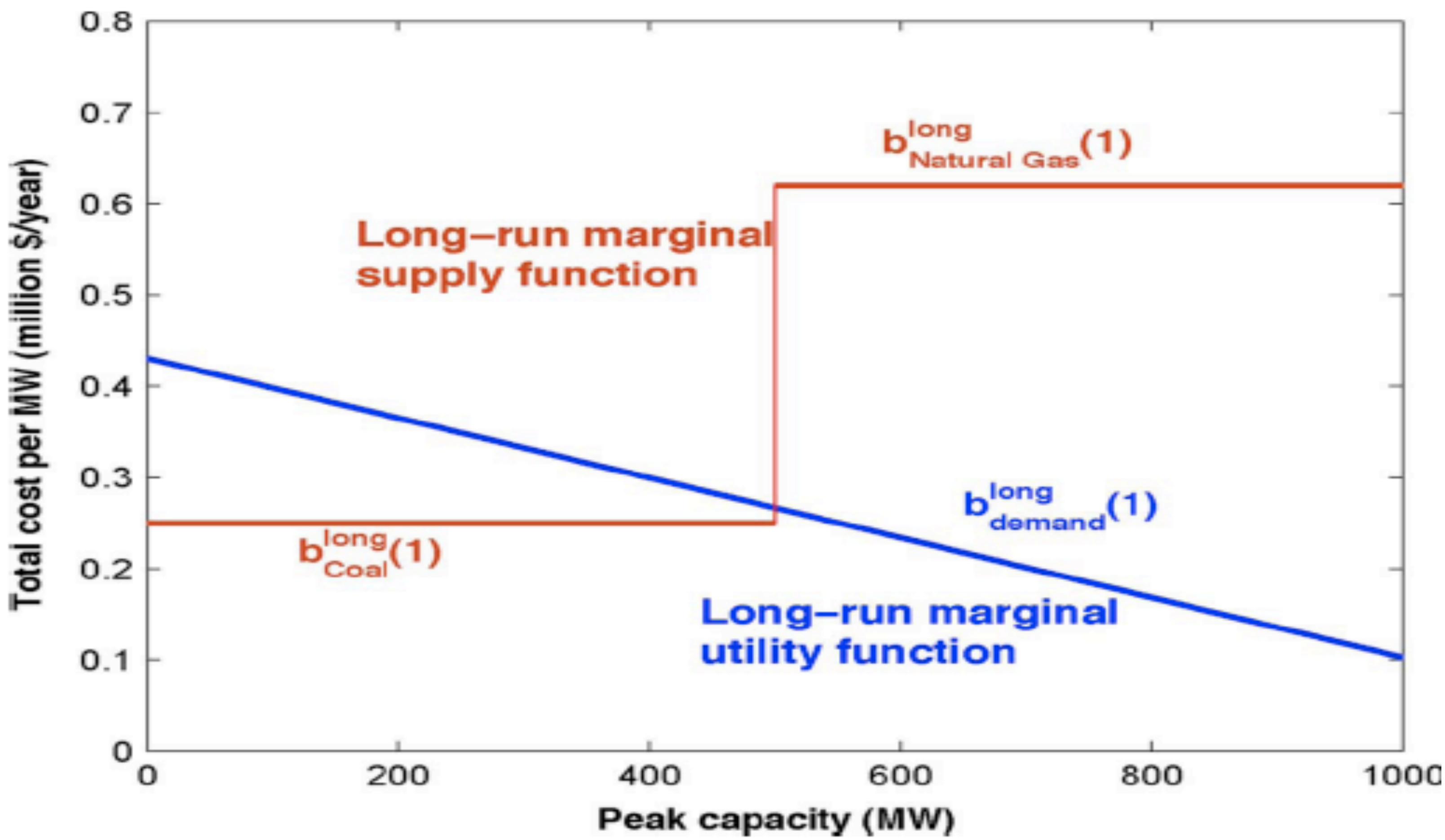


Fig. 14. Long-run bidding functions.

Preliminary findings using DYMONDS-based simulator

- Remco V showing that it is very economical to deploy large amounts and wind to offset the $250%/MWh diesel fuel cost (Section 8 [1])
- LRMC FOR WIND CURVE AND INTERPLAY WITH LRMC EV
- The cost of producing energy by the intermittent resources dependent on embedded IT (the key link-- the hours used determine per hour cost!) COARSE ASSUMPTIONS ABOUT``EFFICEINCY'/ ``CAPACITY FACTORS" MISLEADING

An interactive energy operating framework (IOF) for efficient asset utilization

- Operate the existing and new resources in an interactive way with the system operator; the new resources offer times and conditions when available according to their own objectives; system operator selects the right combination out of all possible offers (win-win)

