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Knowledge Engineering and Decision Support Research Group

isep Instituto Superior de Engenharia do Porto

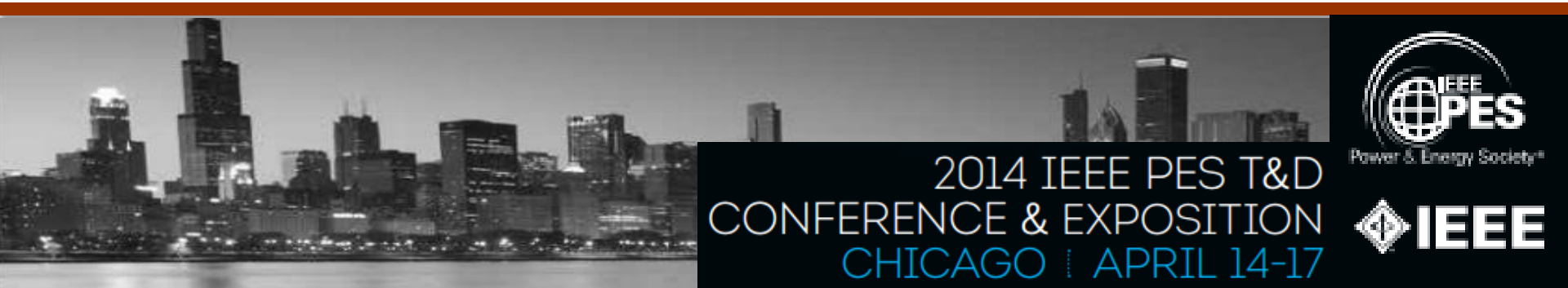
INSTITUTO POLITÉCNICO DO PORTO

# Modified Particle Swarm Optimization Applied to Integrated Demand Response and DG Resources Scheduling


pnfar@isep.ipp.pt
pnsfaria@gmail.com

**Pedro Faria**, João Soares, Zita Vale, Hugo Morais, Tiago Sousa

GECAD – Knowledge Engineering and Decision Support Research Group
Polytechnic of Porto
Portugal

# Presentation outline

- ✓ **Introduction / objectives**
- ✓ **Developed methodology**
- ✓ **Case study**
- ✓ **Conclusions**



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# Introduction

- ✓ Objectives and motivation
  - Demand Response (DR) and Distributed Generation (DG) in smart grids.
  - Intensive use of Distributed Energy Resources (DER) and technical and contractual constraints

    large-scale non linear optimization problems
  - Particle Swarm Optimization (PSO) for a Virtual Power Player (VPP) operation costs minimization
  - 937 bus distribution grid, 20310 consumers, 548 DG
  - Compare deterministic, PSO without mutation, and Evolutionary PSO.



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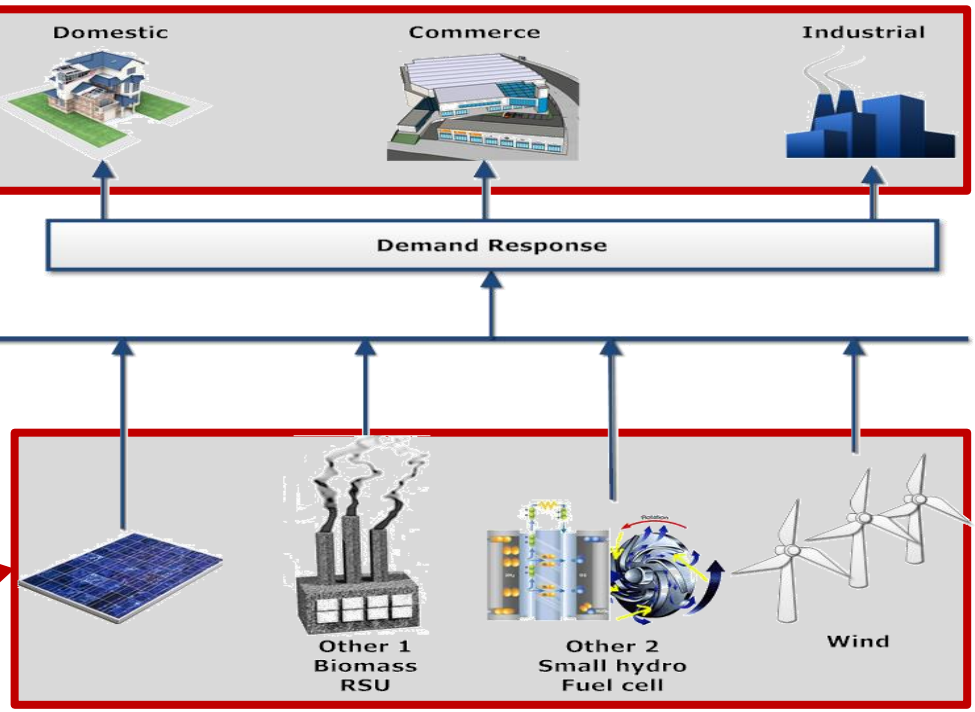
# Introduction

