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A SURVEY ON OPTIMIZATION APPLIED TO MULTI-SOURCE SYSTEMS: FROM MICRO-GRID APPLICATIONS TO ELECTRICAL SYSTEMS

Dhaker ABBES, Bruno FRANCOIS, Benoit ROBYNS

Univ. Lille, Centrale Lille, Arts et Métiers Paristech, HEI, EA 2697 – L2EP –

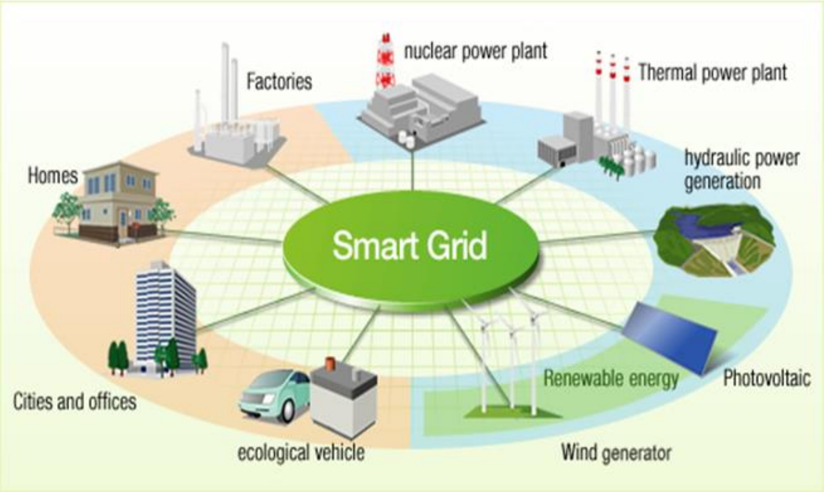
Laboratoire d'Electrotechnique et d'Electronique de Puissance, F-59000 Lille, France

Power Grid evolves toward Smart Grids to :

- Increase **dispersed generators** (renewable and cogengerators)
- Increase energy **efficiency** and **fiability** of electrical energy
- Integrate renewable energies into the **electrical market**
- Master the **load demand** (buildings, EVs, railway systems,…)

Challenges :

- Design of the size and characteristics of the devices (sources, storage systems,…)
- Design of a multi-objectives energy management of sources, storage and loads.
- Couple design of sizing and energy management, because cleverly designed supervision reduces the size of components.
- Uncertainties on some renewable productions.
- State of Charge of the storage system SOC dependent on time multiplying the optimization variables.



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This work is a survey focusing on the optimal design and supervision of multisource systems. A detailed state of the art is developed in the paper illustrated by many case studies.

Two groups of optimization methods

- **Explicit Optimization :**
  - Direct (from an explicit mathematical function to optimize) :
    - ✓ Mono-objective optimization (Linear and non linear)
    - ✓ Multi-objective optimization (Scalarizing ,NSGA II , Particle swarm)
  - Through the dynamic simulation of the system (example to minimize the energy in a building by dynamic thermal simulation of it.)
- **Implicit optimization :**
  - Mathematical model difficult to determine.
  - Intuitive algorithms (examples: energy management of multi-source systems with fuzzy logic, algorithms for maximizing photovoltaic or wind power MPPT, etc.).

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Case studies

Systems	Sizing	Energy management
Hybrid wind-photovoltaic system with batteries	- Linear explicit optimization - Non linear explicit optimization: SQP algorithm NGAII algorithm	
Hybrid railway power substation with renewable and storage system	- Non linear explicit optimization: SQP algorithm GA algorithm	Combination of explicit method for predictive management and implicit method for real-time management
Day-ahead Optimal Operational Planning of Generators in a micro grid		Predictive management with an explicit method: dynamic programming

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Case study 1 : Design and supervision of a hybrid wind-photovoltaic system with batteries

Example of explicit linear optimization:

Optimizing the size of renewable sources and storage system size predetermined.

Objective function (Optimum):

