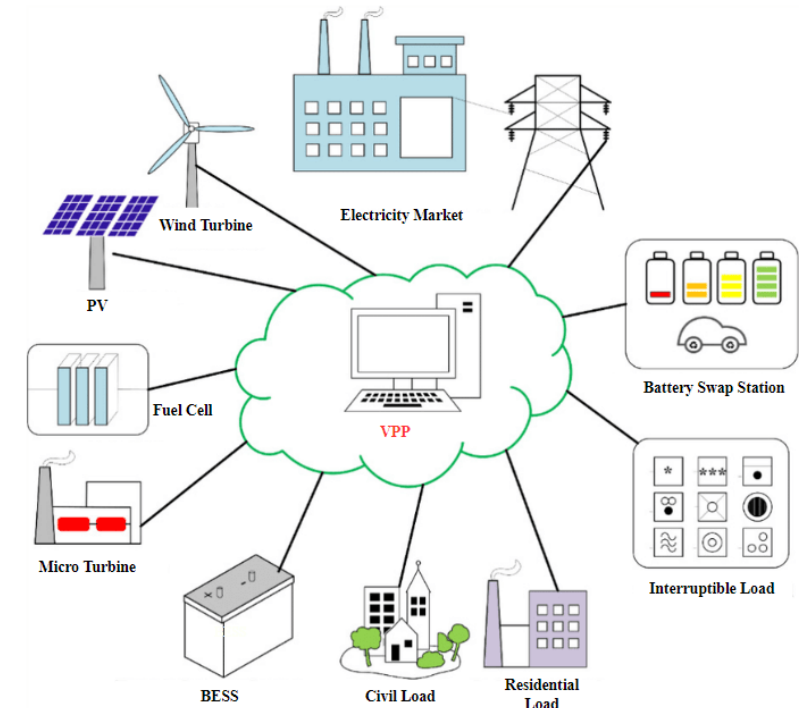


OPTIMAL OPERATION OF A SELF-REGULATING SMART DISTRIBUTION SYSTEM

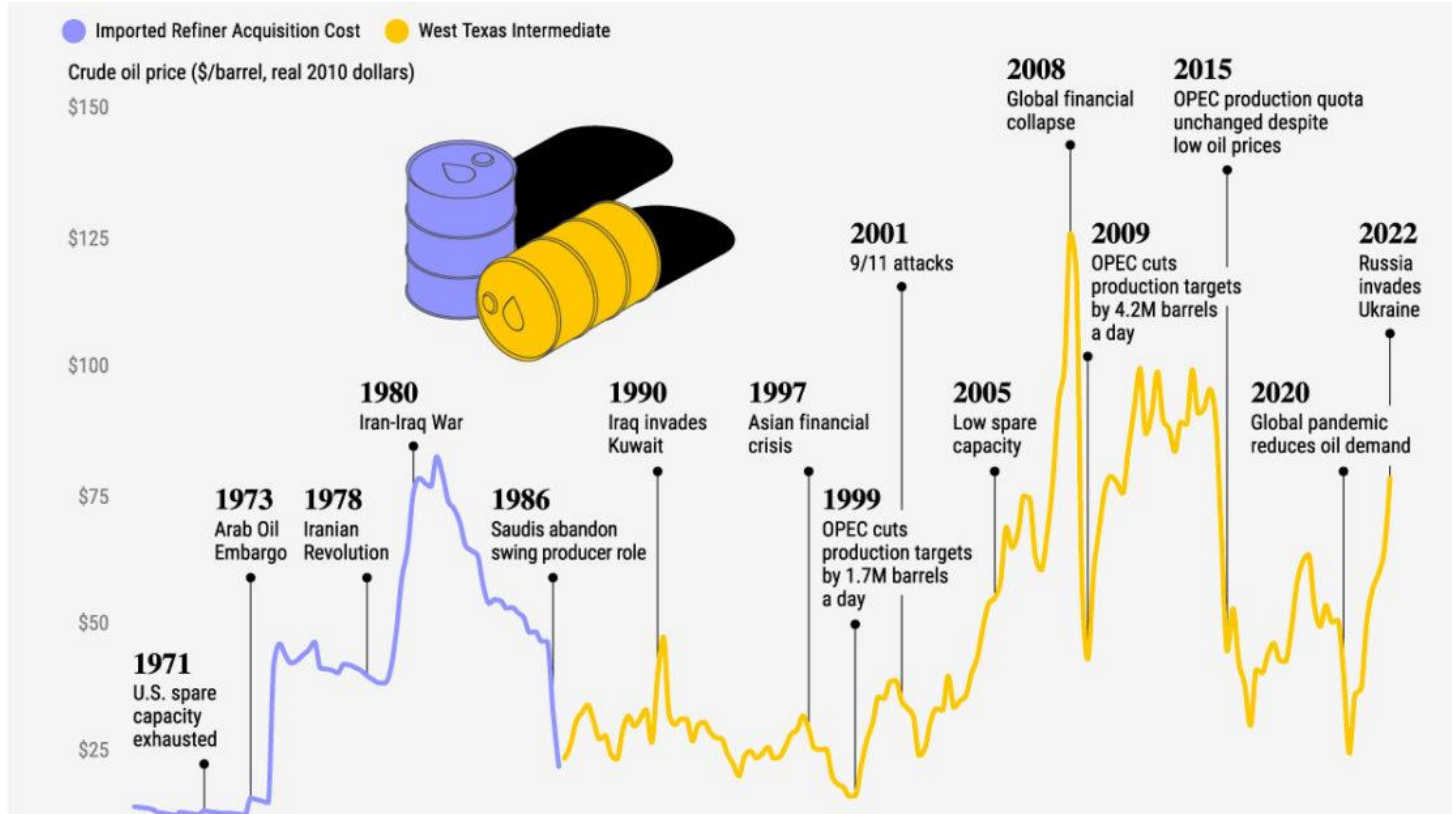
Adel Younis, PhD, P.Eng.
Mechanical Engineering Department
Australian University of Kuwait

Objectives

- Introducing innovative solutions to preserve grid reliability, economic viability, and environmental sustainability.
- Integrating renewable energy generation, loads, and corresponding DR control strategy as efficiently as possible.
- Introducing a unique hybrid optimization methodology for smart grid DR systems.