- ✓ VPP operation

**Customers response to DR programs**

**Participate in the market to sell or buy energy**

**Electricity generation based on several technologies**



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# Resources dispatch methodology

***Objective Function***

*Minimize*

$$C = \sum_{t=1}^{T} \left[ \begin{array}{l} \sum_{DG=1}^{N_{DG}} \left( \begin{array}{l} c_{A(DG,t)} \times X_{DG(DG,t)} + c_{B(DG,t)} \times P_{DG(DG,t)} \\ + c_{C(DG,t)} \times P^2_{DG(DG,t)} + P_{EAP(DG,t)} \times c_{EAP(DG,t)} \end{array} \right) \\ + \sum_{SP=1}^{N_{SP}} c_{SP(SP,t)} \times P_{SP(SP,t)} \\ + \sum_{L=1}^{N_L} \left( \begin{array}{l} c_{RED_A(L,t)} \times P_{RED_A(L,t)} + c_{RED_B(L,t)} \times P_{RED_B(L,t)} \\ + c_{RED_C(L,t)} \times P_{RED_C(L,t)} + P_{NSD(L,t)} \times c_{NSD(L,t)} \end{array} \right) \\ + \sum_{S=1}^{N_S} \left( c_{Dch(S,t)} \times P_{Dch(S,t)} - c_{Ch(S,t)} \times P_{Ch(S,t)} \right) \end{array} \right]$$

Quadratic DG costs

DG

EAP

Number of periods

Suppliers

Operation cost

DR

NSD

Storage charge and discharge

Cost

Power



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# Resources dispatch methodology

## *Balance equations*

$$\sum_{DG=1}^{N_{DG}^{i}}\left(P_{DG(DG,t)}^{i}-P_{EAP(DG,t)}^{i}\right)+\sum_{SP=1}^{N_{SP}^{i}}P_{SP(SP,t)}^{i}+\sum_{S=1}^{N_{S}^{i}}\left(P_{Dch(S,t)}^{i}-P_{Ch(S,t)}^{i}\right)-$$

$$\sum_{L=1}^{N_{L}^{i}}\left(P_{Load(L,t)}^{i}-P_{DR_A(L,t)}^{i}-P_{DR_B(L,t)}^{i}-P_{NSD(L,t)}^{i}\right)=$$

$$\sum_{j=1}^{N_B}V_{i(t)}\times V_{j(t)}\left(G_{ij}\cos\left(\theta_{i(t)}-\theta_{j(t)}\right)+B_{ij}\sin\left(\theta_{i(t)}-\theta_{j(t)}\right)\right)$$

$$\forall t\in\{1,..,T\};\ \forall i\in\{1,..,N_B\}$$

Active power balance

In each period and each bus

$$\sum_{DG=1}^{N_{DG}^{i}}Q_{DG(DG,t)}^{i}+\sum_{SP=1}^{N_{SP}^{i}}Q_{SP(SP,t)}^{i}-\sum_{L=1}^{N_{L}^{i}}Q_{Load(L,t)}^{i}=$$

$$\sum_{j=1}^{N_B}V_{i(t)}\times V_{j(t)}\left(G_{ij}\sin\left(\theta_{i(t)}-\theta_{j(t)}\right)-B_{ij}\cos\left(\theta_{i(t)}-\theta_{j(t)}\right)\right)$$

$$\forall t\in\{1,..,T\};\ \forall i\in\{1,..,N_B\}$$

Reactive power balance



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# Resources dispatch methodology

***Constraints***

- ✓ Bus voltage and line capacity

$$\left|\overline{U_{i(t)}} \times \left[\overline{y_{ij}} \times \left(\overline{U_{i(t)}} - \overline{U_{j(t)}}\right) + \overline{y_{sh_i}} \times \overline{U_{j(t)}}\right]^*\right| \leq S_{Lk}^{max}$$

$$\forall t \in \{1,..,T\}; \forall i,j \in \{1,..,N_B\}; i \neq j; \forall k \in \{1,..,N_k\}$$

$$V_i^{min} \leq V_{i(t)} \leq V_i^{max}$$

$$\theta_i^{min} \leq \theta_{i(t)} \leq \theta_i^{max}$$

$$\forall t \in \{1,..,T\}; \forall i \in \{1,..,N_B\}$$

- ✓ Resources maximum capacity

$$P_{DGMin(DG,t)} \times X_{DG(DG,t)} \leq P_{DG(DG,t)} \leq P_{DGMax(DG,t)} \times X_{DG(DG,t)}$$