Minimum→Economic cost:

$$LCC = Cwt \times Awt + Cpv \times Apv$$

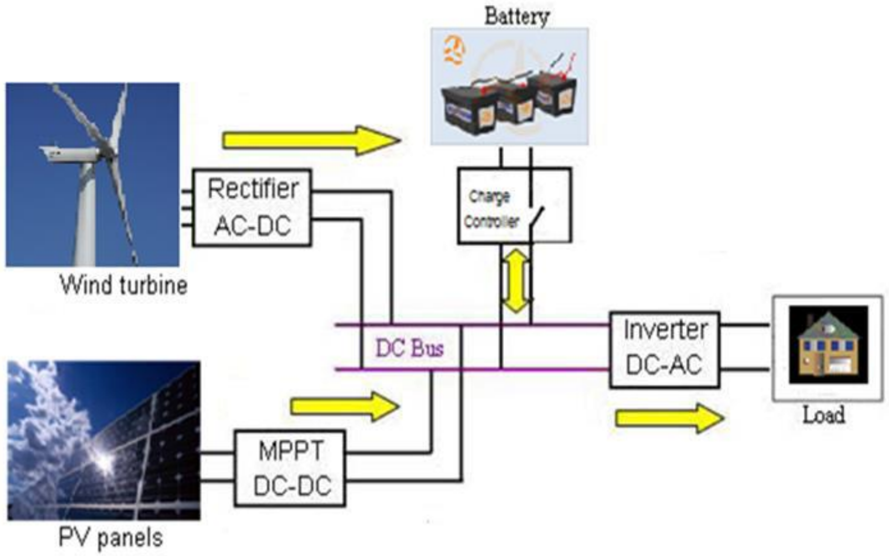
Subject to the restrictions imposed by the criterion of energy satisfaction :

$$E_{pv}^{Month} \times A_{pv} + E_{WT}^{Month} \times A_{wt} \geq E_{Load}^{Month}$$

Taking into account the constraints of feasibility for an autonomous residence :

$$Apv_{min} \leq Apv \leq Apv_{max}$$

$$Awt_{min} \leq Awt \leq Awt_{max}$$



Schematic diagram of Wind- PV hybrid system with battery storage

→ **Optimization problem can be resolved using Exel (SIMPLEX)**

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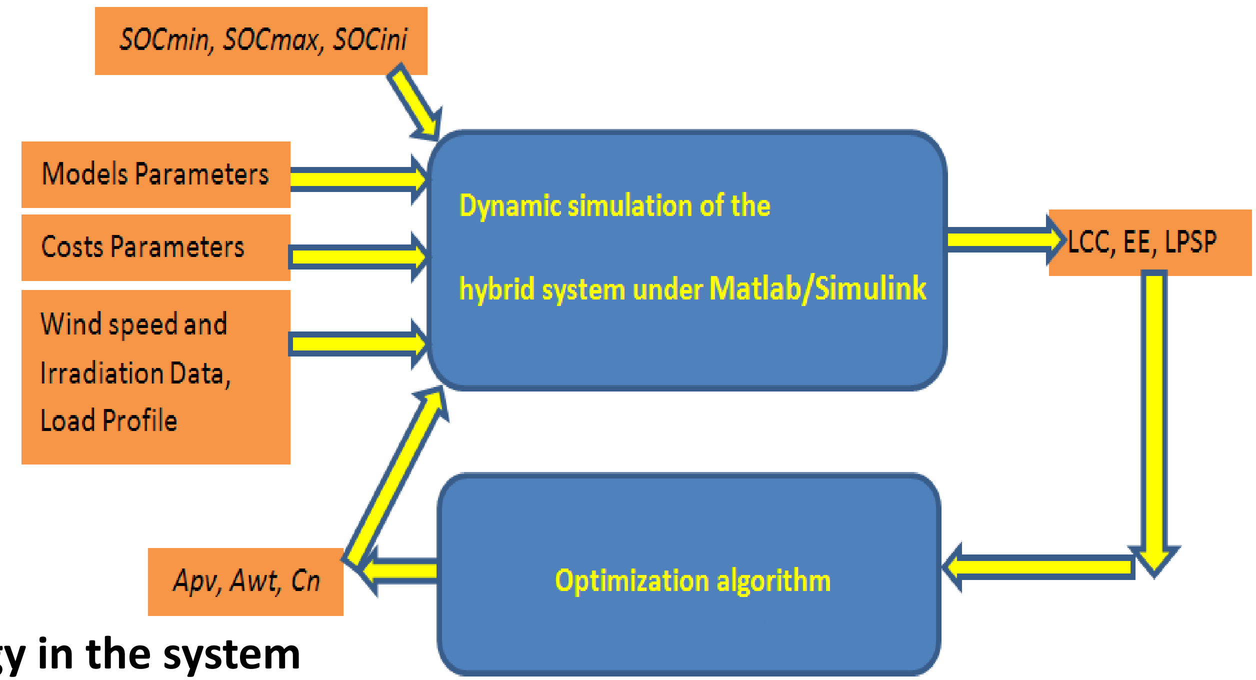
Case studies

Case study 1 : Design and supervision of a hybrid wind-photovoltaic system with batteries

Example of non-linear explicit optimization:

Optimizing the size of renewable sources and the size of the storage system. Energy management predetermined.