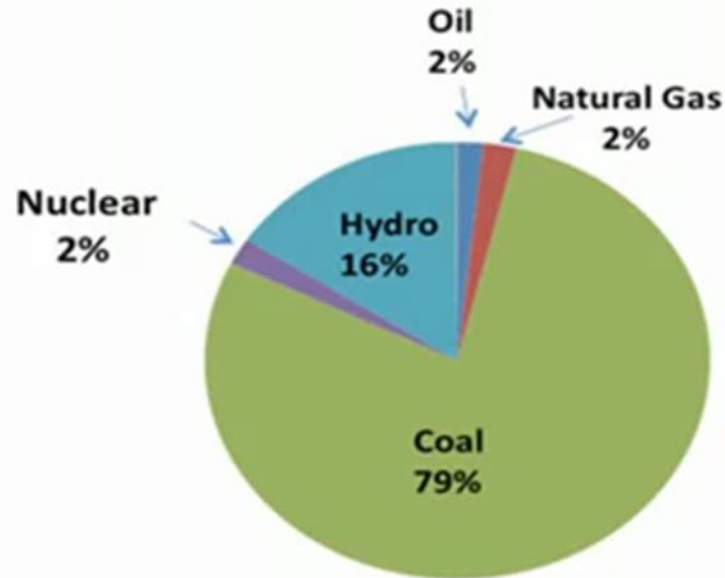


Motivations



Oil Prices

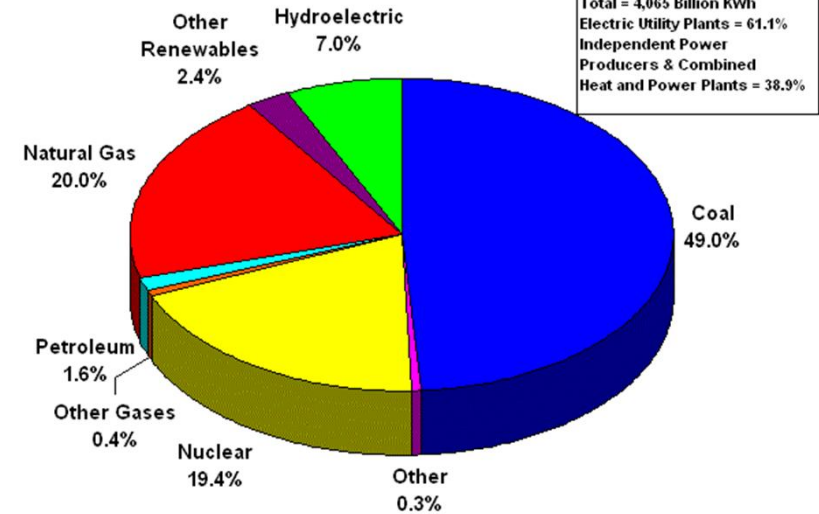
Motivations



2006

2,773 billion kilowatt hours

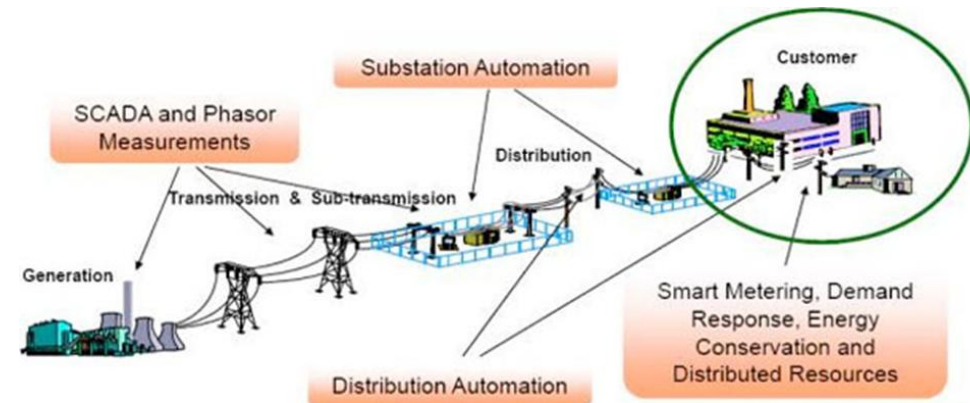
Generation Sources in China



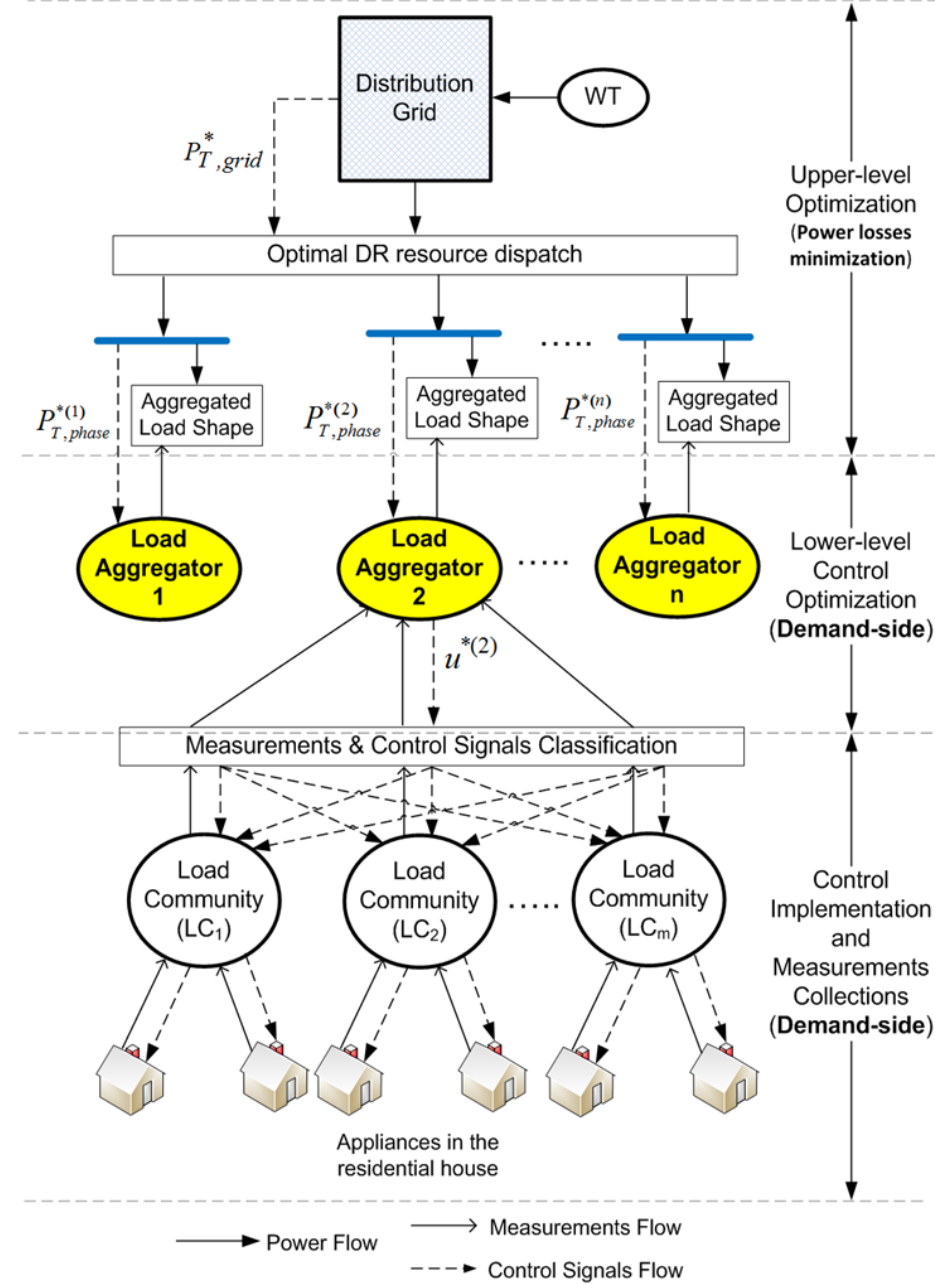
Generation Sources in US

Introduction

- DR programs are crucial for preserving the balance between supply and demand
- DR encourages consumers to adjust their electricity consumption in response to price signals or grid conditions.
- Optimal operation and management in a quasi-steady-state simulation environment require strong global optimization techniques
- Reducing hardware cycling and maintained a smooth response to changing power needs

