Cooperative management of IT and Electrical systems

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Workshop of renewable energy-powered datacenters
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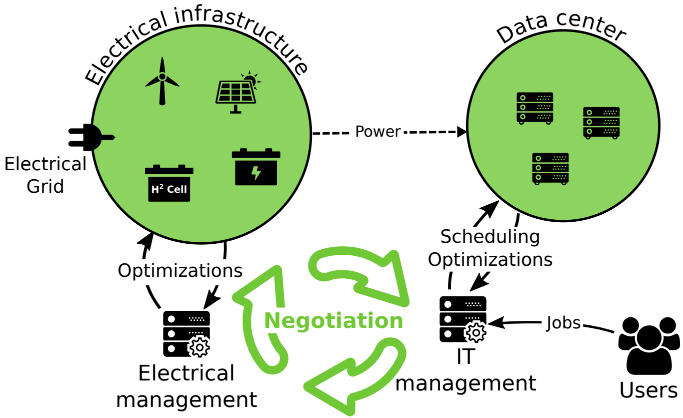
Context

DATAZERO : the big picture



Multi-objective aspect

- Each DM has one or more objectives to satisfy
- Objectives may differ between DM
  - QoS related for ITDM, environmental impact for PDM

Managing different objectives

3 options studied :

- Finding a set of good solutions (set of possible trade-offs) (See previous presentation)
- Maximizing the weighted sum of the utilities, under the constraint of a distance between the two resulting profiles (SAN approach)
- Playing a game between the PDM and the ITDM so that each one maximizes its profit (GAN approach)

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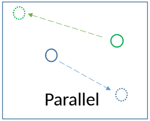
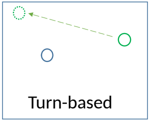
Outline

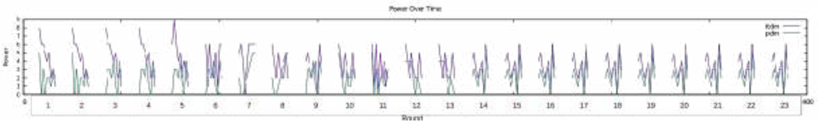
SAN and GAN : Turn based approaches

Main points

- Both algorithms are based on scheduling
  - DMs generate multiple scheduling solutions
  - Then we find negotiation solution from those scheduling solutions
- Both SAN and GAN negotiates in turn-based strategy
  - When ITDM runs scheduling (to follow PDM), PDM does not, and vice versa
  - We define 2 modes : "Follow PDM" mode (FLW_PD) and "Follow ITDM" mode (FLW_IT)
  - For both SAN and GAN, the whole system is executed under only 1 mode at a time







SCHEDULING BASED NEGOTIATION (SAN)

SAN algorithm

Definitions

- The set of ITDM profiles is $\{x_1, x_2, ..., x_m\}$
- The set of PDM profiles is $\{y_1, y_2, ..., y_n\}$
- Depending on each specific context, a profile may also be named "hint" or "candidate"

2 stages

- Stage 1 : Checking for matched pair
  - Decision variable : the pair {PDM profile, ITDM profile} : $\{x \in \{x_1, x_2, ..., x_m\}, y \in \{y_1, y_2, ..., y_n\}\}$
  - Objective : maximize sum of utility

$$\max_{\{x,y\}} (u(x) + u(y)) \tag{1}$$

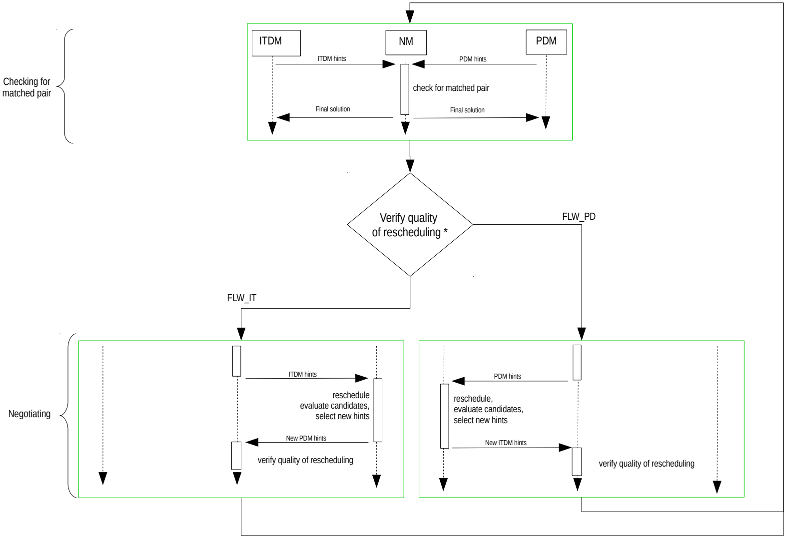
  - Constraint : $d(x, y) < \epsilon$
    where $d()$ is the distance between x and y
  - If we can't find any matched pair, run Stage 2 : Negotiating.