$$Q_{DGMin(DG,t)} \times X_{DG(DG,t)} \leq Q_{DG(DG,t)} \leq Q_{DGMax(DG,t)} \times X_{DG(DG,t)}$$

$$\forall t \in \{1,...,T\}; \forall DG \in \{1,...,N_{DG}\}$$

DG

DR

$$P_{RED_A(L,t)} \leq P_{MaxRED_A(L,t)}$$

$$P_{RED_B(L,t)} \leq P_{MaxRED_B(L,t)}$$

$$P_{RED_C(L,t)} \leq P_{MaxRED_C(L,t)}$$

$$\forall t \in \{1,...,T\}; \forall L \in \{1,...,N_L\}$$

Suppliers

$$P_{SP(SP,t)} \leq P_{SPMax(SP,t)}$$

$$Q_{SP(SP,t)} \leq Q_{SPMax(SP,t)}$$

$$\forall t \in \{1,...,T\}; \forall SP \in \{1,...,N_{SP}\}$$

- ✓ Storage constraints

Zita Vale, Hugo Morais, Pedro Faria, Carlos Ramos, "Distribution System Operation Supported by Contextual Energy Resource Management Based on Intelligent SCADA", Renewable Energy, vol. 52,pp. 143-153, April, 2013.



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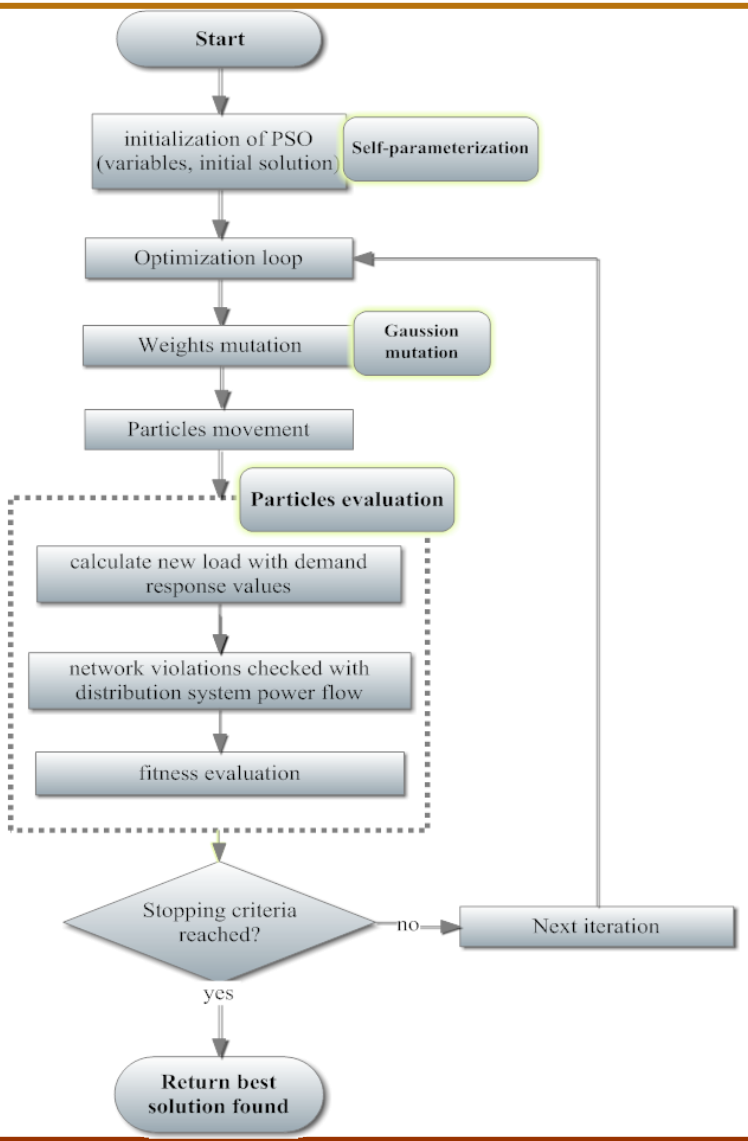
# Resources dispatch methodology - PSO

- ✓ Modified PSO
  - Gaussian mutation
  - Self-parameterization
- ✓ Results validation
  - GAMS
  - EPSO [Miranda, 2005]
- ✓ Self-parameterization in EPSO



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# Resources dispatch methodology - PSO

- ✓ Self-parameterization
  - The variables with lower price have higher velocities.

$$maxVel_i = 1/(Vector\ of\ Prices_i)^{1.5}$$

generator marginal cost prices and demand response cut prices

  - If the energy supplier price tends to be cheaper, then the minimum velocity limits tend to be lower in order to have less load cuts.

$$minVel = -\frac{Number\ of\ variables}{Position\ in\ price\ rank}$$



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# Resources dispatch methodology - PSO

- ✓ Mutation
  - Only in PSO-MUT
  - Particles movement

$$^{*}v_i = w_{i(inertia)} v_i + w_{i(memory)} \left(b_i - x_i\right) + w_{i(coop)} \left(bG - x_i\right)$$

  - Used in each PSO iteration for diversification in the search process rather than the standard version using fixed and random weights.