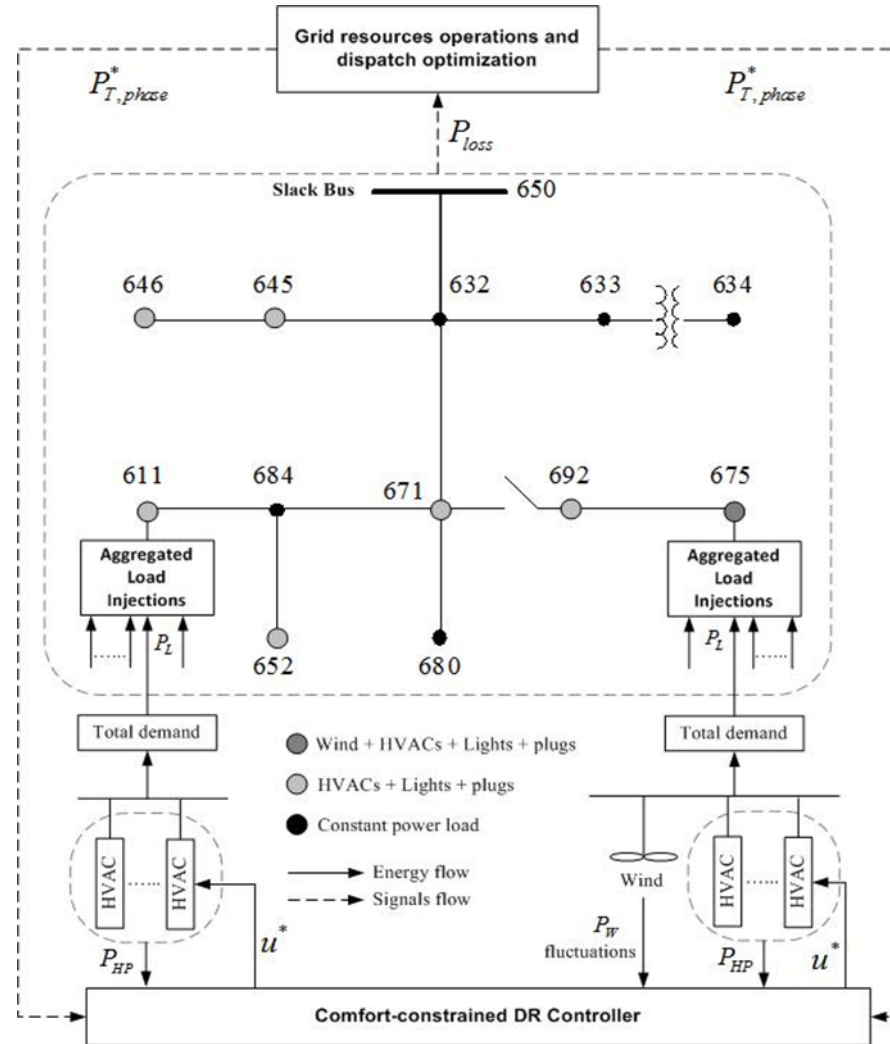


Smart Self-regulating Distribution System Modeling

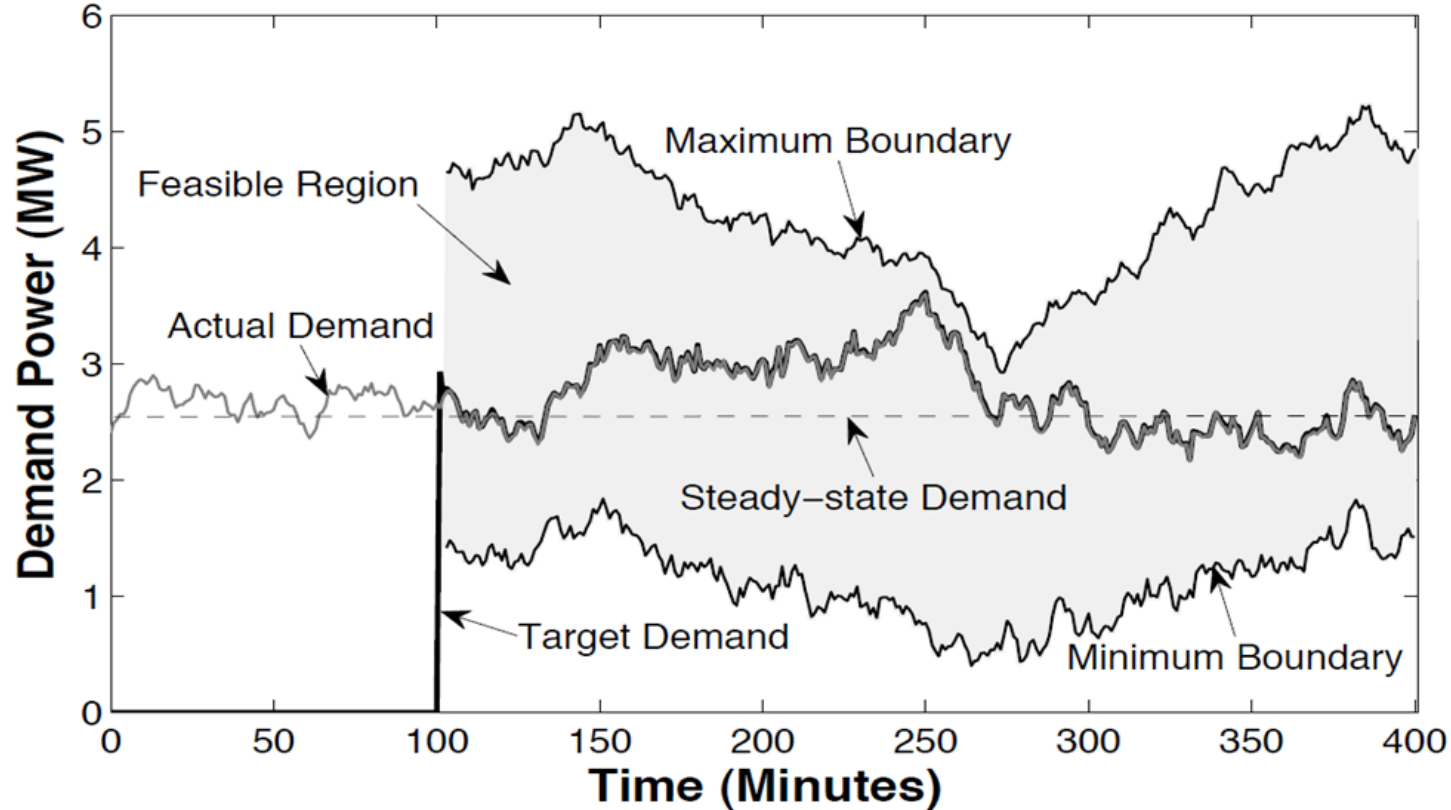


Unbalanced Distribution System

IEEE 13 distribution feeder grid schematic

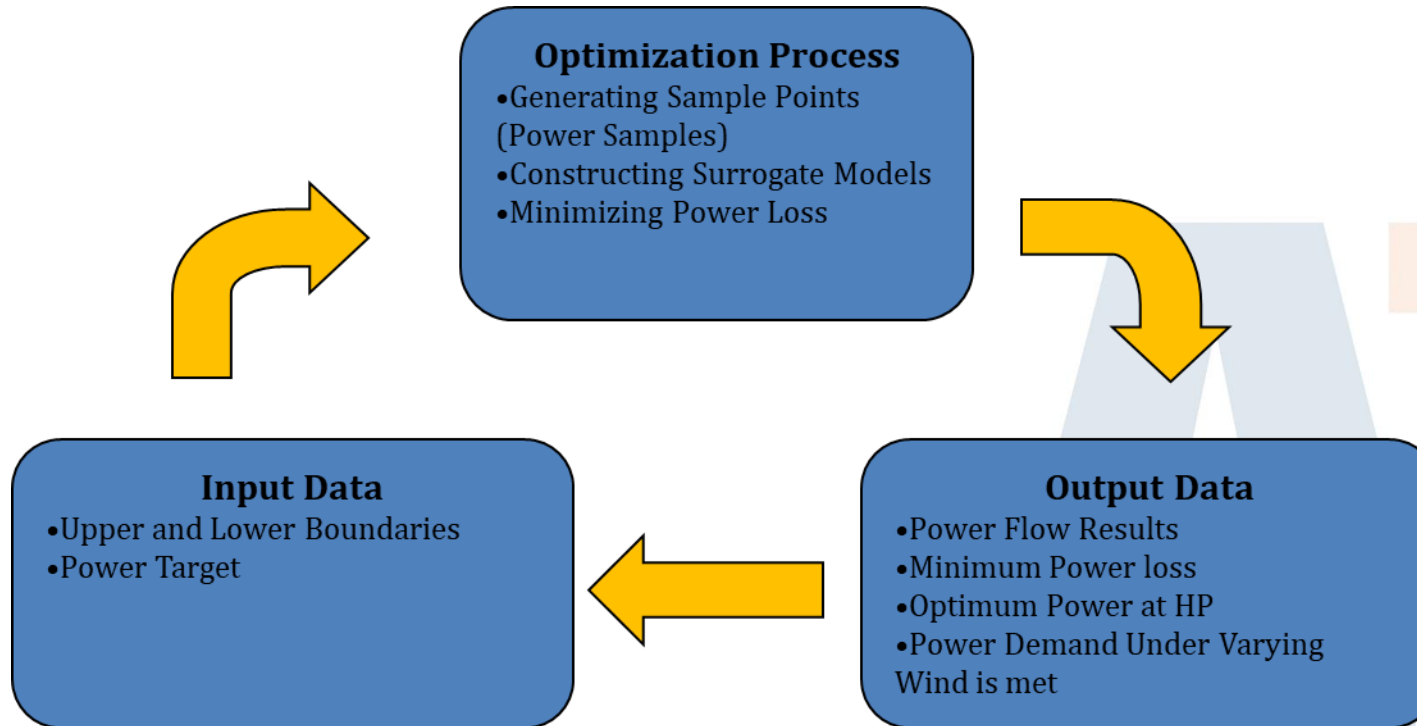


Comfort-Constrained DR Control Strategy



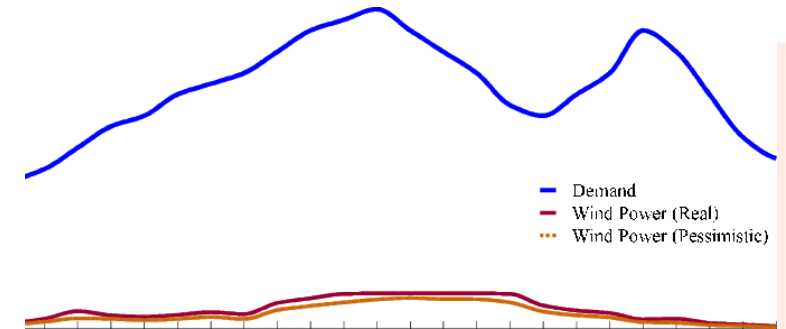
An example of a 100 heat pumps using the proposed DR control methodology, where actual demand is determined by simulating transient models coupled to the thermostats [7]

The Optimization Process



Benefits of the System

- Ability to meet power demand under varying wind.
- Higher energy efficiency.
- Minimize transmission/distribution power loss.
- Possibility to apply to a larger distribution network attached to a transmission system, and positively influence load saving, load flowing and ramping ancillary services, and GHG emissions.