SAN algorithm

Stage 2 : Negotiating :

- General mechanism
  - At a time, the whole system is executed under only 1 mode : follow ITDM (FLW_IT) or follow PDM (FLW_PD)
  - NM decides to switch between two modes using *"verify quality of rescheduling"*
  - Repeat until matched pair found
- Two modes :
  - FLW_IT : Follow the ITDM
    - NM sends the ITDM hints to PDM
    - PDM uses an algorithm (e.g. greedy, linear program) to find multiple scheduling solutions as candidates
    - PDM evaluates quality of candidates by *"weighted similarity"* to hints
    - PDM selects candidates with high *"weighted similarity"* as its news hints and sends back to NM
  - FLW_PD : Similar to FLW_IT, following the PDM

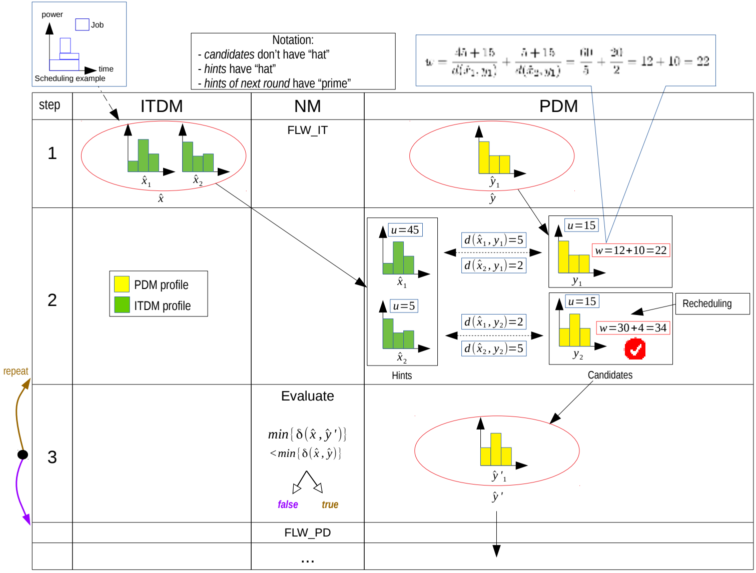
Algorithm



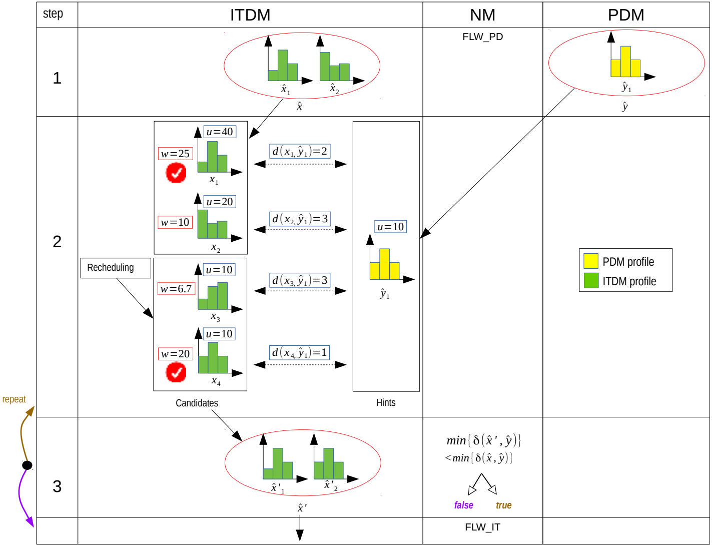
(*) verfify quality of rescheduling: compare “distance between the best ITDM hint and the best PDM hint” before and after rescheduling