  - Particle's (*i*) weights (*wi*) changed in each iteration using Gaussian mutation

learning parameter, externally fixed between 0 and 1

resulting particle's weights after mutation

$$^{*}w_i = w_i + \delta N(0,1)$$

- ✓ All the PSO solutions use an AC power flow in order to consider the network constraints and the power losses



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# Case study – *Scenarios*

- ✓ 30 kV distribution network
- ✓ 60/30kV, 90MVA substation
- ✓ 6 feeders, 937 buses, 464 MV/LV transformers
- ✓ 20,310 consumers
- ✓ Peak power demand is 62,630 kW
- ✓ DR levels of 10% (RedA), 5% (RedB), 5% (RedC)

| *Type of consumer* | Reduction capacity (kW) | | | Reduction costs (m.u./kWh) | | |
|---|---|---|---|---|---|---|
| | RedA | RedB | RedC | RedA | RedB | RedC |
| Domestic | 936.9 | 468.47 | 468.47 | 0.16 | 0.20 | 0.24 |
| Small Commerce | 798.3 | 399.17 | 399.17 | 0.15 | 0.19 | 0.22 |
| Medium Commerce | 1125.4 | 562.74 | 562.74 | 0.18 | 0.20 | 0.26 |
| Large Commerce | 1088.0 | 544.02 | 544.02 | 0.17 | 0.24 | 0.26 |
| Industrial | 2314.2 | 1157.1 | 1157.1 | 0.17 | 0.26 | 0.28 |
| Total | 6262.8 | 3131.5 | 3131.5 | - | - | - |



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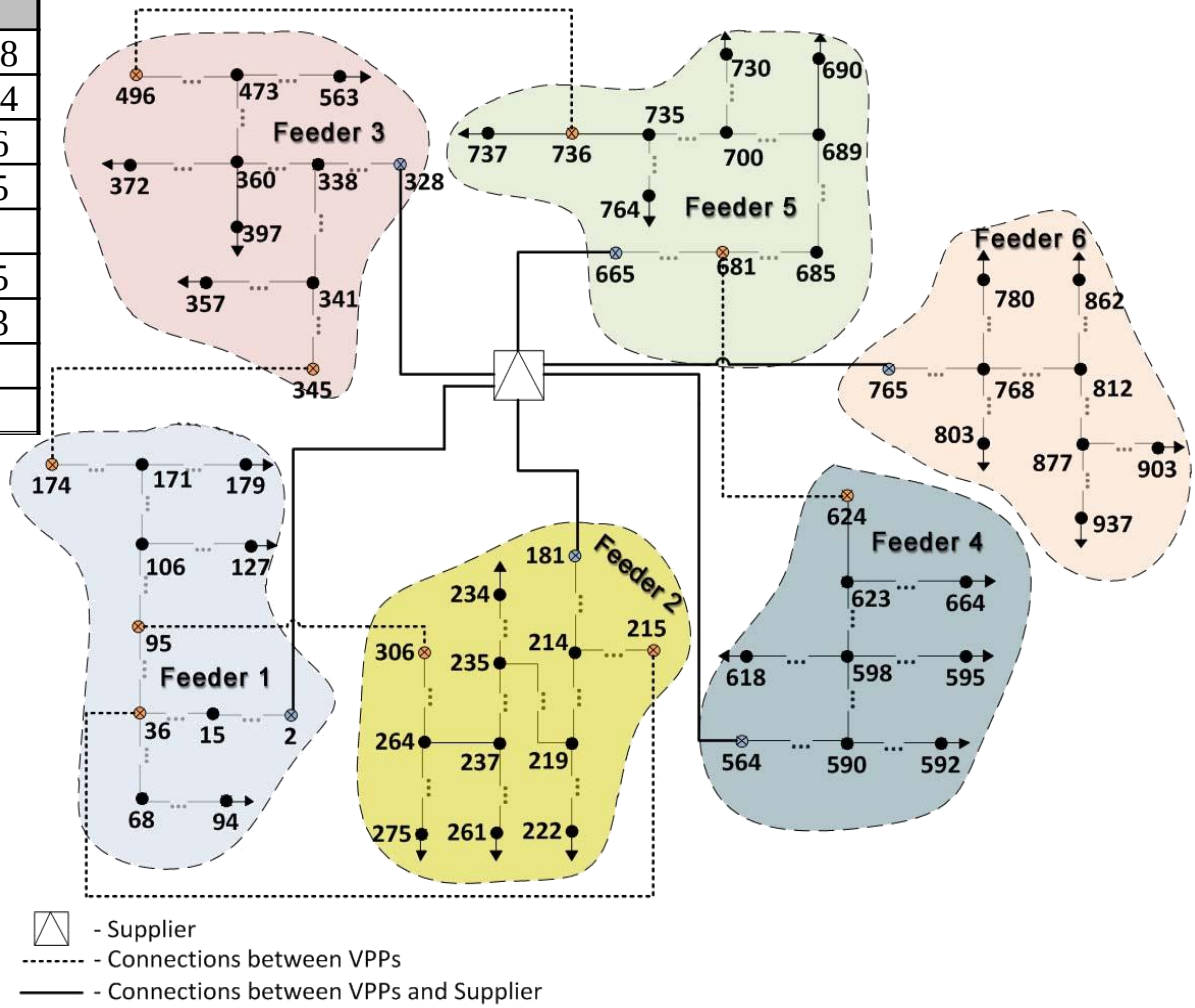
# Case study – *Scenarios*