Result of distributed UC by the system users given the system signal

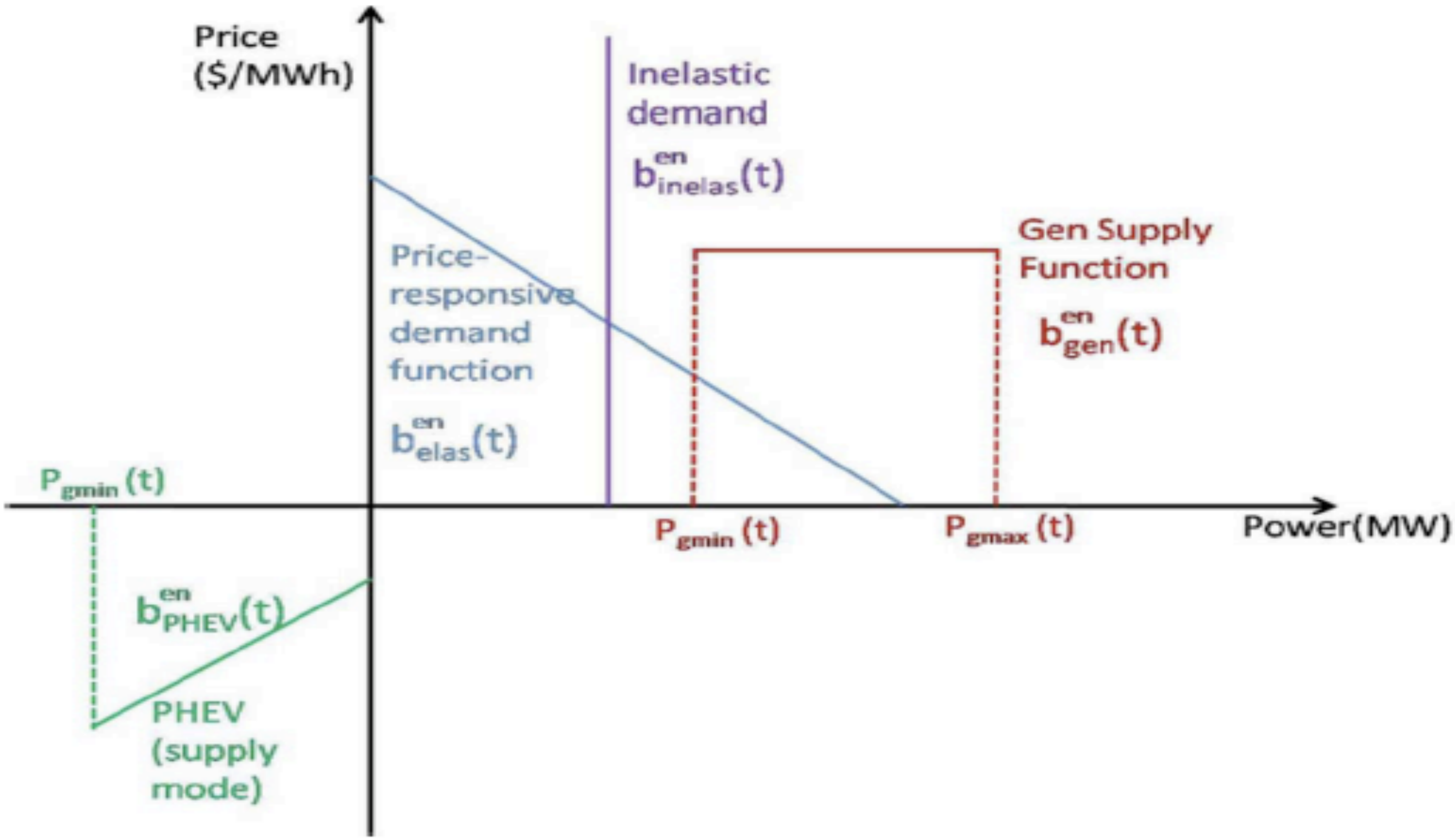


Fig. 6. Typical supply and demand curves for different technologies.

Illustration of results of the proposed interactive planning and operations [1]

- The case for investing in large wind power deployment; spilling wind is OK as long as the potential value exceeds the cost of providing wind (Section 5 [1])
- The case for adaptive load management (ALM) (Sections 6 and 7 [1])
- The case for large-scale deployment of wind
- The case for large penetration of EVs
- The notion of an ``optimal new mix”--- any mix of new resources whose total cost is lower than the total cost of the technology being replaced

Contracting the results with centralized UC which assumes wind as a negative load

- Section 3 done by IST using Dplan for Flores and SMG
- As wind penetration increases, lots of wind must be spilled; the cost is high
- ESSENTIAL TO MAKE WIND PREDICTABLE AND DYNAMICALLY DISPATCHABLE
- Should dispatch hydro (critical); look ahead scheduling hydro in anticipation of wind output to avoid diesel use the last minute

Treating Wind Power as Negative Load

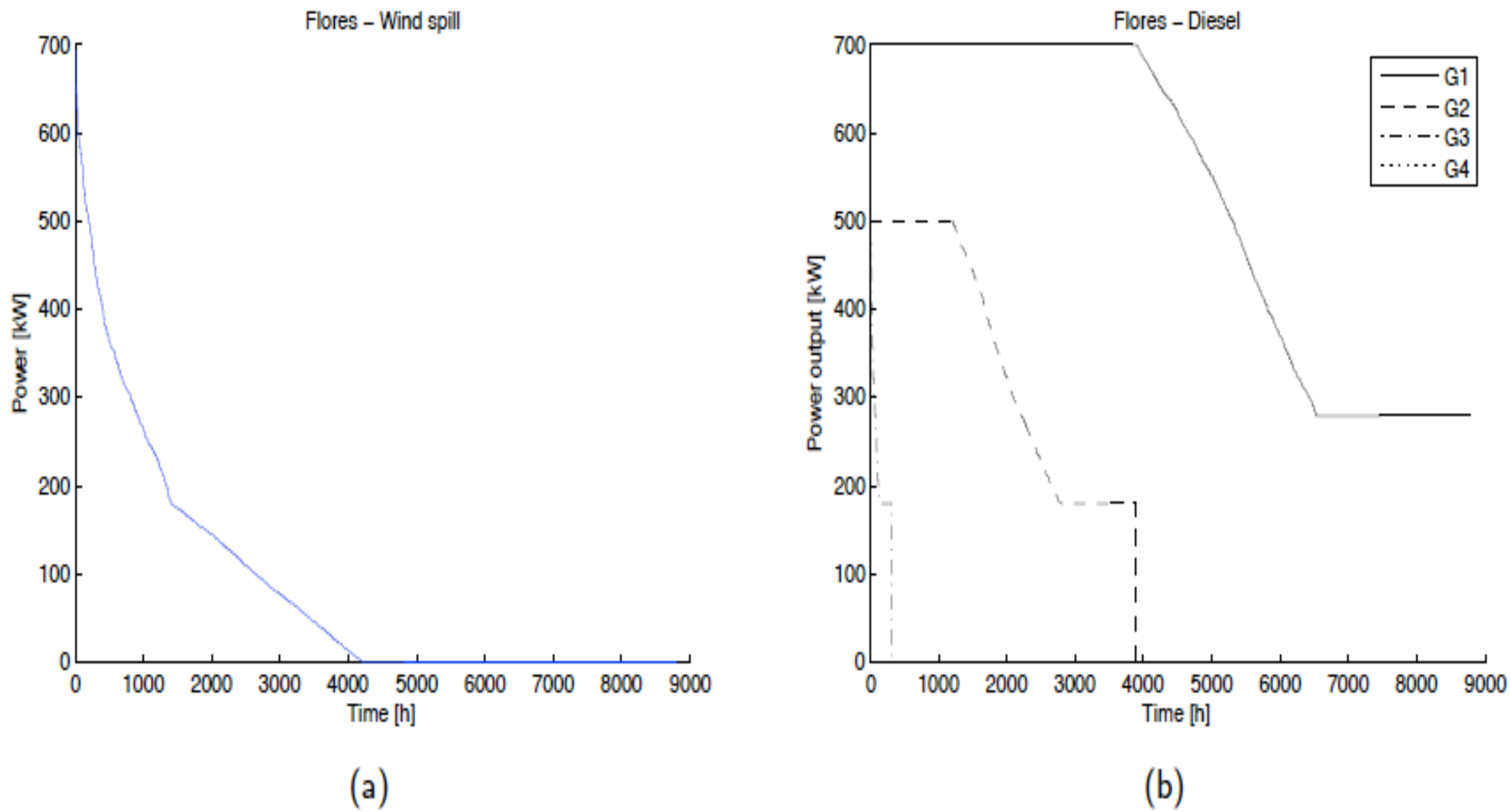


Figure 3: Duration curves - 2 turbines.

Estimated cost—Doesn't look very good

Table 3: Total diesel costs - 2008.

N Wind Turbines	Total Energy Produced [MWh]	Cost [Eur]
2	6,091	63,000
3	5,354	56,250
4	4,911	51,593
5	4,662	48,974
6	4,495	47,222

Table 7: Wind spill by turbine - Flores 2008.

Wind Turbines	Wind spill [%]
1	2.1
2	11.8
3	22.5
4	34.33
5	43.13
6	51.96

Value of predictive dynamic decision making by wind power -Flores (Section 5 [1])

In this case, the wind generation capacity is assumed to be 0.6MW, the hydro generation capacity is assumed to be 1.5MW, the diesel generation capacity is assumed to be 2.5MW.