Example

Follow ITDM


power
Job
time
Scheduling example
Notation:
- *candidates* don't have "hat"
- *hints* have "hat"
- *hints of next round* have "prime"
$w = \frac{45+15}{d(\hat{x}_1, y_1)} + \frac{5+15}{d(\hat{x}_2, y_1)} = \frac{60}{5} + \frac{20}{2} = 12 + 10 = 22$
step
ITDM
NM
PDM
1
$\hat{x}_1$
$\hat{x}_2$
$\hat{x}$
FLW_IT
$\hat{y}_1$
$\hat{y}$
2
PDM profile
ITDM profile
$u=45$
$\hat{x}_1$
$u=5$
$\hat{x}_2$
Hints
$d(\hat{x}_1, y_1)=5$
$d(\hat{x}_2, y_1)=2$
$d(\hat{x}_1, y_2)=2$
$d(\hat{x}_2, y_2)=5$
$u=15$
$w=12+10=22$
y_1
$u=15$
$w=30+4=34$
y_2
Candidates
Recheduling
repeat
3
Evaluate
$min\{\delta(\hat{x}, \hat{y}')\}$
$< min\{\delta(\hat{x}, \hat{y})\}$
false
true
$\hat{y}'_1$
$\hat{y}'$
FLW_PD
...

Follow PDM


step
ITDM
NM
PDM
1
FLW_PD
$\hat{x}_1$
$\hat{x}_2$
$\hat{x}$
$\hat{y}_1$
$\hat{y}$
2
$u=40$
$w=25$
x_1
$u=20$
$w=10$
x_2
$u=10$
$w=6.7$
x_3
$u=10$
$w=20$
x_4
Recheduling
$d(x_1, \hat{y}_1)=2$
$d(x_2, \hat{y}_1)=3$
$d(x_3, \hat{y}_1)=3$
$d(x_4, \hat{y}_1)=1$
$u=10$
$\hat{y}_1$
Candidates
Hints
PDM profile
ITDM profile
repeat
3
$\hat{x}'_1$
$\hat{x}'_2$
$\hat{x}'$
$min\{\delta(\hat{x}', \hat{y})\}$
$< min\{\delta(\hat{x}, \hat{y})\}$
false
true
FLW_IT

Game Based Negotiation (GAN)

Model

Game players

ITDM:

- Objective: (2) (1)
  - max {payment from users – payment to PDM}
- Decision variables:
  - price
  - scheduling

revenue - cost

PDM:

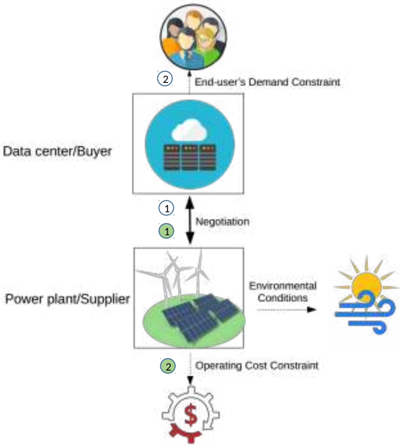
- Objective: (1) (2)
  - max {payment from ITDM – (opex + capex cost}
- Decision variables:
  - purchased power
  - scheduling

Game model

Hybrid model

- Non-cooperative: each player maximizes their own utility
- Cooperative: sometimes a player follows the other's suggestion

Supplier-buyer game diagram



Model

Motivation

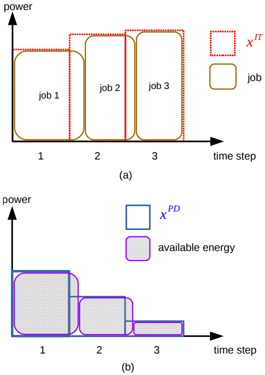
- The buying-selling nature of the system
  - Selling : PDM is selling power → controls the price
  - Buying : ITDM is buying power → decide the order/purchase
- Advantages of pricing
  - Power source availability can be reflected in price
  - Through price, pattern of order reflects pattern of PDM's desirable supply → drive demand toward supply