| *Resource* | Price (m.u./kWh) | Capacity (kW) | Units # |
|---|---|---|---|
| PV | 0.2 | 7061.2 | 208 |
| Wind | 0.05 | 5866.0 | 254 |
| CHP | 0.08 | 6910.1 | 16 |
| Biomass | 0.15 | 2826.5 | 25 |
| MSW | 0.11 | 53.1 | 7 |
| Hydro | 0.15 | 214.0 | 25 |
| Fuel cell | 0.3 | 2457.6 | 13 |
| Supplier1 | 0.05 | 3000.0 | - |
| Supplier2 | 0.07 | 3000.0 | - |

| *Resource* | Price (m.u./kWh) | Capacity (kW) |
|---|---|---|
| Supplier3 | 0.09 | 3000 |
| Supplier4 | 0.11 | 3000 |
| Supplier5 | 0.13 | 3000 |
| Supplier6 | 0.15 | 3000 |
| Supplier7 | 0.17 | 3000 |
| Supplier8 | 0.19 | 3000 |
| Supplier9 | 0.21 | 10000 |
| Supplier10 | 0.23 | 10000 |
| Total | - | 69388 |



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# Case study – *PSO parameters*

- ✓ Learning parameter = 0.8
- ✓ 62046 variables

| ***Parameters*** | PSO Methodologies | |
|---|---|---|
| | PSO | PSO-MUT / EPSO |
| Inertia Weight | 1 | Gaussian mutation weights |
| Acceleration Coefficient Best Position | 2 | |
| Cooperation Coefficient | 2 | |
| Initial swarm population | Randomly generated between the upper and lower bounds of the variables | |
| Stopping Criteria | 150 iterations | |
| Max. velocity | Refer to Section III | |
| Min. velocity | Refer to Section III | |

- ✓ 20 particles
- ✓ 150 iterations
- ✓ No benefit for more iterations /particles



