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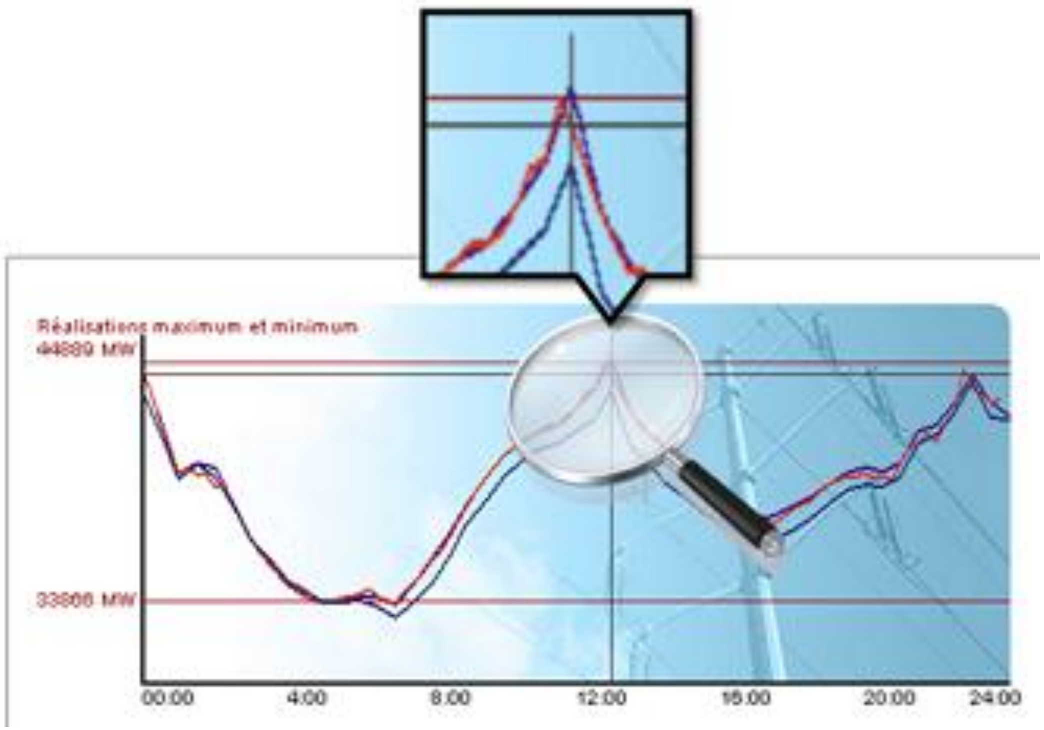
Strategies for demand load control to reduce balancing costs

Problem

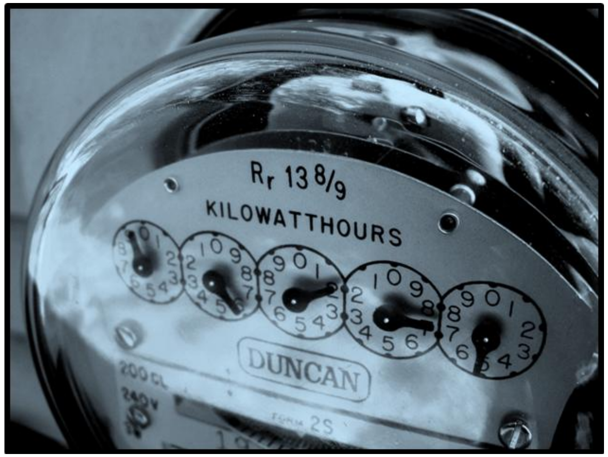
- Generation = Consumption + Losses



- Direct load control : heater, air conditioner and water heater shedding

Study Framework

1. Formulation of the problem
2. Policies for balancing mechanisms
3. Simulation results
4. Conclusion



1. Formalisation of the problem

System modeling

Assumption 1	The power system is represented as a single bus
Assumption 2	Study carried on T consecutive time instants
Assumption 3	Peak generation is limited to P_{Gpeak}^{max}
Assumption 4	Direct load control is limited to P_{DLC}^{max}

1. Formalisation of the problem

Cost functions

Assumption :