Optimization Problem

$$\min P_{loss}(\mathbf{V}, \boldsymbol{\theta}, P_{HPi})$$

Subject to:

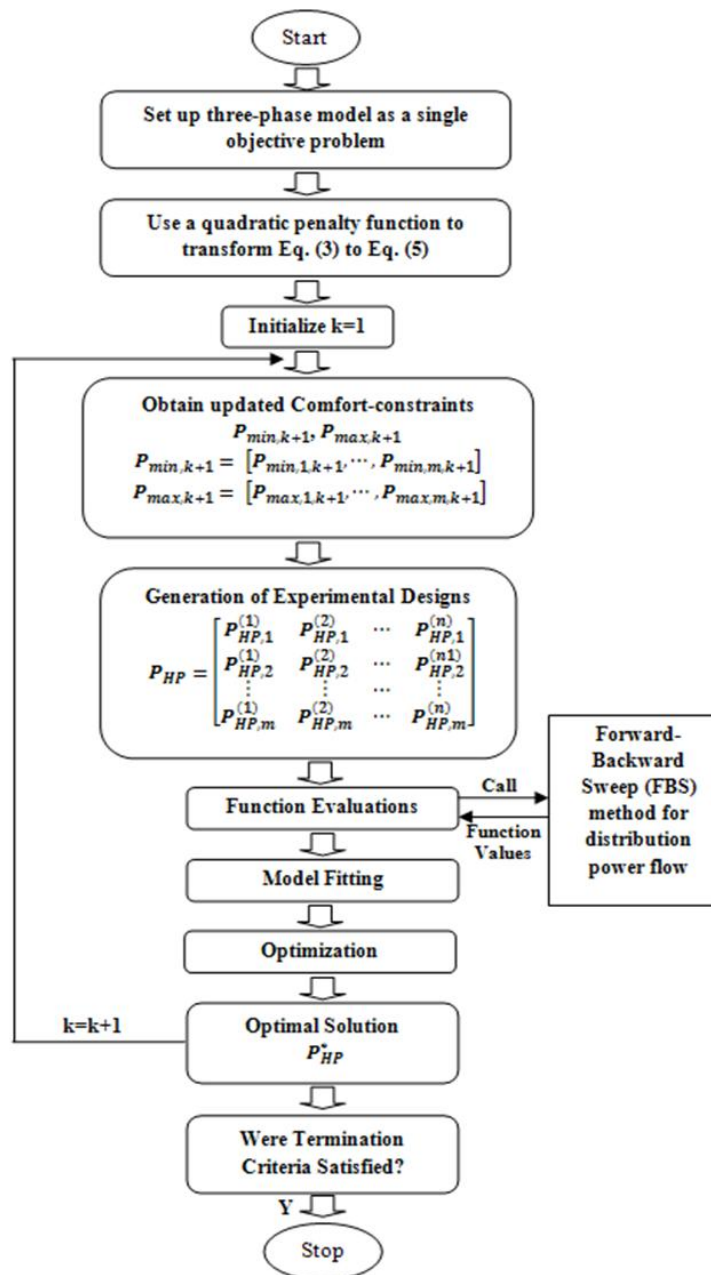
$$g(\mathbf{V}, \boldsymbol{\theta}) = 0$$

$$P_{T,grid}^* = \sum_{i=1}^N P_{HPi} + P_{other} + P_{loss}$$

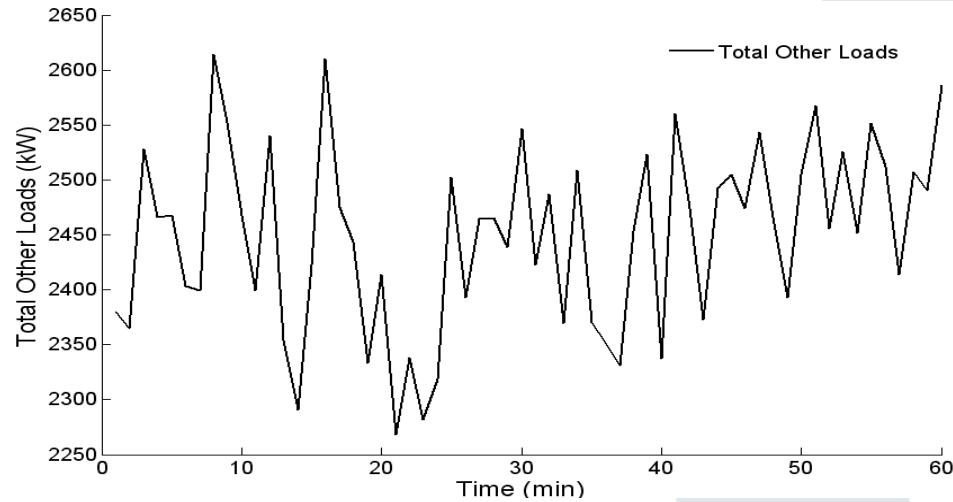
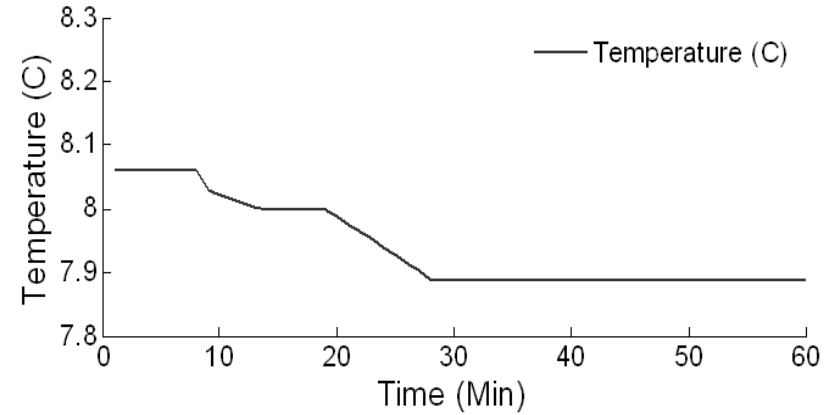
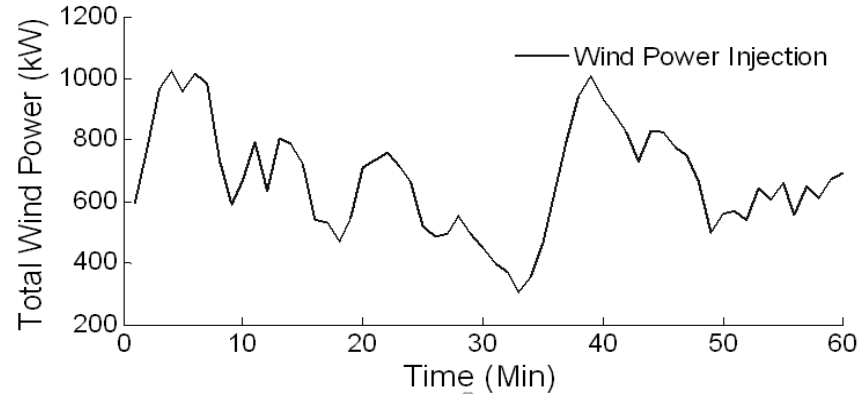
$$P_{min,k} \leq P_{HPi} \leq P_{max,k}$$

$$F = P_{loss}(\mathbf{V}, \boldsymbol{\theta}, P_{HPi}) + K \left(P_{T,grid}^* - \sum_{i=1}^N P_{HPi} + P_{other} + P_{loss} - P_w \right)^2$$

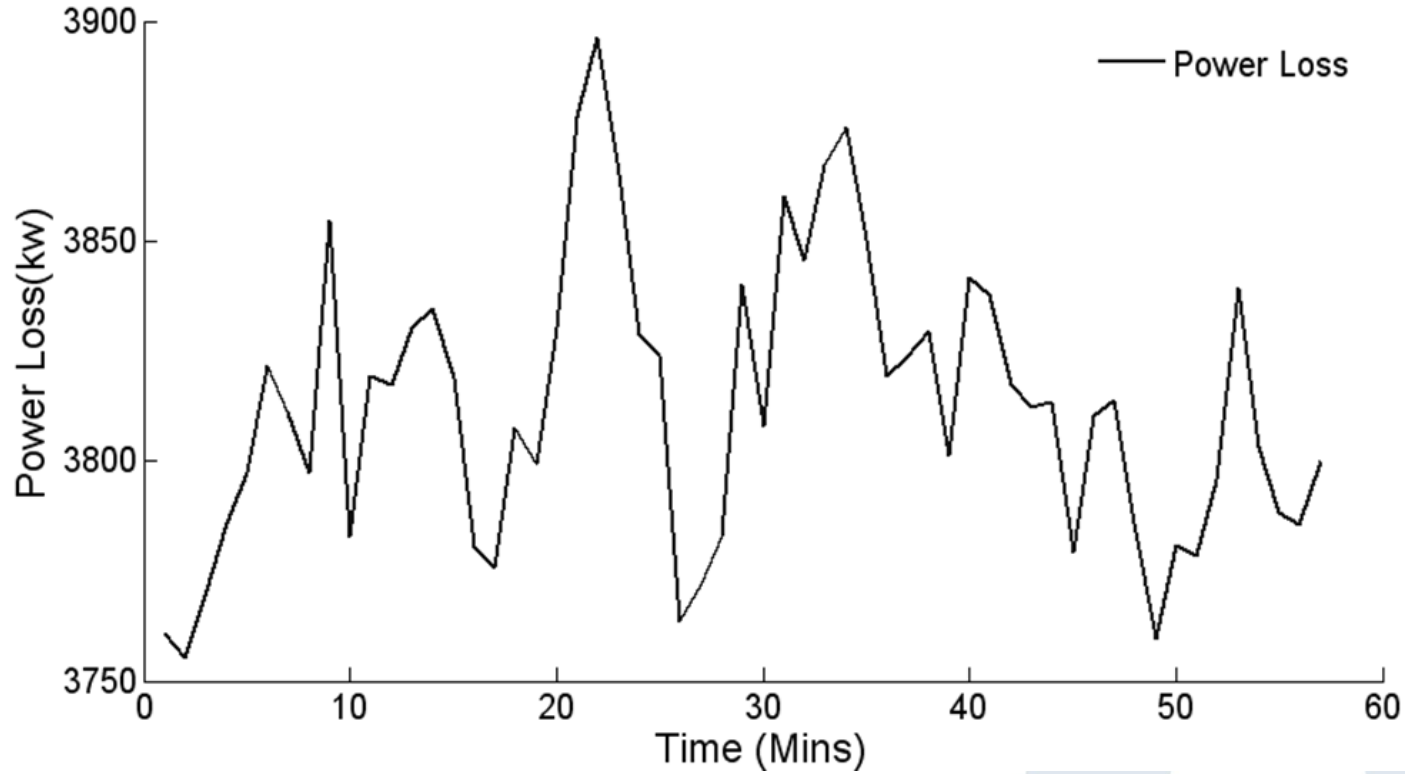
SG Metamodeling Based Optimization Flowchart