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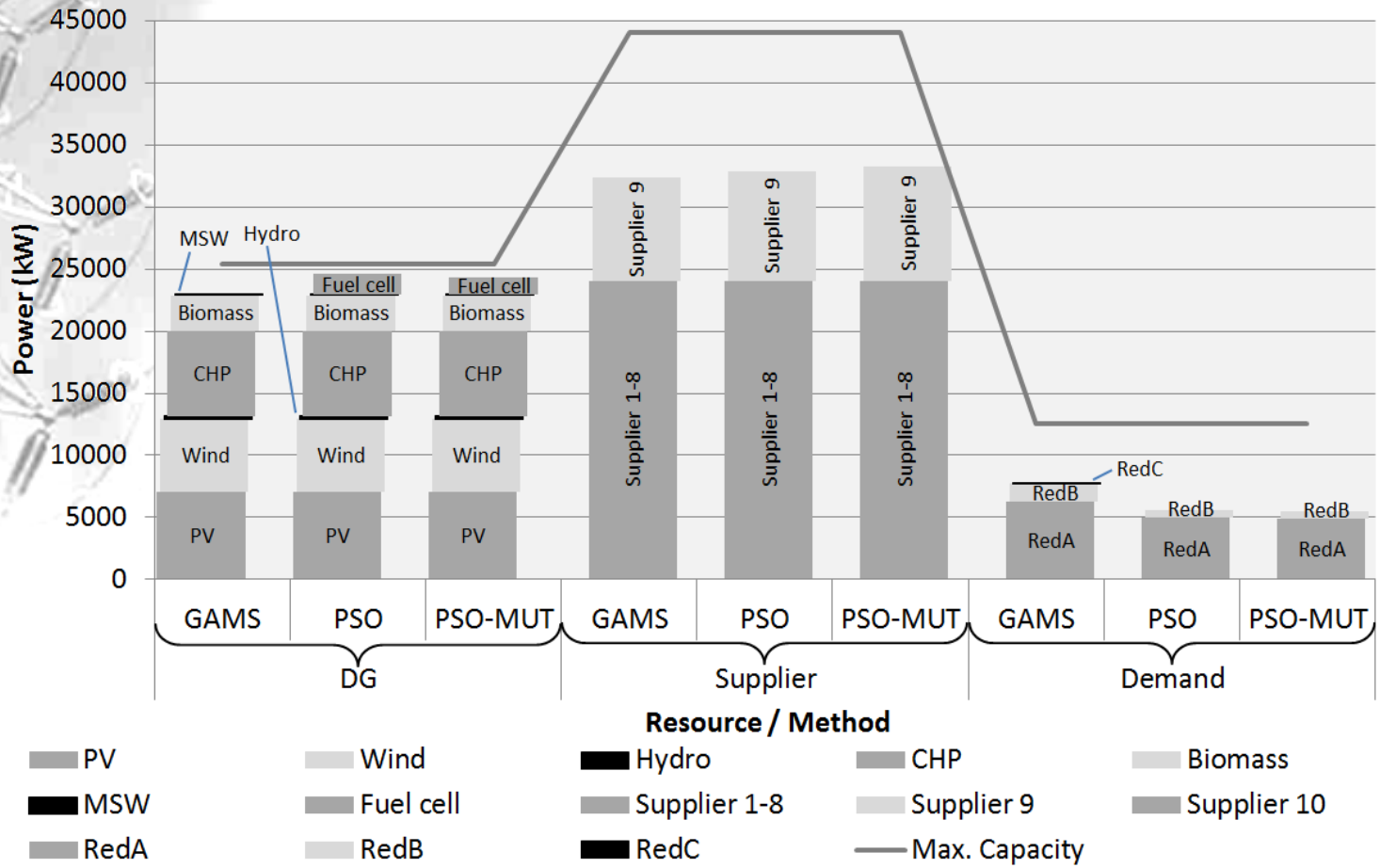
# Case study – *Results*

- Energy resources schedule




PSO schedules all the resources but not all the available capacity



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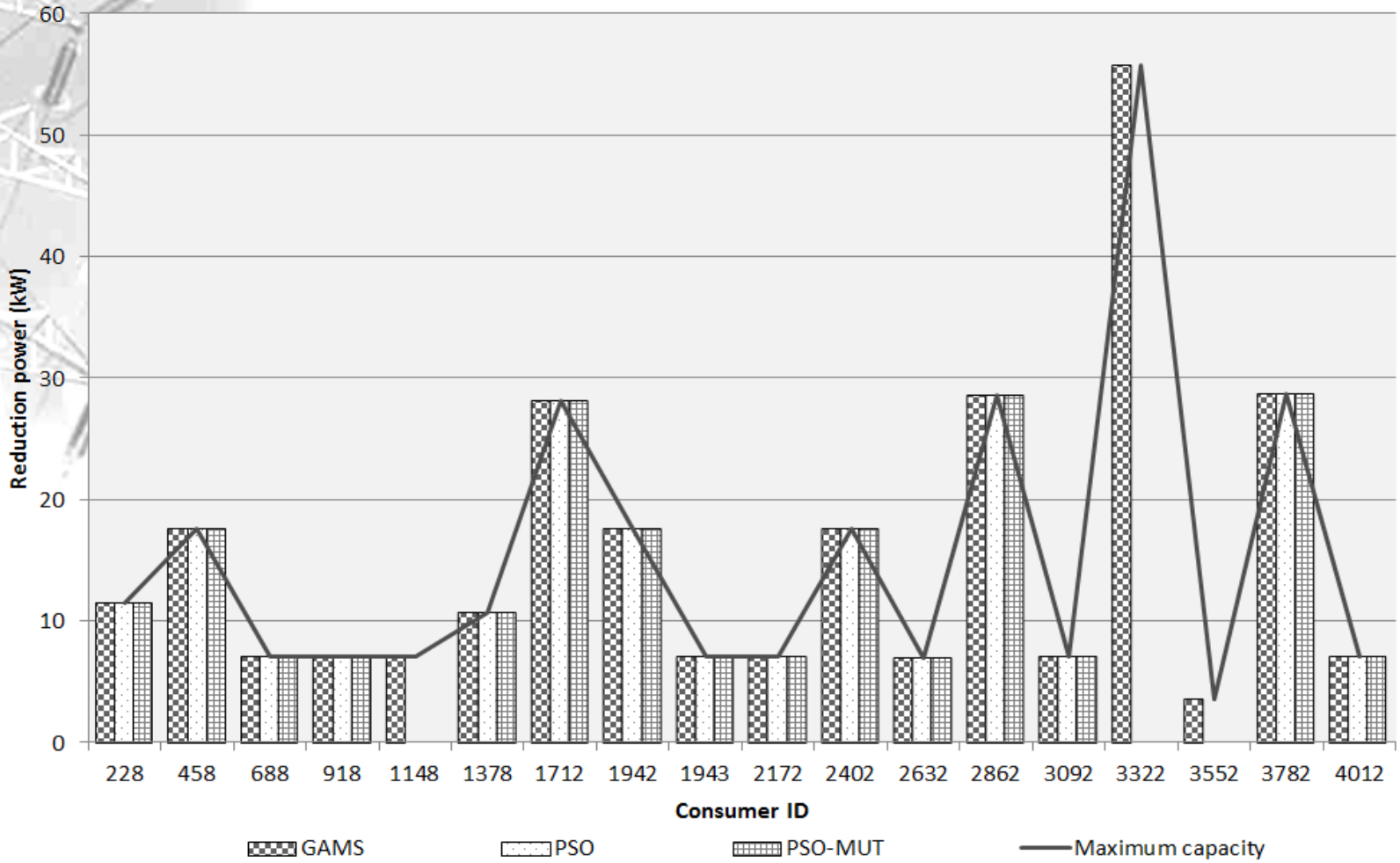
# Case study – *Results*