Cost functions for peak generation and DLC are known beforehand

- Peak generation cost function is a time-invariant polynomial

$$C_{Gpeak}(k) = \alpha_{Gpeak} P_{Gpeak}(k)^2 + \beta_{Gpeak} P_{Gpeak}(k)$$

- Direct load contol cost function is a time-invariant polynomial

$$C_{DLC}(k) = \alpha_{DLC} P_{DLC}(k)^2 + \beta_{DLC} P_{DLC}(k)$$

1. Formalisation of the problem

Constraints

Constraint 1

Effective demand is equal to the effective production

$$P_{Gbase}(k)+P_{Gpeak}(k)+P_{DLC}(k)-P_D(k)=0$$

Constraint 2

The DLC selected at time instant k, cannot be used at the next time instant k+1

$$P_{DLC}(k)\leq P_{DLC}^{\max}-P_{DLC}(k-1)$$

Constraint 3

A payback effect of 100% is considered

Constraint 4

The payback effect occurs during the two next time instants

$$P_D(k)=\overline{P_D}(k)+\chi\cdot P_{DLC}(k-1)+(1-\chi)\cdot P_{DLC}(k-2)$$

Constraint 5

70% of the payback effect on time instant k+1

30% of the payback effect on time instant k+2

2. Policies

Policy 1

Minimization of the balancing cost for the entire period

the TSO minimizes balancing costs for the entire period.

Optimization problem:

$$\min_{P_{Gbase}(k), P_{Gpeak}(k), P_{DLC}(k), \forall k \in [1,N]} \sum_{k=1}^{N} [C_{Gpeak}(k) + C_{DLC}(k)]$$

Subject to :

$$P_{Gbase}(k) + P_{Gpeak}(k) + P_{DLC}(k) - P_D(k) = 0$$

$$P_D(k) = \overline{P_D}(k) + \chi \cdot P_{DLC}(k-1) + (1-\chi) \cdot P_{DLC}(k-2)$$

$$P_{DLC}(k) \leq P_{DLC}^{\max} - P_{DLC}(k-1)$$

2. Policies

Policy 2

Successive independent merit orders

At every instant k, the TSO minimizes the balancing cost regardless of the consequences at instants k+1, k+2, etc

Optimisation problem:

$$\min_{P_{Gbase}(k), P_{Gpeak}(k), P_{DLC}(k)} \left[C_{Gpeak}(k) + C_{DLC}(k) \right]$$

Subject to :

$$P_{Gbase}(k) + P_{Gpeak}(k) + P_{DLC}(k) - P_D(k) = 0$$

$$P_D(k) = \overline{P_D}(k) + \chi \cdot P_{DLC}(k-1) + (1-\chi) \cdot P_{DLC}(k-2)$$

$$P_{DLC}(k) \leq P_{DLC}^{\max} - P_{DLC}(k-1)$$

2. Policies

Policy 3

Successive predictive merit orders

Proposed regulation : At every time instant *n*, the TSO selects the program changes that would be applied if it were to minimize the balancing costs for the next three time instants

Optimization problem : $$\min_{P_{Gbase}(k), P_{Gpeak}(k), P_{DLC}(k), \forall k \in [n, n+2]} \sum_{k=n}^{n+2} [C_{Gpeak}(k) + C_{DLC}(k)]$$

Subject to :