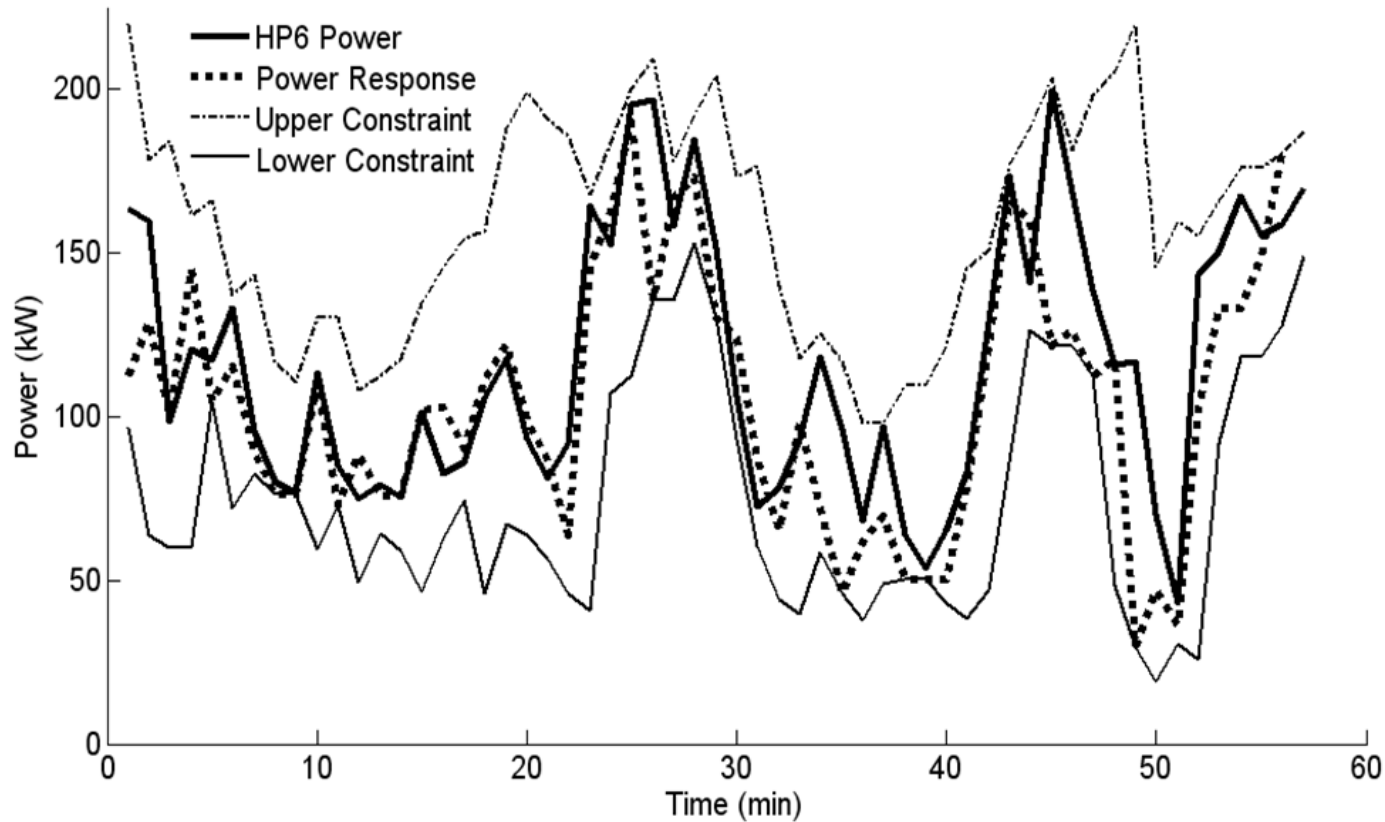
Wind, temperature and Other loads



Optimized Power Loss



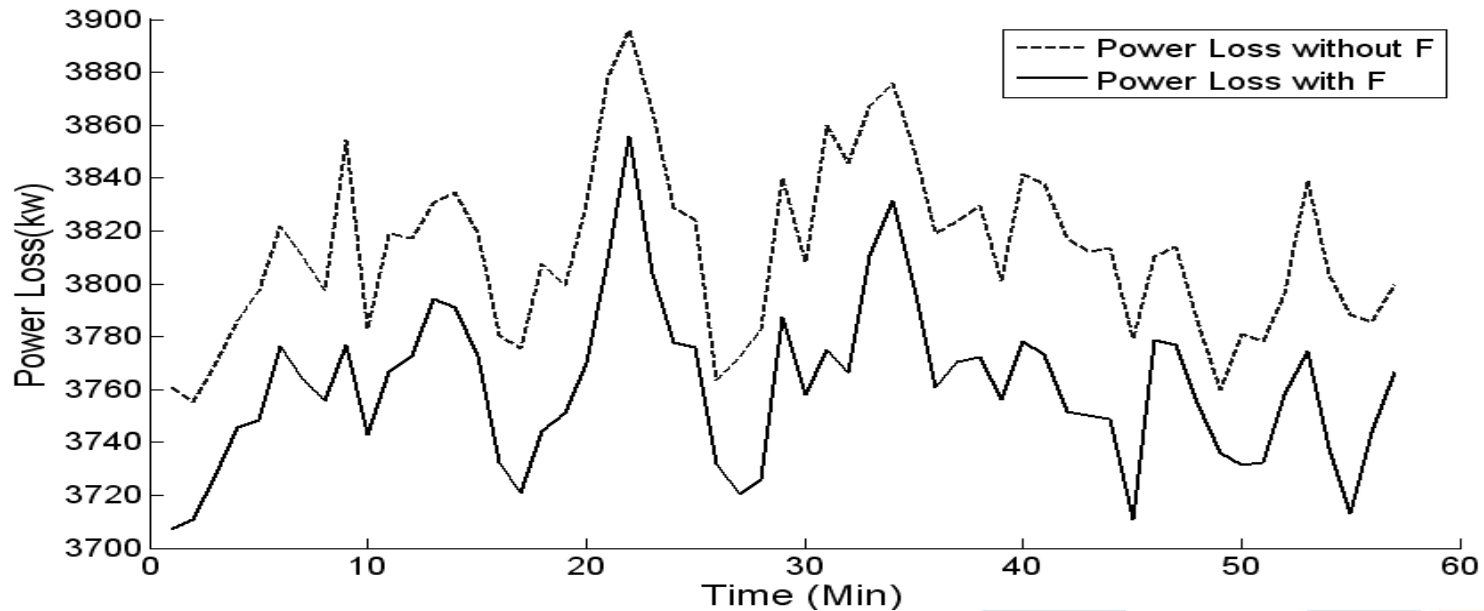
Optimized Power Loss



Typical HP optimized power response

Optimized Power Loss

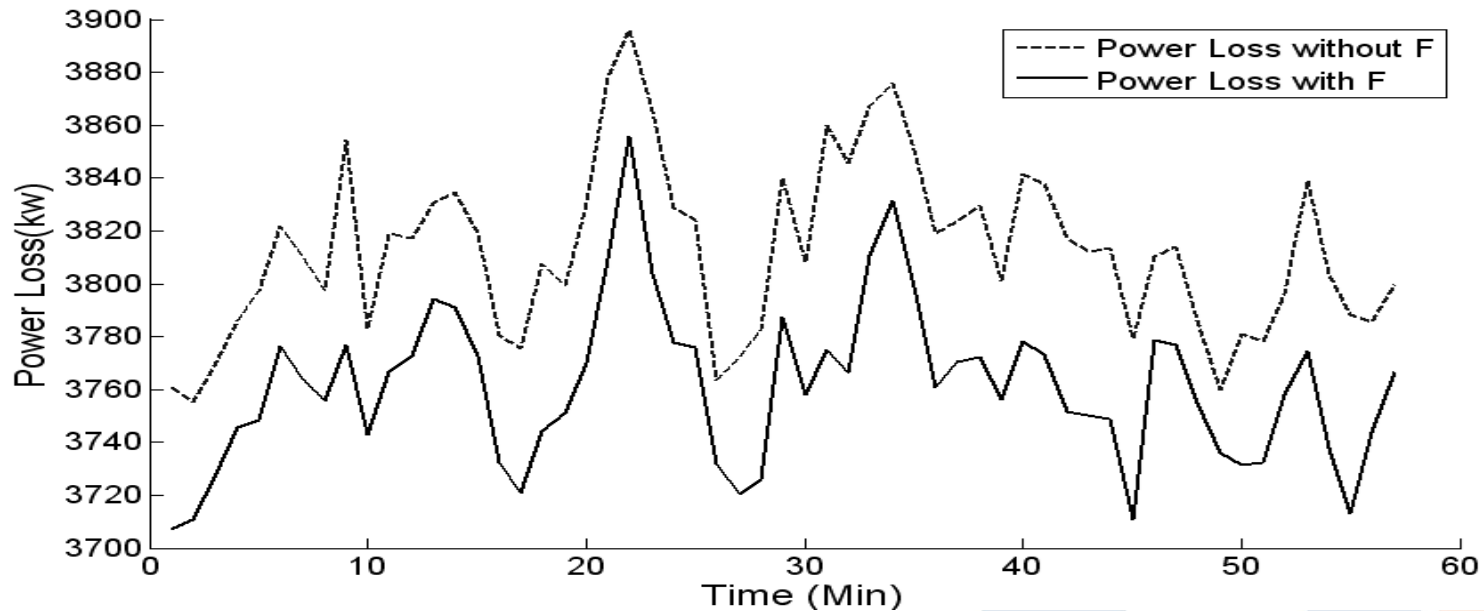
$$F = P_{loss}(\mathbf{V}, \boldsymbol{\theta}, P_{HPi}) + K \left(P_{T,grid}^* - \sum_{i=1}^N P_{HPi} + P_{other} + P_{loss} - P_w \right)^2$$