- ✓ Feeder 1 MC consumers schedule in RedA program




Some of the consumers are not scheduled by PSO



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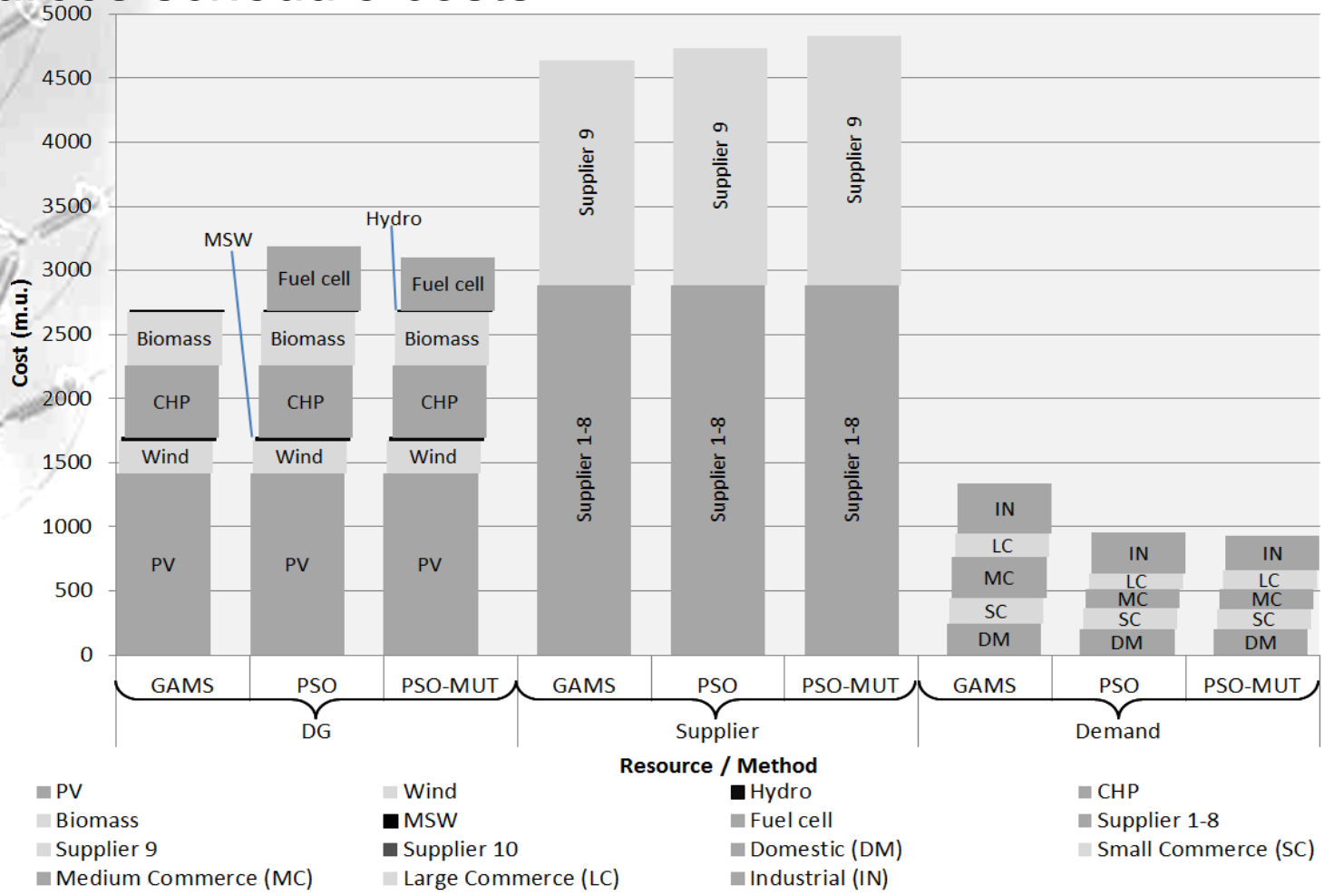
# Case study – *Results R500 and R800*