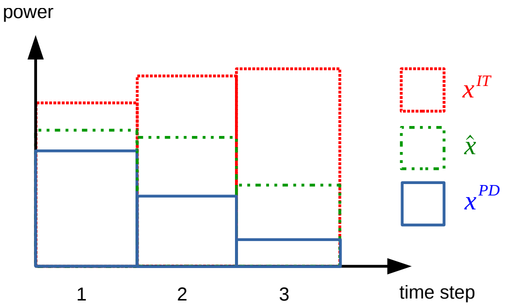
Model

Preliminary

- Players are selfish
  - They try to maximize their utility
  - Each player negotiates just because he foresees some benefit
  - We introduce *incentive pricing mechanism* : each player tries to find offers that are attractive to the other player.
- An unexpected situation may occurred : all players can't foresee their benefit and stop negotiate without reaching any agreement.
  - From the view of the whole system, this situation is unacceptable, no transaction is done, the players obtain zero utility
  - If this situation occurred, we introduce *sacrifice mechanism*, in which the players gradually sacrifice their utility until they reach an agreement.

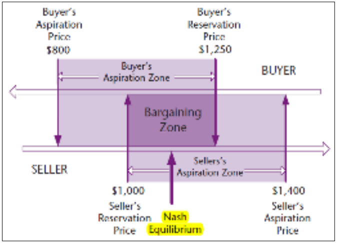
- T : Time window
- $\hat{x}, x^{IT}, x^{PD}$ are profiles
- $\hat{x} = \{\hat{x}_1, \hat{x}_2, ..., \hat{x}_T\}$, $x^{IT} = \{x_1^{IT}, x_2^{IT}, ..., x_T^{IT}\}$ $x^{PD} = \{x_1^{PD}, x_2^{PD}, ..., x_T^{PD}\}$



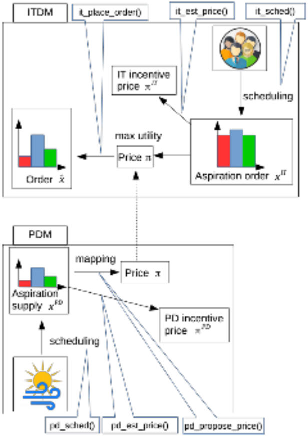


Definition 2

- $\pi = \{\pi_1, \pi_2, ..., \pi_T\}$, $\pi^{IT} = \{\pi_1^{IT}, \pi_2^{IT}, ..., \pi_T^{IT}\}$, $\pi^{PD} = \{\pi_1^{PD}, \pi_2^{PD}, ..., \pi_T^{PD}\}$



2006__Krause__Bargaining Stances and Outcomes in Buyer–Seller Negotiations: Experimental Results (The Journal of Supply Chain Management)

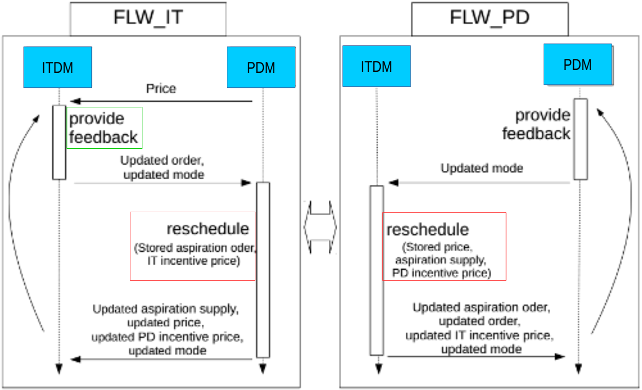


Algorithm

Algorithm

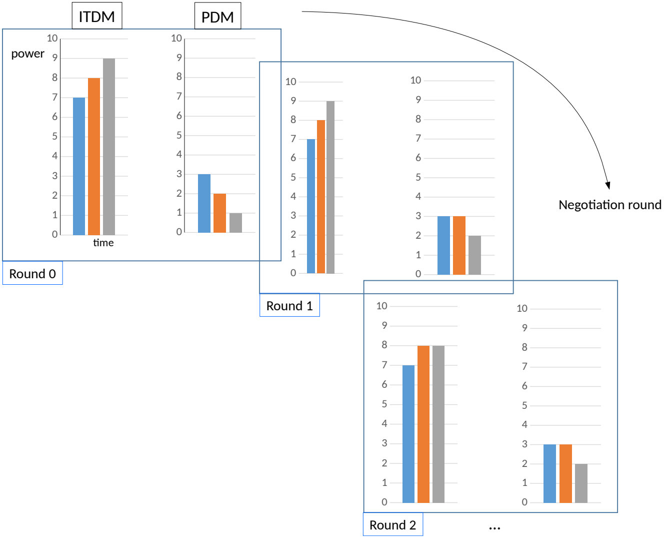
Note :