Generation Type	Marginal Cost ($/MWh)	Installed Capacity (MW)	Ramping Rate
Diesel	50	2.5	56% of Pgmax/min (1.4MW/min)
Hydro	9	1.5	4% of Pgmax/min (0.06MW/min)
Wind	5	0.6	10% of Pgmax/min (0.06MW/min)

Value of Look-Ahead Dispatch (diesel)

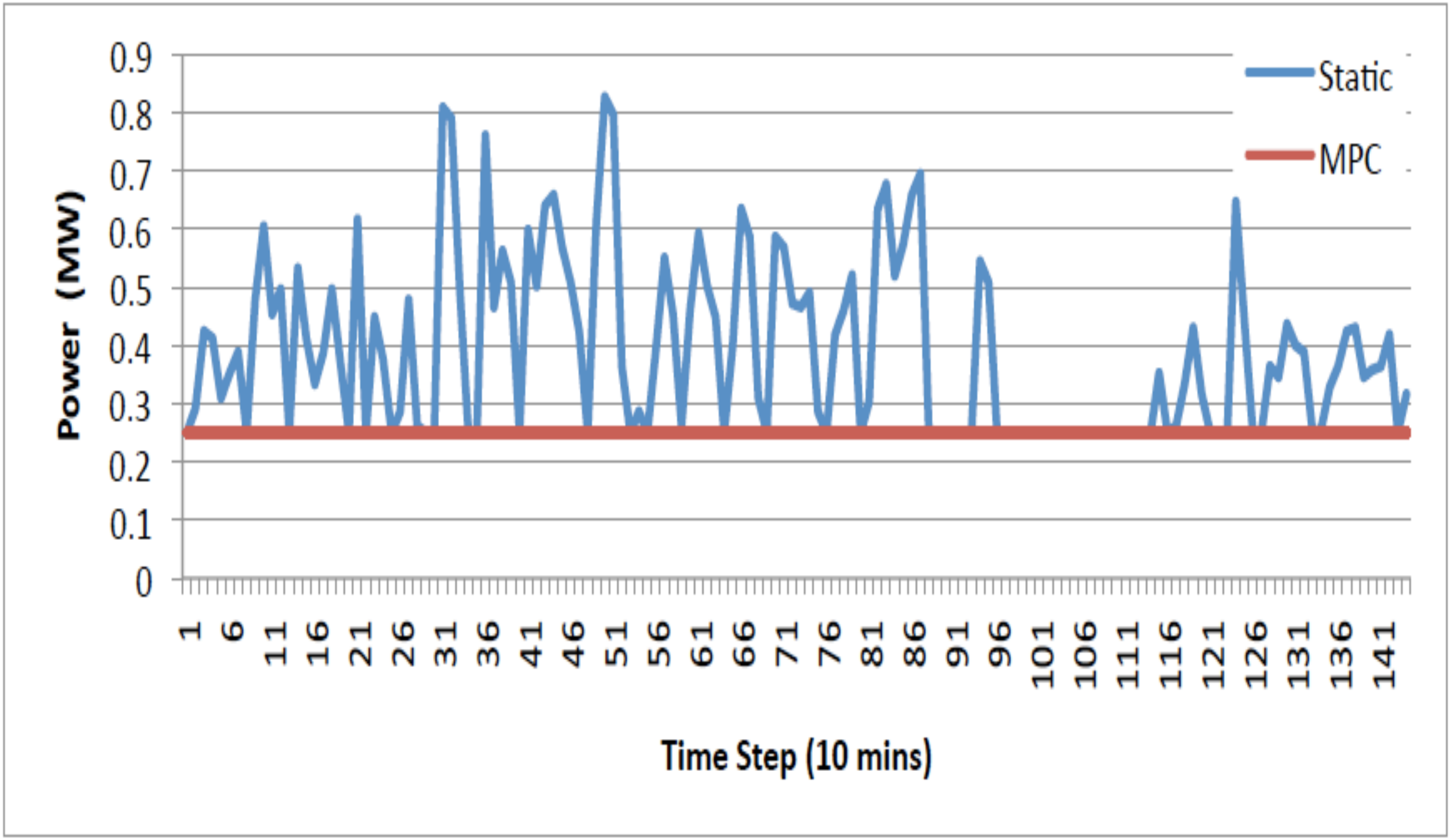


Figure 3 Diesel unit generation output with two dispatch methods

Value of Look-Ahead Dispatch (hydro)