Typical power loss predictions with and without the penalty factor (K)

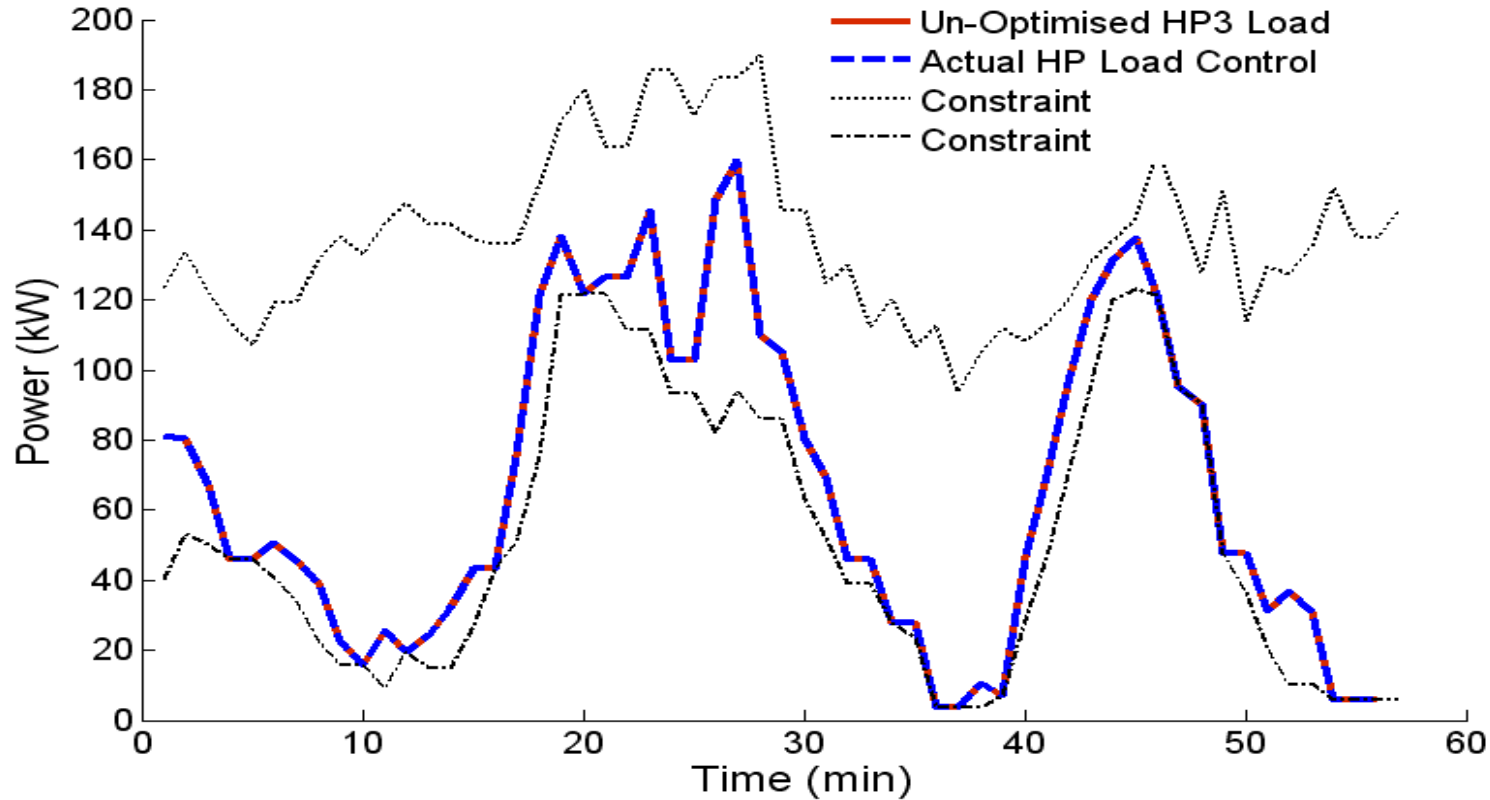
Optimized Power Loss

$$F = P_{loss}(\mathbf{V}, \boldsymbol{\theta}, P_{HPi}) + K \left(P_{T,grid}^* - \sum_{i=1}^N P_{HPi} + P_{other} + P_{loss} - P_w \right)^2$$



Typical power loss predictions with and without the penalty factor (K)

Optimized Power Loss



HP3 control and actual HP3 load (no optimization applied to HP)