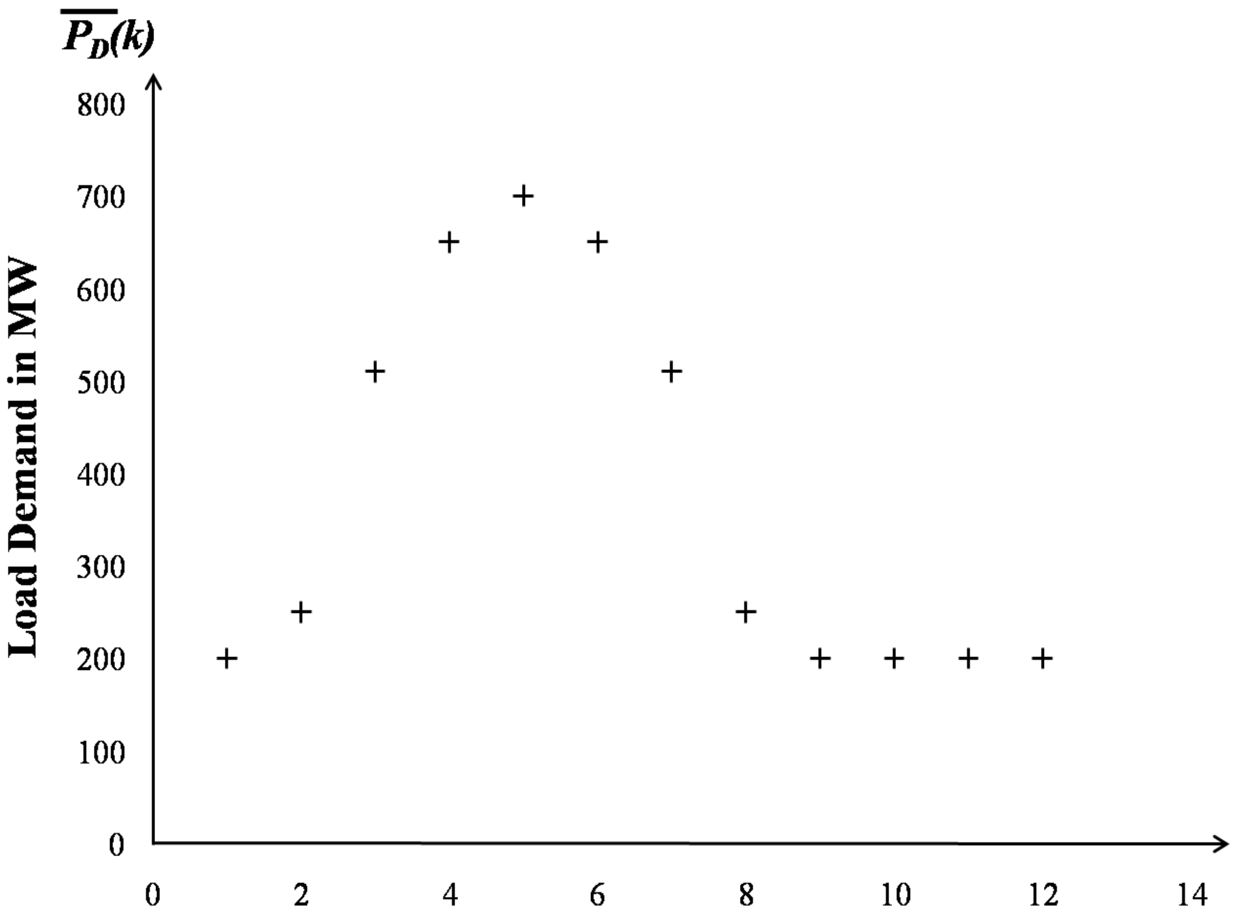
$$P_{Gbase}(k) + P_{Gpeak}(k) + P_{DLC}(k) - P_D(k) = 0$$

$$P_D(k) = \overline{P_D}(k) + \chi \cdot P_{DLC}(k-1) + (1-\chi) \cdot P_{DLC}(k-2)$$