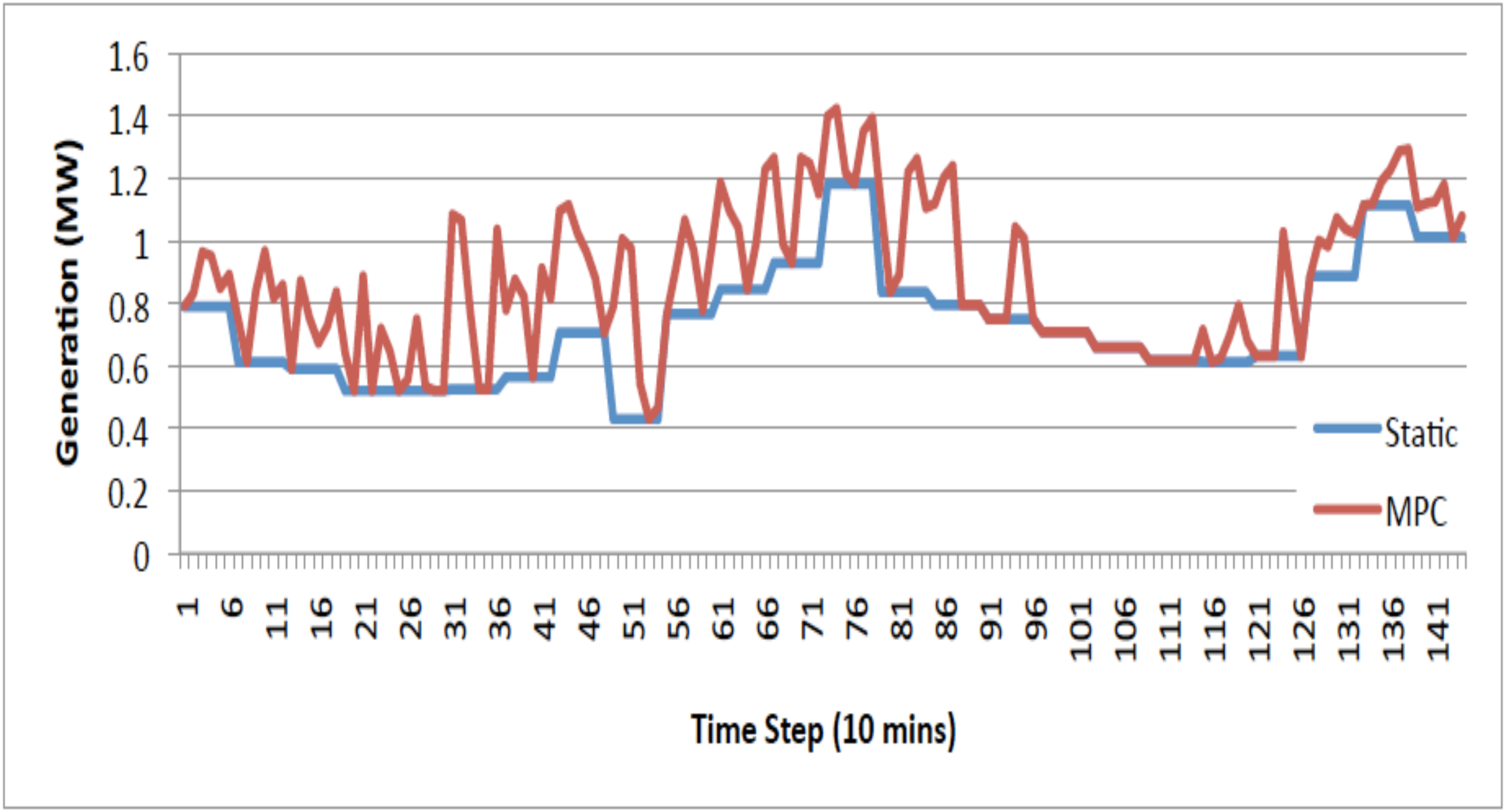


Figure 4 Hydro unit generation output with two dispatch methods

Value of look-ahead dispatch (wind)

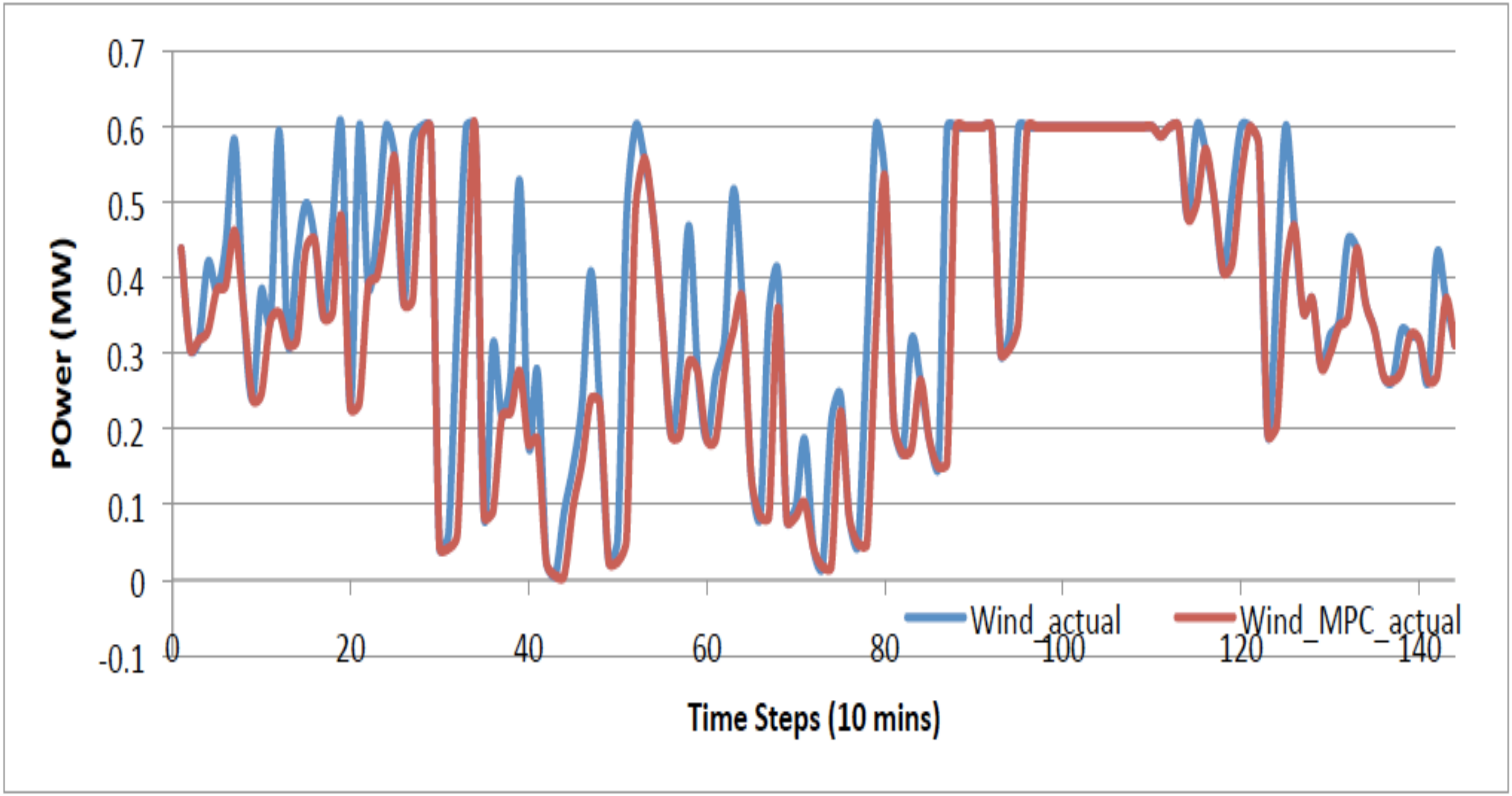


Figure 2 Wind Generation in Static and MPC dispatch

Value of spilling wind

Table 1 Diesel Unit Performance in a Typical Day

	Total Electricity Generation (MWh)	Total CO2 Emission (Tons)
Static Dispatch	57.2	142.5
MPC Dispatch	36	90

(Part II) A method for ensuring reliable and efficient grid implementation

- Ensuring feasible power flow solution with new resources
- Minimizing system delivery losses by placing the new resources at the right locations and/or optimizing voltage profile in the grid (Section 12 [1] Nazari talk)
- Putting enough flexible resources to ensure high quality regulation of frequency in a system with lots of hard-to-predict fluctuations (flywheels, and storage) (Section 13)
- Having enough voltage regulation (capacitor banks/power electronics) to ensure voltage regulation for hard to predict fluctuations
- Ensuring that the system is robust (small signal stable) (Section 13 [1] Nazari talk)

The effect of technology choice on frequency regulation (Liu, Popli,Bachovian)

- Conventional AGC –comparison of technology mix effects with large amounts of wind
- Conventional AGC--effects of wind prediction accuracy
- Better design of AGC—quality of response vs cost of control tradeoffs

Capturing value of fast flywheels and other storage

1. **Conventional Control:** It is based on the concept of **Area Control Error (ACE)**. The technology so implemented is similar to the one employed by most of the ISOs in USA, i.e. average system frequency is sensed and control is executed over 1-minute period.
2. **Vector-based Control:** For Flores network, penetrated with high percentage of wind, it is crucial to take into account the network constraints and execute control over a time-scale faster than 1-minute.