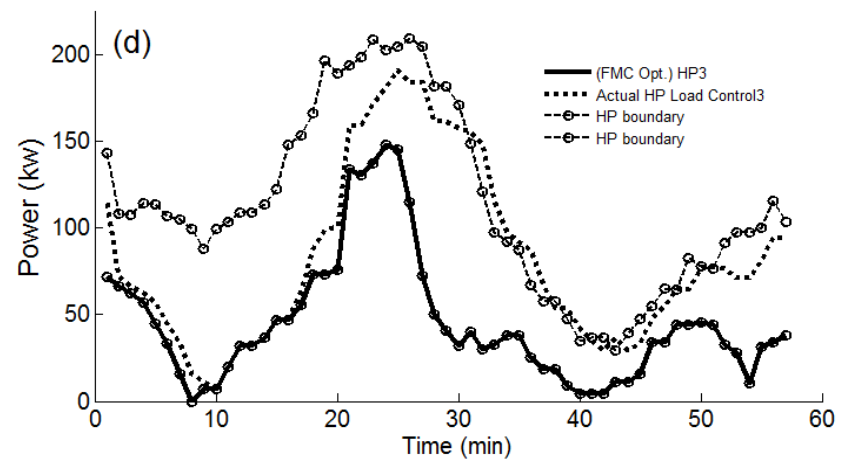
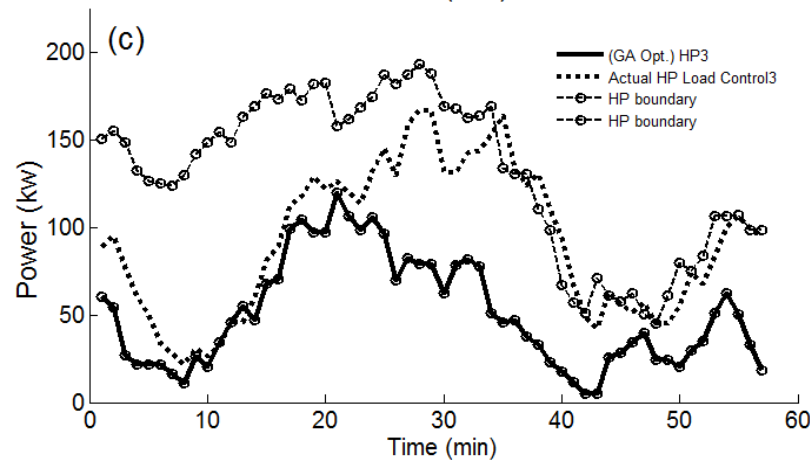
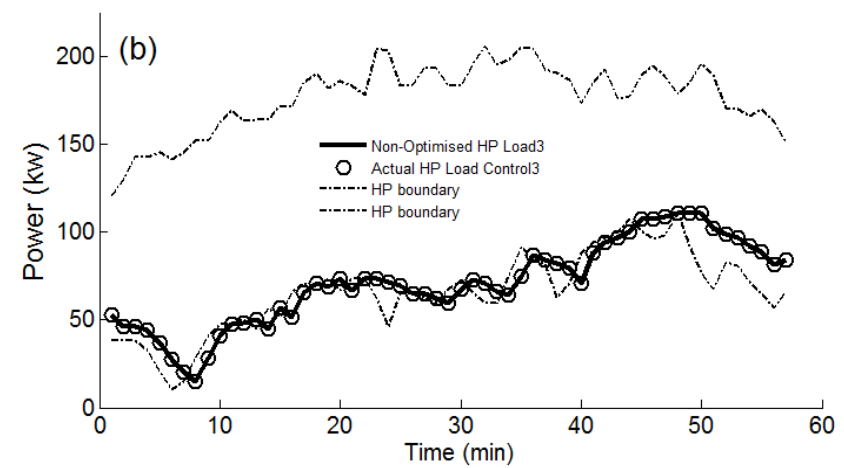
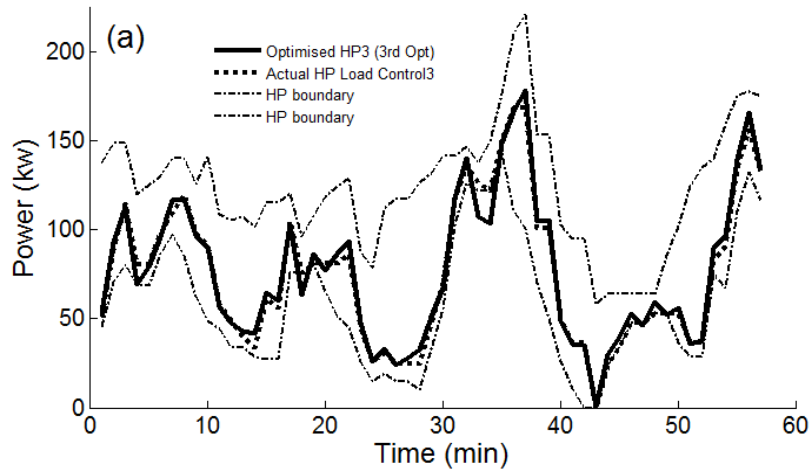
Optimum Power Loss Results at Different Penalty Factors and Sample Sizes

Penalty factor	K=5,000 (CPU= 1319.7 Sec) Sample size=20,10,5		K=5,000 (CPU= 1237.8sec) Sample size=40,20,10		K=500 (CPU=1283.0sec) Sample size=20,10,5		K=200 (CPU= 764.62sec) Sample size=10,5,3	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
<i>Power loss (Un-Opt.)</i>	3810	43.47	3811	49.62	3821	53.64	3822	37.77
<i>Power loss (Opt.)</i>	3750	37.98	3760	45.08	3767	49.85	3769	35.74
<i>Power Target</i>	7230	241	7260	230.6	7293	230.9	7261	221.8
<i>HP Sum</i>	2199	148.9	2190	137.55	2216	164.4	2196	122.8

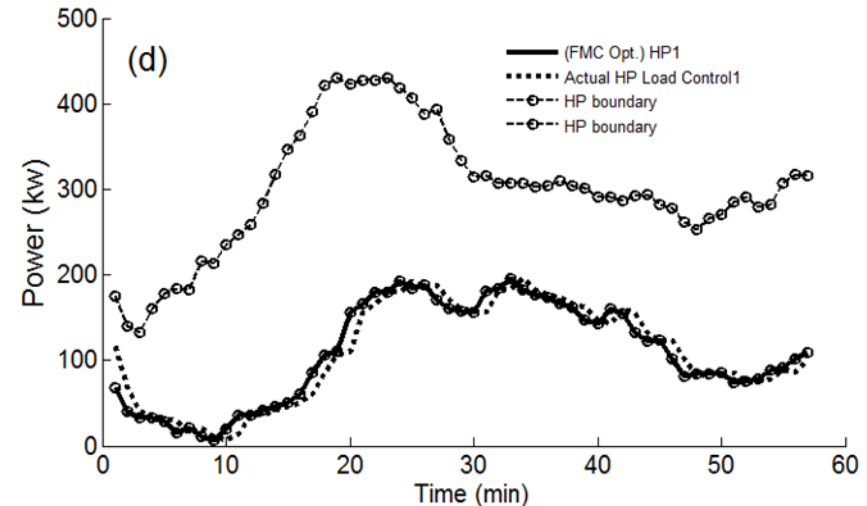
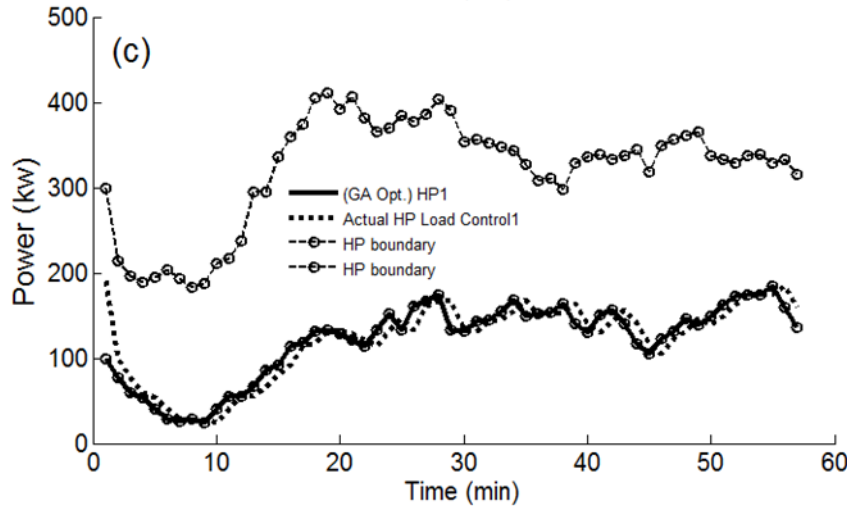
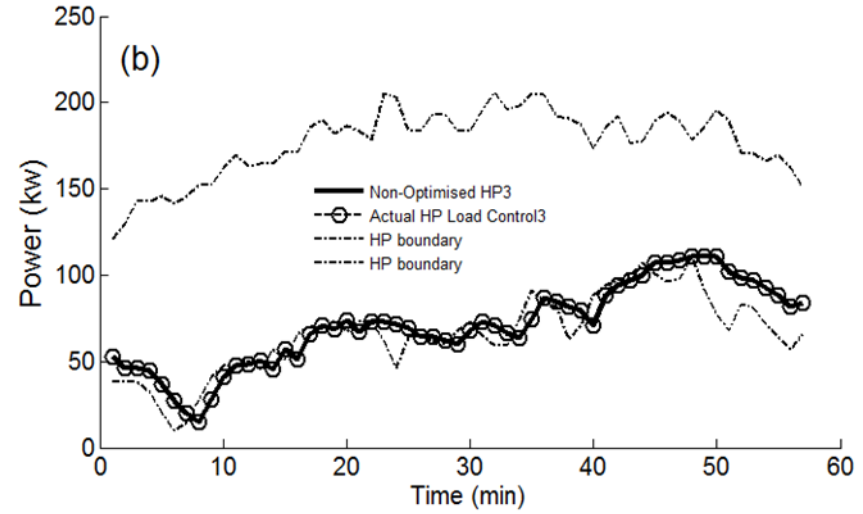
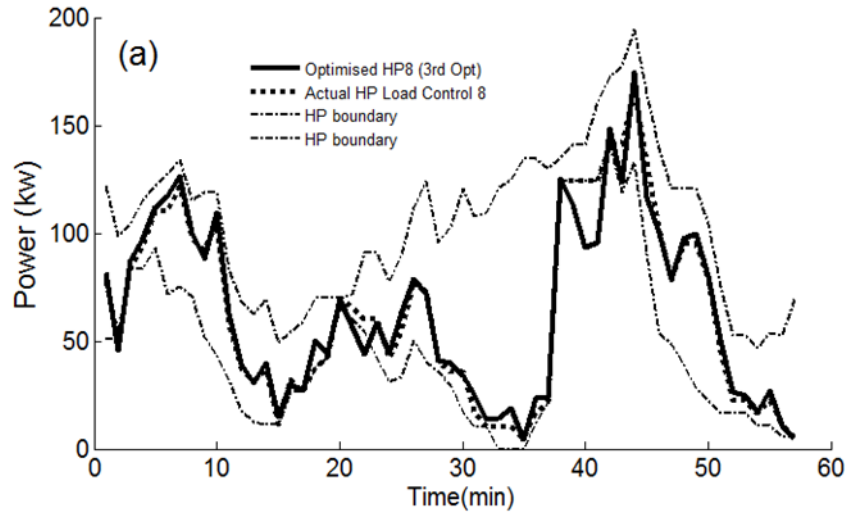
Optimization Results Comparison