- At a time, the whole system is executed under only one mode : FLW_IT or FLW_PD
- DMs only exchange data that have been updated/modified, other data can be stored and reused



Algorithm

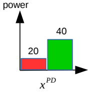
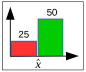
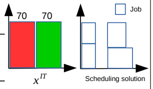
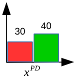
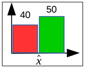
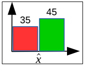
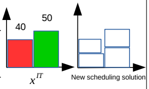
Graphical interpretation of the algorithm



Example

Example

Simplified example

round	row	PD-Player	Common Space	IT-Player
1	1		$\pi^{PD}=\{7,6\}$ $\pi=\{8,6\}$  $\pi^{IT}=\{3,3\}$	
	2	Assume $\begin{cases} r(x^{IT},\pi^{IT})+\alpha=0.25 \\ r(\hat{x},\pi)=0.22 \end{cases}$ $r(x^{IT},\pi^{IT})+\alpha>r(\hat{x},\pi)$ → ***true***		Assume $\begin{cases} c(x^{PD},\pi^{PD})-\alpha=0.13 \\ c(\hat{x},\pi)=0.15 \end{cases}$ $c(x^{PD},\pi^{PD})-\alpha<c(\hat{x},\pi)$ → ***true***
	3	*pd_pre = FLW_IT*	***mod = FLW_IT***	*it_pre = FLW_PD*
2	4		$\pi^{PD}=\{7,6\}$ $\pi=\{7,6\}$  $\pi^{IT}=\{3,3\}$	
	5	Assume $\begin{cases} r(x^{IT},\pi^{IT})+\alpha=0.25 \\ r(\hat{x},\pi)=0.28 \end{cases}$ $r(x^{IT},\pi^{IT})+\alpha>r(\hat{x},\pi)$ → ***false***		Assume $\begin{cases} c(x^{PD},\pi^{PD})-\alpha=0.16 \\ c(\hat{x},\pi)=0.17 \end{cases}$ $c(x^{PD},\pi^{PD})-\alpha<c(\hat{x},\pi)$ → ***true***
	6	*pd_pre = FLW_PD*	***mod = FLW_PD***	*it_pre = FLW_PD*
3	7		$\pi^{PD}=\{7,6\}$ $\pi=\{7,6\}$  $\pi^{IT}=\{6,5\}$	
	8	Assume $\begin{cases} r(x^{IT},\pi^{IT})+\alpha=0.23 \\ r(\hat{x},\pi)=0.24 \end{cases}$ $r(x^{IT},\pi^{IT})+\alpha>r(\hat{x},\pi)$ → ***false***		Assume $\begin{cases} c(x^{PD},\pi^{PD})-\alpha=0.16 \\ c(\hat{x},\pi)=0.14 \end{cases}$ $c(x^{PD},\pi^{PD})-\alpha<c(\hat{x},\pi)$ → ***false***
repeat	9	*pd_pre = FLW_PD*		*it_pre = FLW_IT*
	10	$d(x^{PD},\hat{x})>\varepsilon$ ***true*** ***false***		$d(x^{PD},\hat{x})>\varepsilon$ ***true*** ***false***

EXPERIMENT

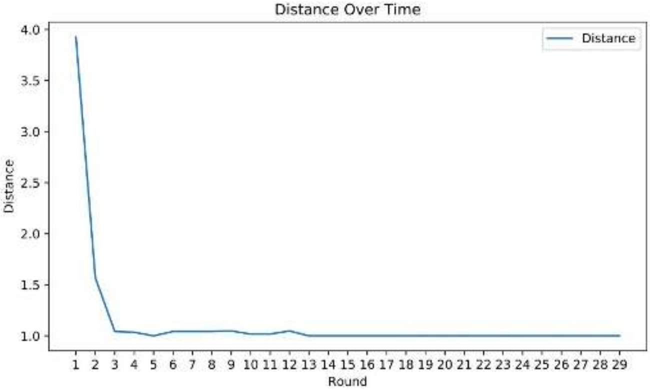
Setup of Experiment for SAN

Real PDM & ITDM

- PDM weather information : 1 month
- Time window : 3 days or 72 hours
- Timestep : 1 hour or 3,600,000 ms
- PDM sizing : ≈1kW
- Run time : ≈10 minutes