The four different combination scenarios are listed as:

Scenario 1: AGC with Hydro only;
Scenario 2: AGC with Diesel only;
Scenario 3: AGC with Flywheel;
Scenario 4: AGC with Flywheel and Diesel;

The three different wind power output cases are listed as:

Case 1: Zero mean disturbances (good wind prediction)
Case 2: Negative mean disturbances (overestimated wind prediction)
Case 3: Positive mean disturbances (underestimated wind prediction)

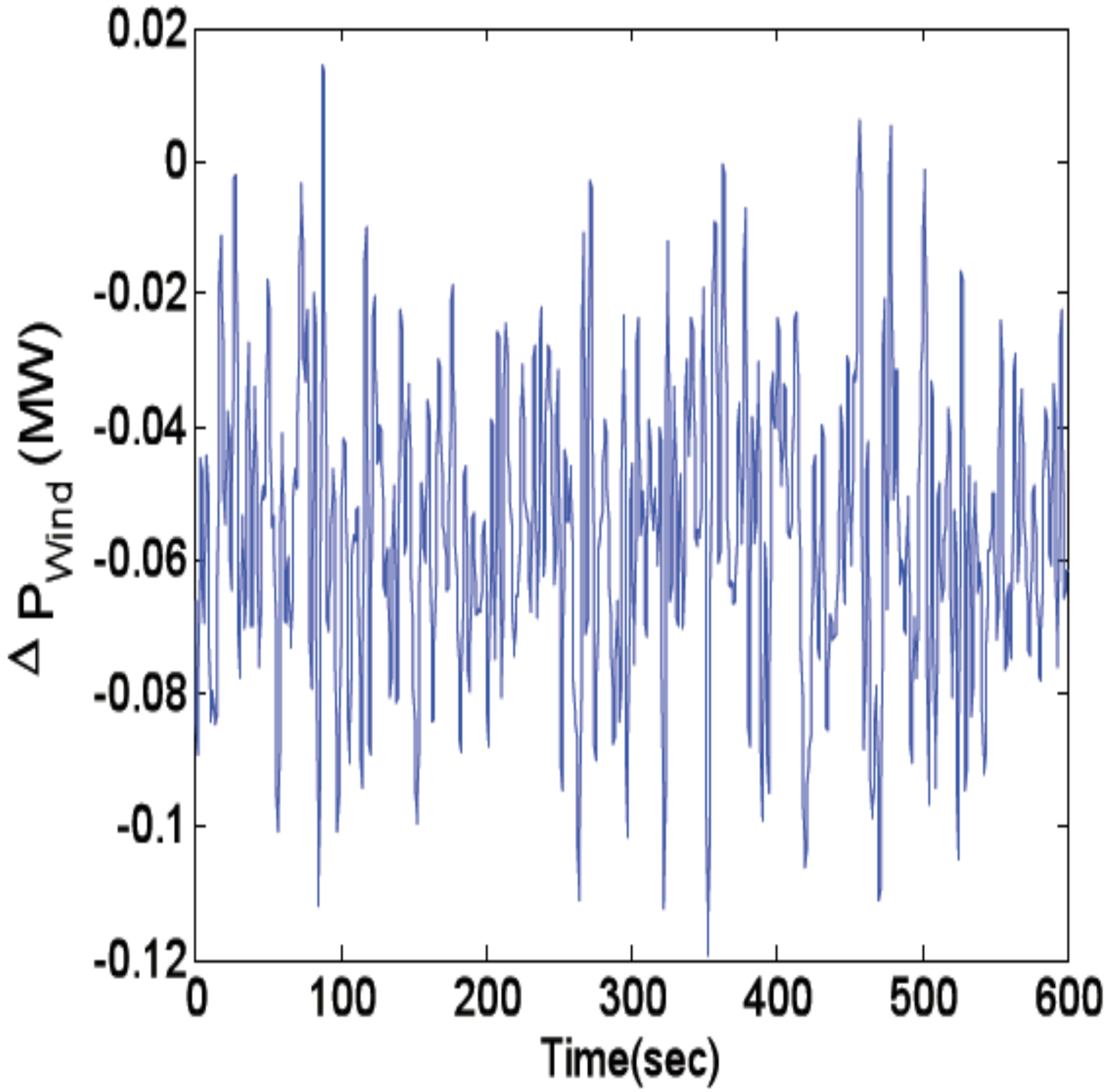
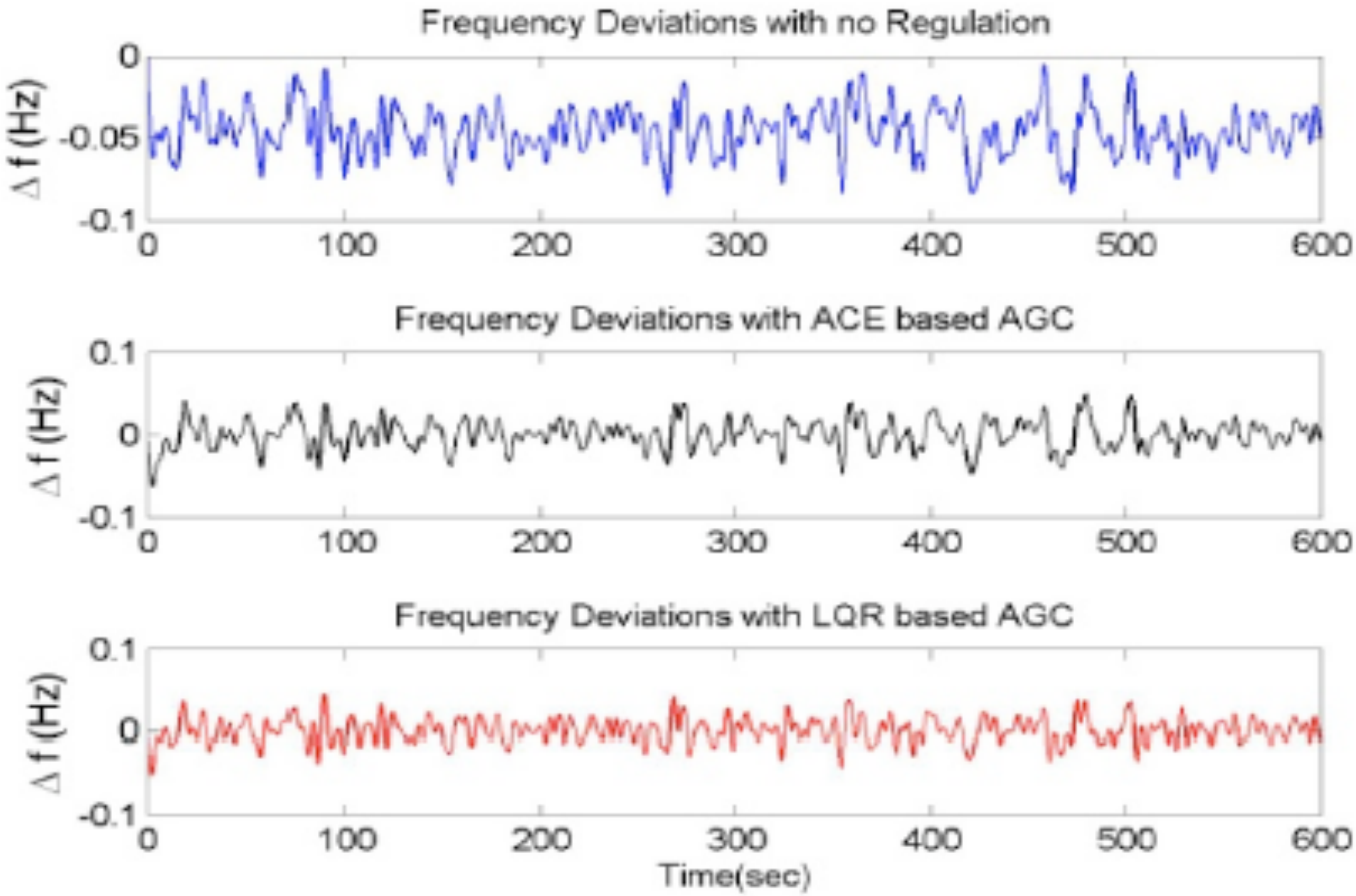
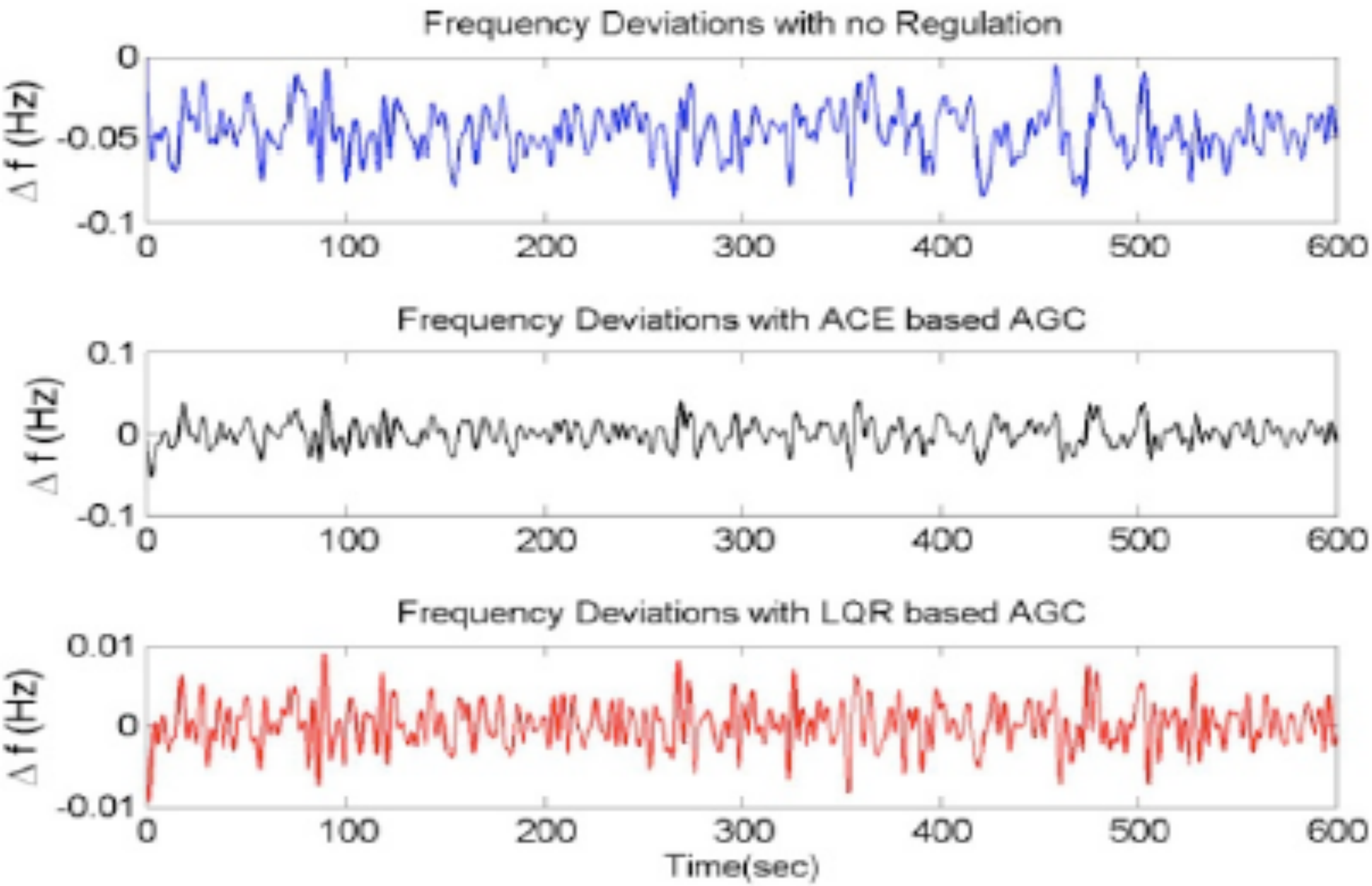