- ✓ Resources schedule costs




Differences between methods related to the resources schedule



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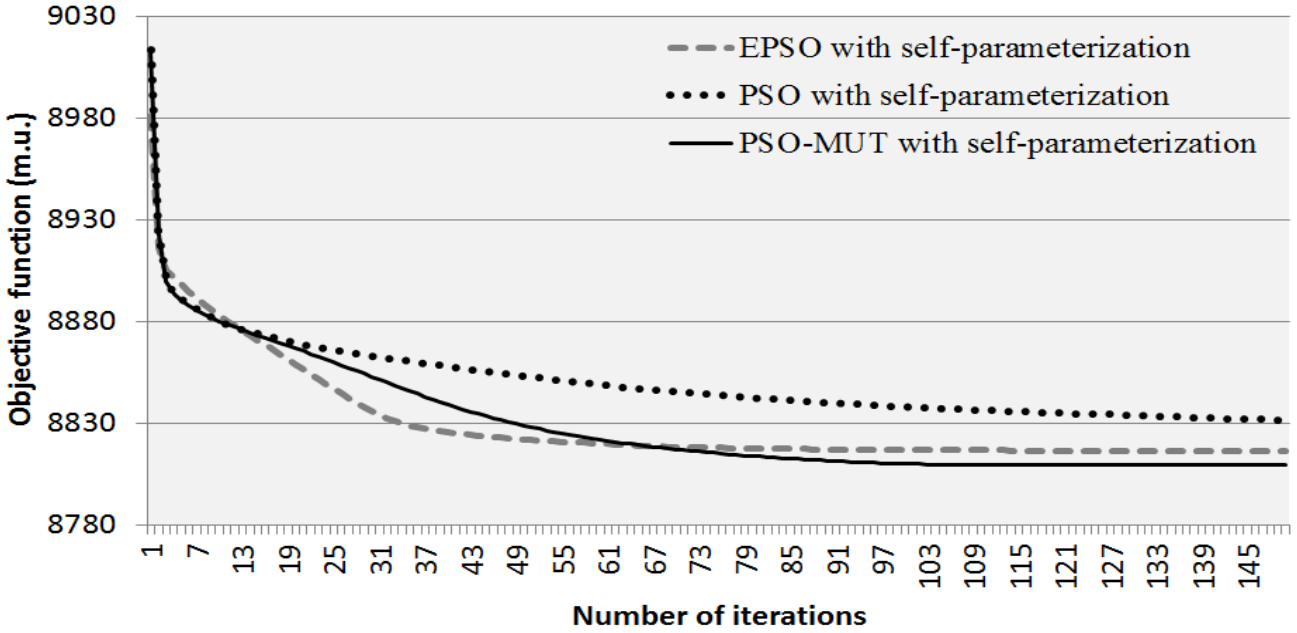
# Case study – *Results R500 and R800*

- Average solutions evolution in PSO




- Time comparison

| Method | Execution time | | Objective function | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (s) | (%) | Best | | Worst | | Average | | Standard deviation |
| | | | (m.u.) | (%) | (m.u.) | (%) | (m.u.) | (%) | (m.u.) |
| GAMS | 1510 | 100 | 8662.6 | 100 | - | - | - | - | - |
| PSO | 59 | 3.9 | 8768.2 | 101.1 | 8876.6 | 102.5 | 8831.3 | 101.9 | 24.8 |
| EPSO | 127 | 8.4 | 8745.1 | 101.0 | 8870.8 | 102.4 | 8816.1 | 101.8 | 29.3 |
| PSO-MUT | 68 | 4.5 | 8726.2 | 100.7 | 8876.9 | 102.5 | 8809.2 | 101.7 | 22.5 |



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# Conclusions

- ✓ Future context of operation of distribution networks will accommodate large amounts of distributed generation.
- ✓ Computational intelligence methods very important in this field.
- ✓ Particle Swarm Optimization (PSO) is applied to the schedule of several energy resources, minimizing the operation costs from the point of view of a VPP.
- ✓ Gaussian mutation of the strategic parameters and self-parameterization of the maximum and minimum particle velocities.
- ✓ Real 937 bus distribution network. PSO-MUT with best average solution; execution times slightly higher than PSO.



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COMPETE

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