Power Criteria	(Un-Optimized)		SEUMRE (Opt.)		GA (Opt.)		SQP (Opt.)	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Power loss	3795	54.6	3826	47.4	3750	76.8	3747	103.1
Power Target	6884	411.8	7542	194.9	6449	706.9	6418	1012
HP Sum	1833	385.7	2185	265.0	1450	538.2	1424	835.1
Power loss Reduction (%)	---	---	+0.8	-13.2	-1.2	+40.7	-1.3	+88.8

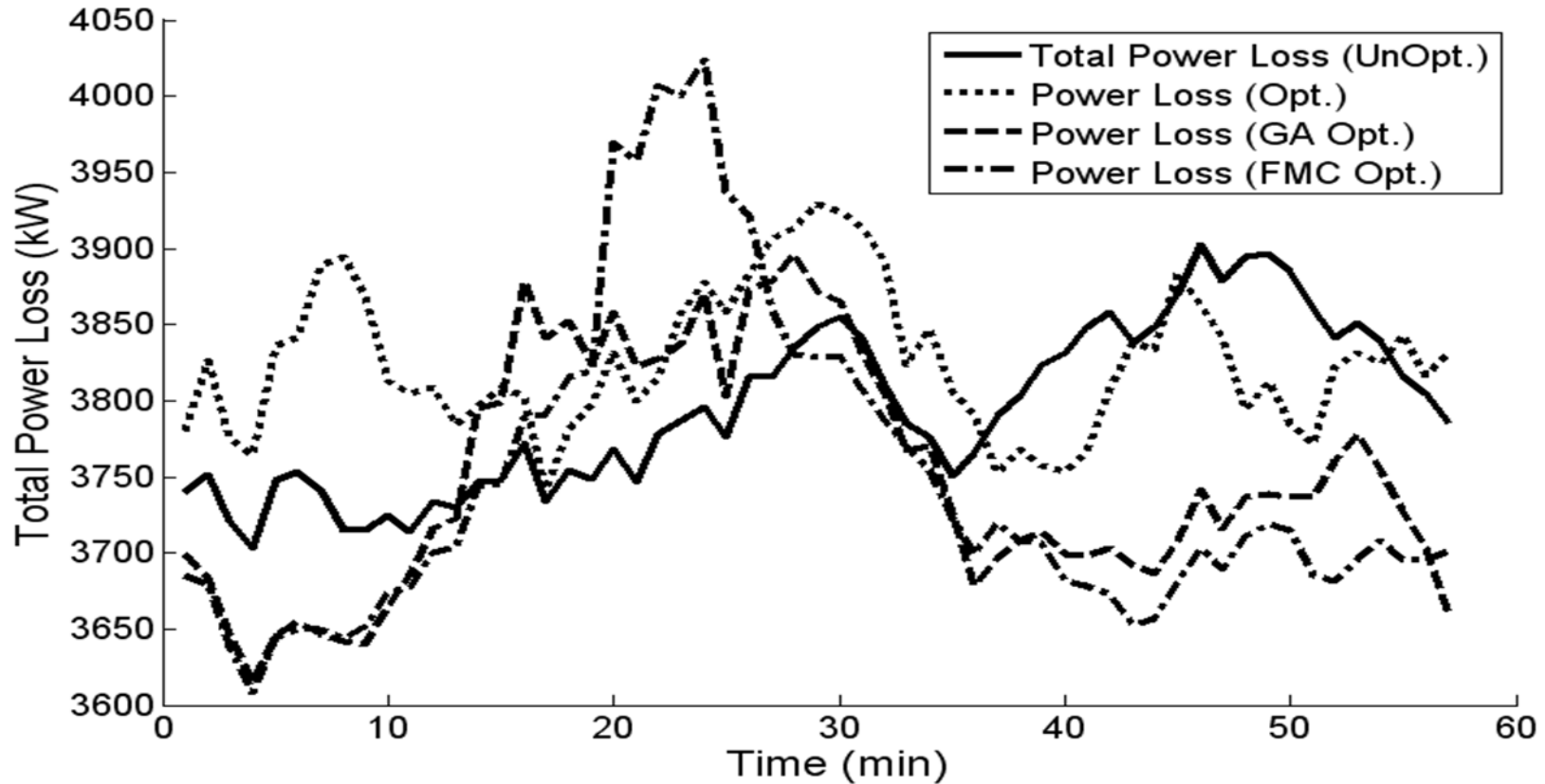
HP3 Comparative Control for each Optimization Algorithm and un-Optimized Case



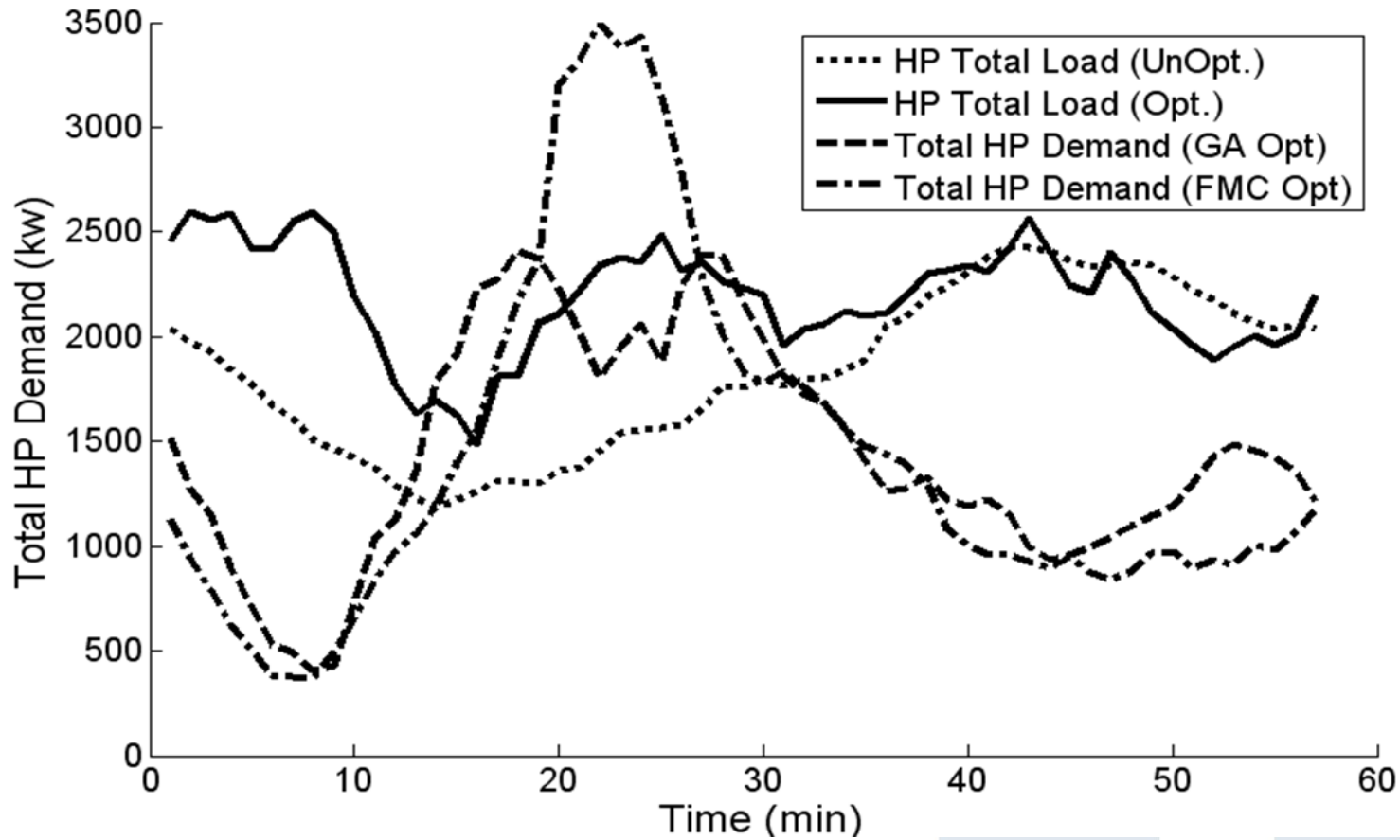
Worst case HPs for each optimization algorithms and the un-optimized case



Total power loss comparison for un-optimized and optimized cases



Total heat pump demand comparison for un-optimized and optimized cases.



Conclusions

- The advanced global optimization search tool has been integrated with a three-phase distribution power flow and heat pump control model
- The three-phase distribution power flow was modeled by a fast Forward-Backward Sweep (FBS) method which provided a confirmation that optimization choices satisfied grid electrical behavior.
- SEUMRE proves that meta modeling-based optimization algorithms are promising tools for complex engineering applications such as for SG applications.

Thank you
Questions?