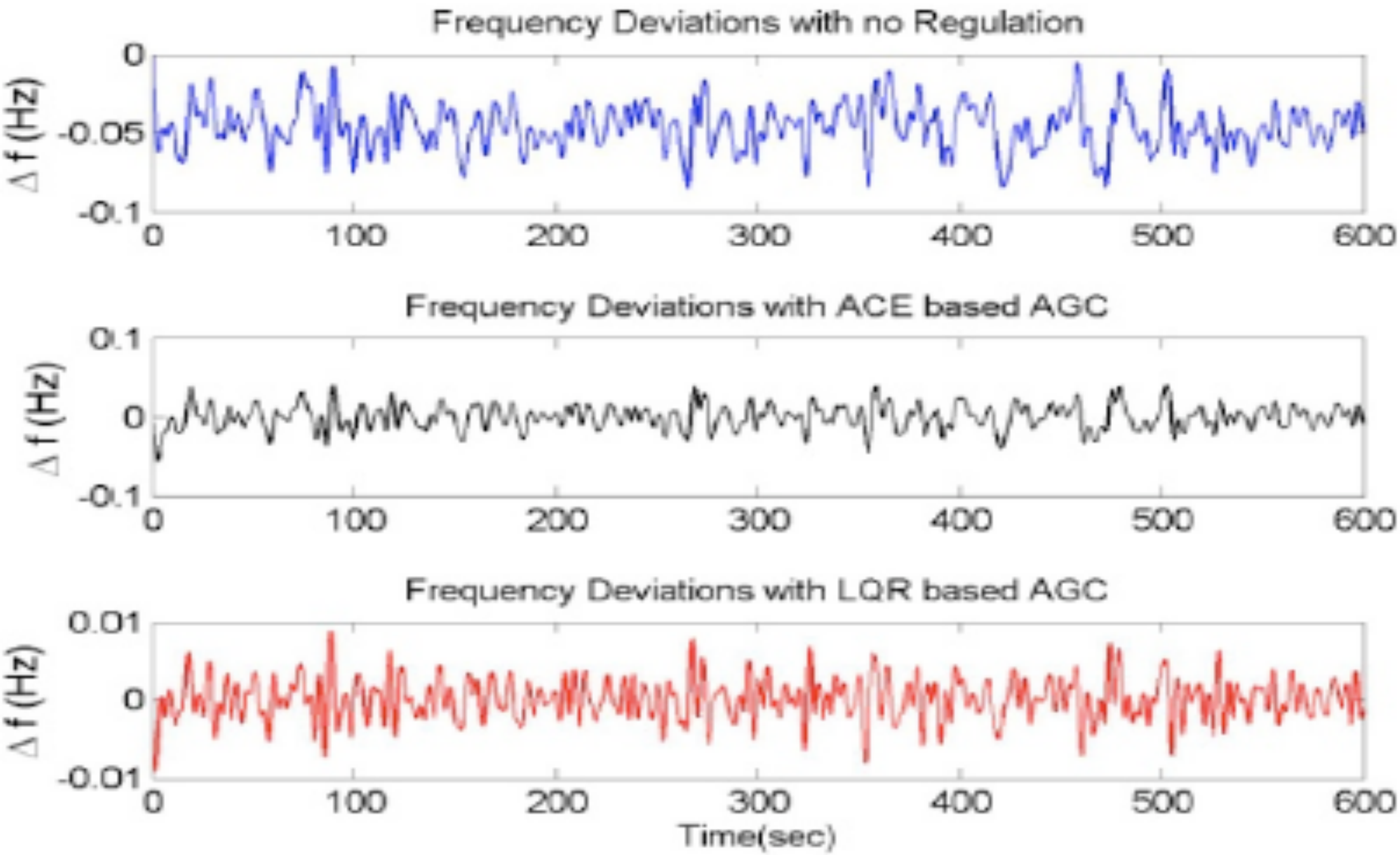
Figure 2.1 Negative Mean Wind Disturbances and 5% Standard Deviation around the Operating Point in 10 minutes.