$$P_{DLC}(k) \le P_{DLC}^{\max} - P_{DLC}(k-1)$$

3. Simulation results

Benchmark system



$P_{Gbase}^{max} = 500$ MW

$P_{Gpeak}^{max} = 200$ MW

$P_{GDLC}^{max} = 140$ MW

$T = 12$ *time instants*

$\alpha_{Gpeak} = 1€/MW^2$

$\alpha_{GDLC} = 0{,}75€/MW^2$

$\beta_{Gpeak} = 80€/MW$

$\beta_{GDLC} = 80€/MW$

3. Simulation results

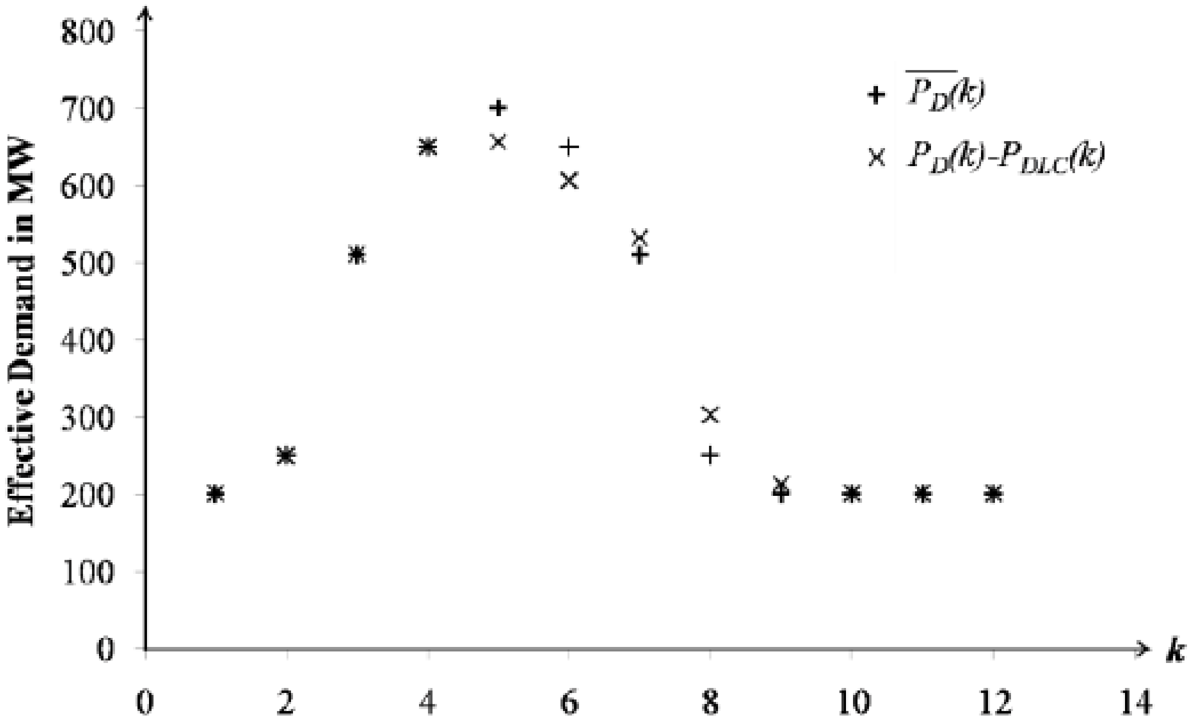
Minimisation of the balancing cost for the entire period

The total cost with Direct Load Control optimized on the entire period :

$$C_T^{OPT} = 115.58 \text{ k€}$$

The total cost without direct load control :

$$C_T^{noDLC} = 126.80 \text{ k€}$$



3. Simulation Results

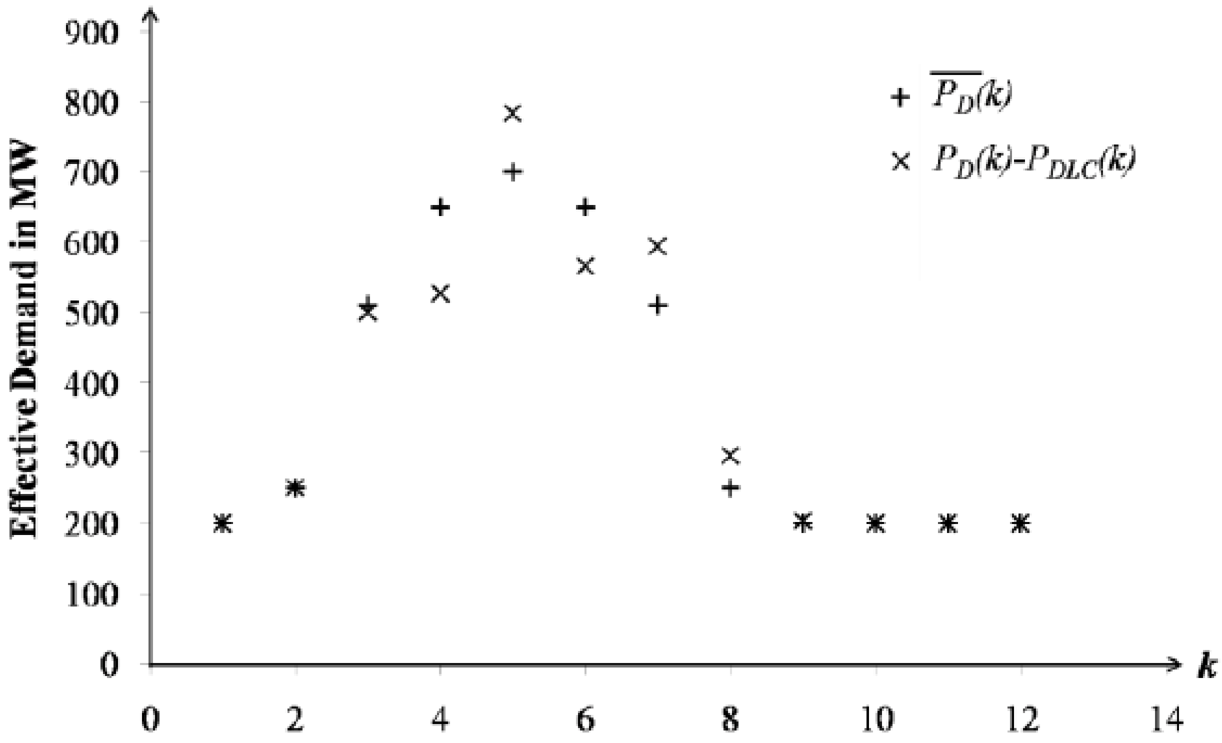
Successive independant merit orders

The total cost with Independant Merit Orders :