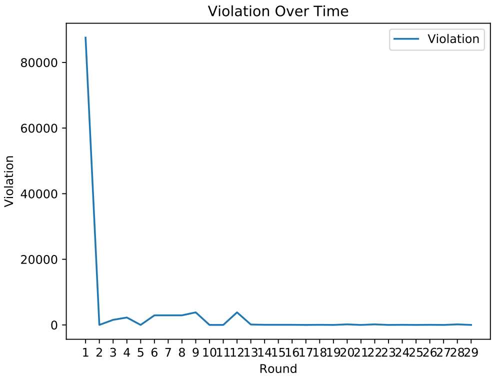
Distance

- Calculation : using Pearson correlation
- Distance is not always decreasing because the profiles are evaluated by both utility and distance
- Negotiation results depend a lot on the series of utilities from DMs

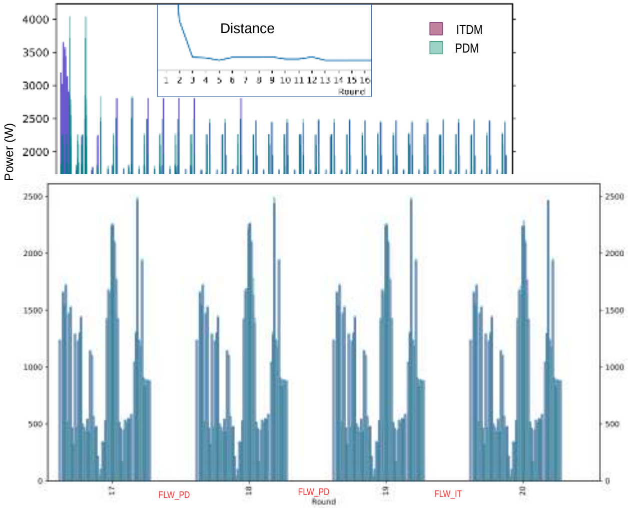


Violation

- Calculation : sum of the amount that the ITDM profiles excesses PDM's profiles
- A significant reason for this result : DMs scheduling algorithms



Power level

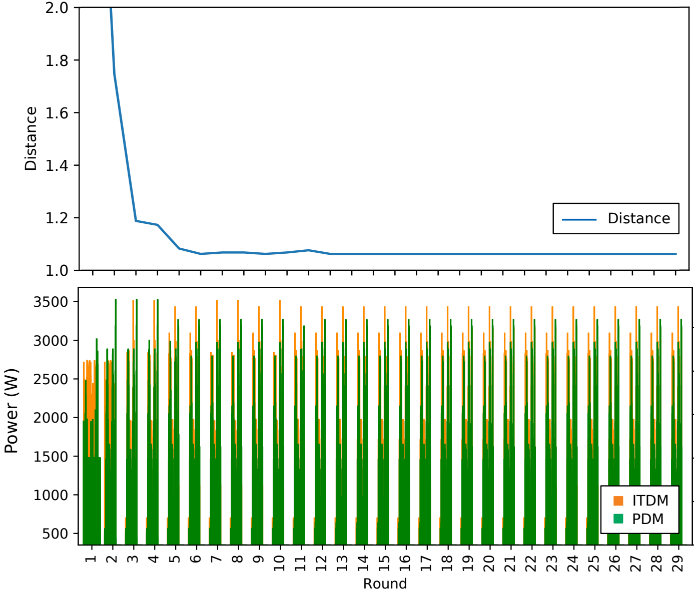


Setup of Experiment for GAN

Real PDM & ITDM

- PDM weather information : 1 month
- Time window : 3 days or 72 hours
- Timestep : 1 hour or 3,600,000 ms
- PDM sizing : ≈4kW
- Run time : ≈10 minutes

Power level and convergence



CONCLUSION

- GAN and SAN provide (semi) black-box based negotiation for renewable-based datacenters
- Guaranty of convergence
- Semi black-box approach achieves higher stability and performance than the black-box one
- Perspectives
  - Performance evaluation of the algorithm itself (number of call to black boxes)
  - Multi-time scale decision
  - Comparison with GreenSlot

See you on `datazero.org`