(a) AGC with Hydro Only

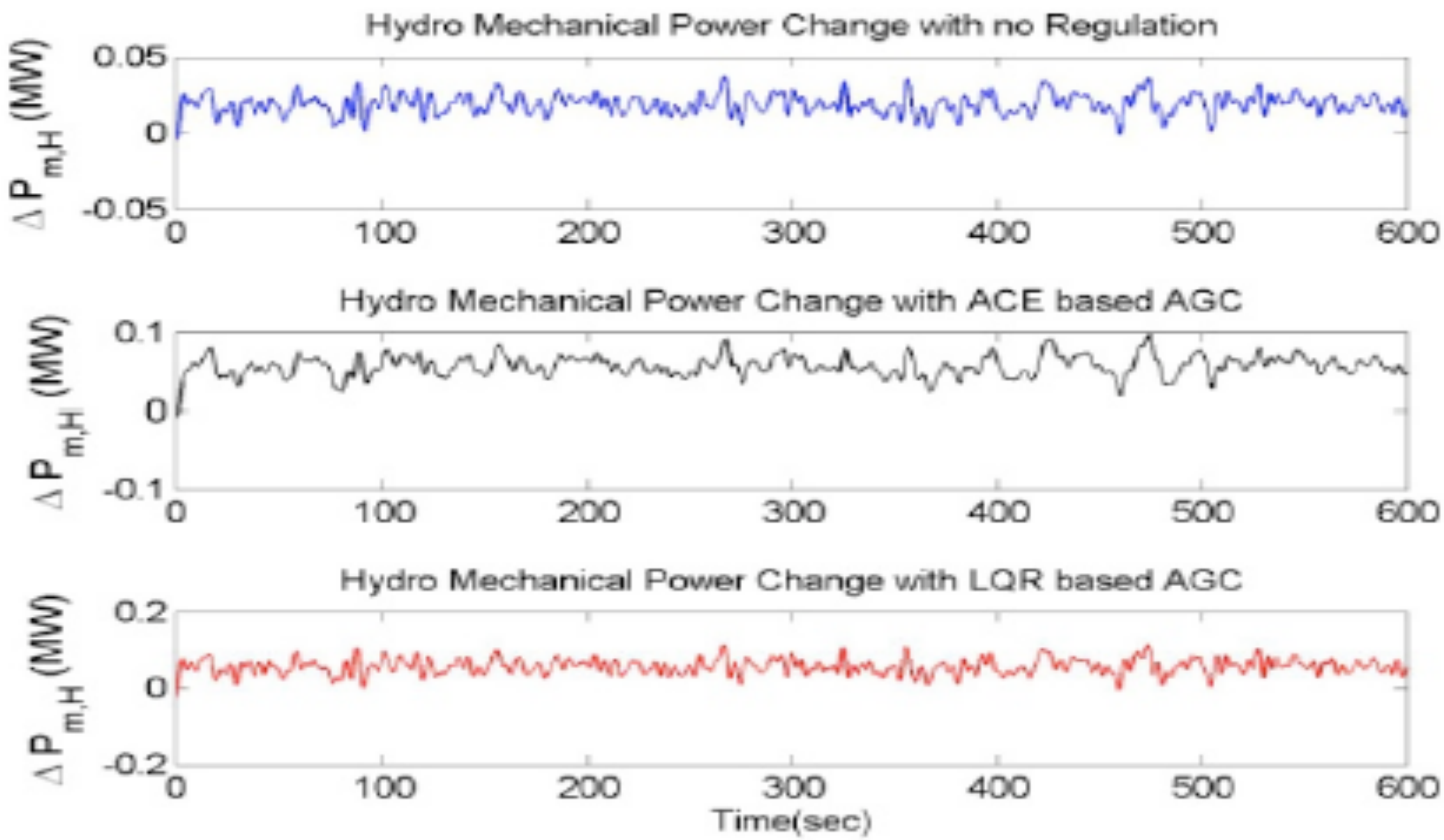


(c) AGC with Flywheel Only



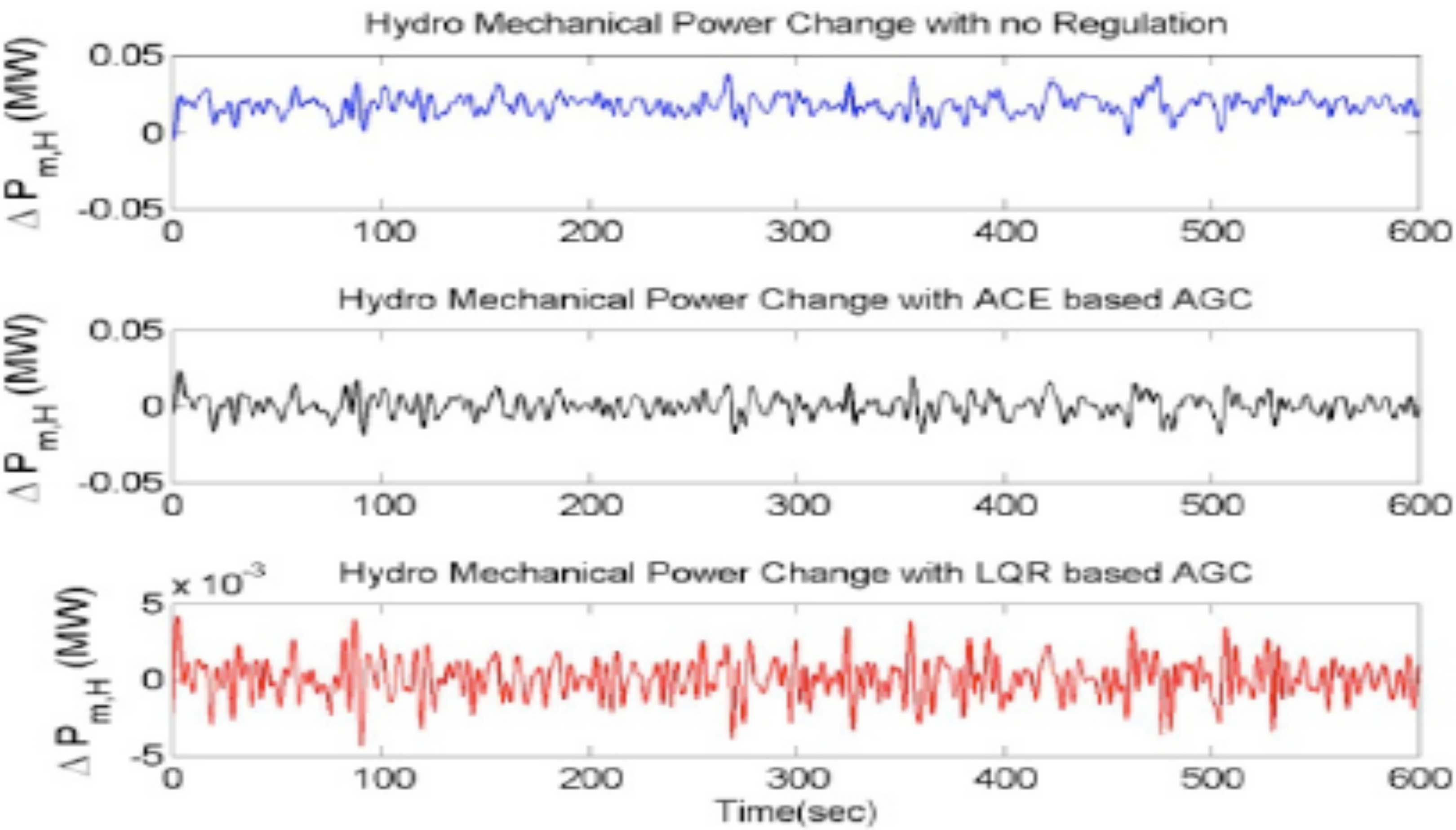
(d) AGC with Diesel and Flywheel

Wear-and-tear cost dependence

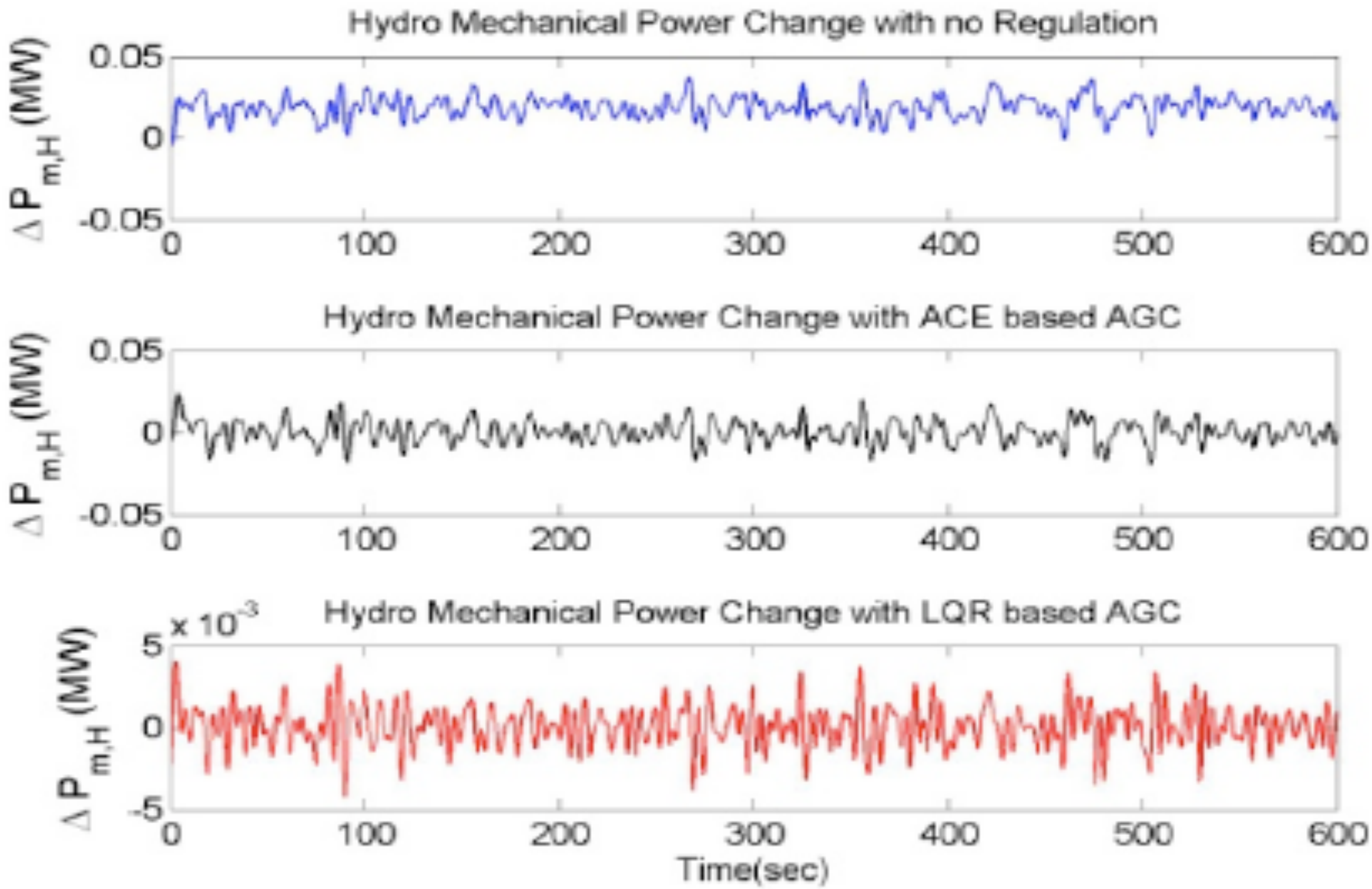


(a) AGC with Hydro Only

Value of fast flywheels



(c) AGC with Flywheel Only



(d) AGC with Diesel and Flywheel

Suggested Next Steps

- Work closely with EDA and collaborators to assess the findings in [1]; incorporate feedback prior to finalizing the report; possibility of a joint publication?
- Consider possible closer collaboration with EDA toward formalizing/adopting an IT-enabled evolution of today's industry practice to support greening of the electric energy system

  -perform extensive studies and analyze with EDA

  -design and carry out an Electricity Demand Experiment (ELDEX) to provide relevant information about electricity users' willingness to participate in greening the islands

Acknowledgments

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- [1] Greening the Azores Islands: The Key Role of Dynamic Monitoring and Decision Systems (DYMONDS), May 2011 (CMU ICTI draft report). ***Available at request starting June 1, 2011.***
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