$$C_T^{IMO} = 181.07 \text{ k€}$$

The total cost without direct load control :

$$C_T^{noDLC} = 126.80 \text{ k€}$$



3. Simulation Results

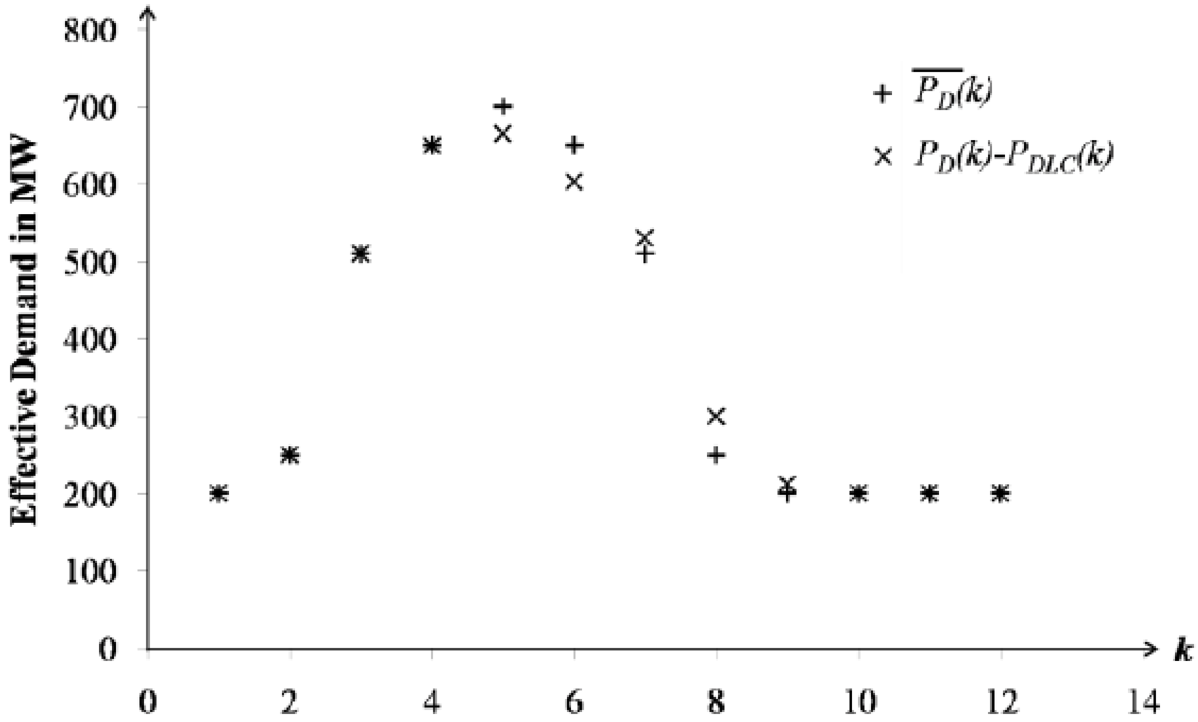
Successive predictive merit orders

The total cost with successive predictive merit orders :

$$C_T^{PMO} = 115.74 \text{ k€}$$

The total cost without direct load control :

$$C_T^{noDLC} = 126.80 \text{ k€}$$



4. Discussion

Formalization limitations

- Payback effect rate 100% : worst case

- Payback effect occuring during the next 2 time instants

- Payback effect distribution

$$P_D(k) = \overline{P_D}(k) + \chi \cdot P_{DLC}(k-1) + (1-\chi) \cdot P_{DLC}(k-2)$$

4. Discussion

Cost functions limitations

- Cost functions are considered constant with time, and determined by polynomial functions of power

➡ Model close to reality for generators
But approximate for demand load control
(zero marginal cost)

Conclusion and further study

- Formalization of DLC as a discrete-time optimal control problem
- 3 formulations of the optimization problems
- Simulations show that actual practices may lead to significant extra-costs for balancing (payback effect)
- Including the predicted behavior of the system in the decision-making process could lead to close to optimal performance while maintaining the principle of a merit order

Further study

- Consider the bidding strategy of demand load control suppliers

The program would then elect the DLC offers to maximize the DLC supplier's income

Thank you !

Question ?

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