- Method based on a dynamic system simulation associated with an optimization algorithm:



- **LCC [€] : Life Cycle Cost**
- **EE [MJ] : Embodied Energy in the system**
- **LPSP [%] : Loss of Power Supply Probability**

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Case study 1 : Design and supervision of a hybrid wind-photovoltaic system with batteries

Example of non-linear explicit optimization:

Two formulations are proposed :

- **A mono-objective formulation solved by the SQP algorithm (Newton Wilson Algorithm) → *1 objective is optimised, both others objectives are constraints***

- **A multi-objective formulation :**
  Finding the best compromise between LCC [€] , EE [MJ] and LPSP [%]

Resolved in two ways :

- By a scalar method with unit weighting coefficients:
  None of the "objective" functions is favored.

- By a Pareto approach (notion of dominance) with the N.S.G.A-II method.

Case study 1 : Design and supervision of a hybrid wind-photovoltaic system with batteries

Comparison of the different methods:

- **Energy approach with linear programming**
  - \+ Simple to implement,
  - \- Slow ,
  - \- Choice of the number of days of autonomy.
  - \- Empirical calculation of the number of batteries
- **Methods based on dynamic simulations**
  - \+ Taking into account the temporal profile of sources and consumption,
  - \+ Optimization of batteries number,
  - \- complex.

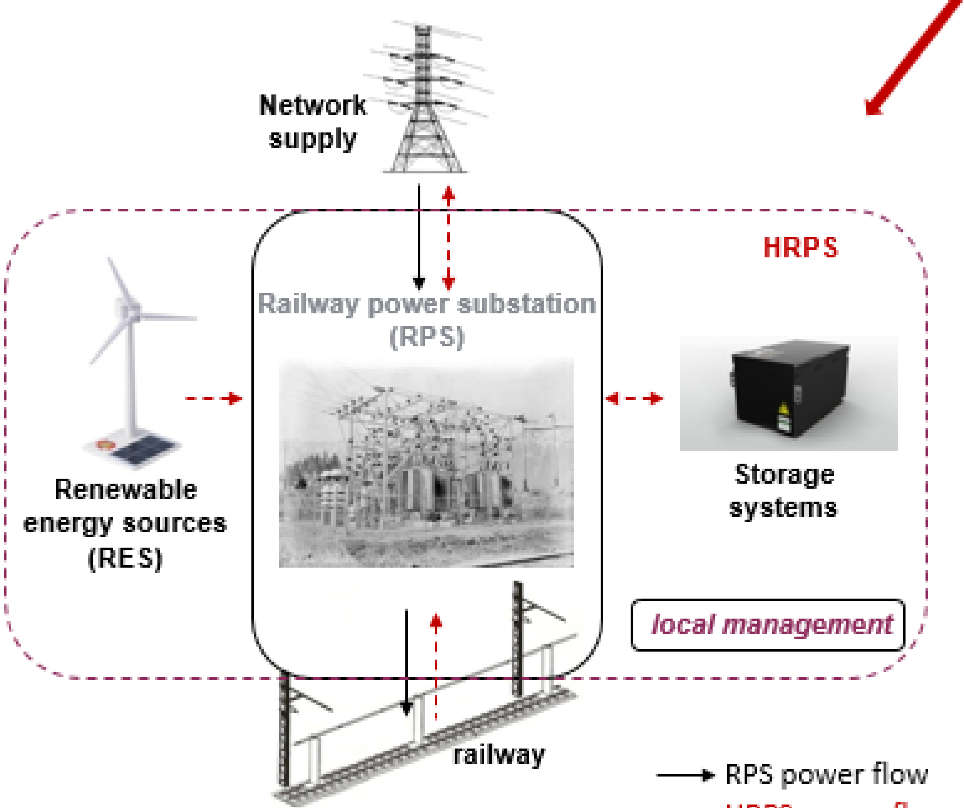
Scalar method (SQP)	NSGA-II Method
+ Rapid - A unique solution - Fixation of LPSPmax	- Slow + Many solutions (Pareto front) + Do not need to set an LPSPmax
→ **A good decision-making tool : the designer decides what to promote: the economic cost, the ecological cost or the satisfaction of the load.**	

Case study 2 : Design and supervision of a hybrid railway power substation

Context

- 90% railway traffic ensured by electrified lines (French railway network: 1500VDC & 25kV/50Hz AC)
- railway traffic increasing
- electricity market liberalization

New solutions to face future energy demand increase (Hybrid Railway Power Substation)



Economic issue:

- HRPS energy bill reduction
- Optimizing the energy purchasing strategy

In energy terms:

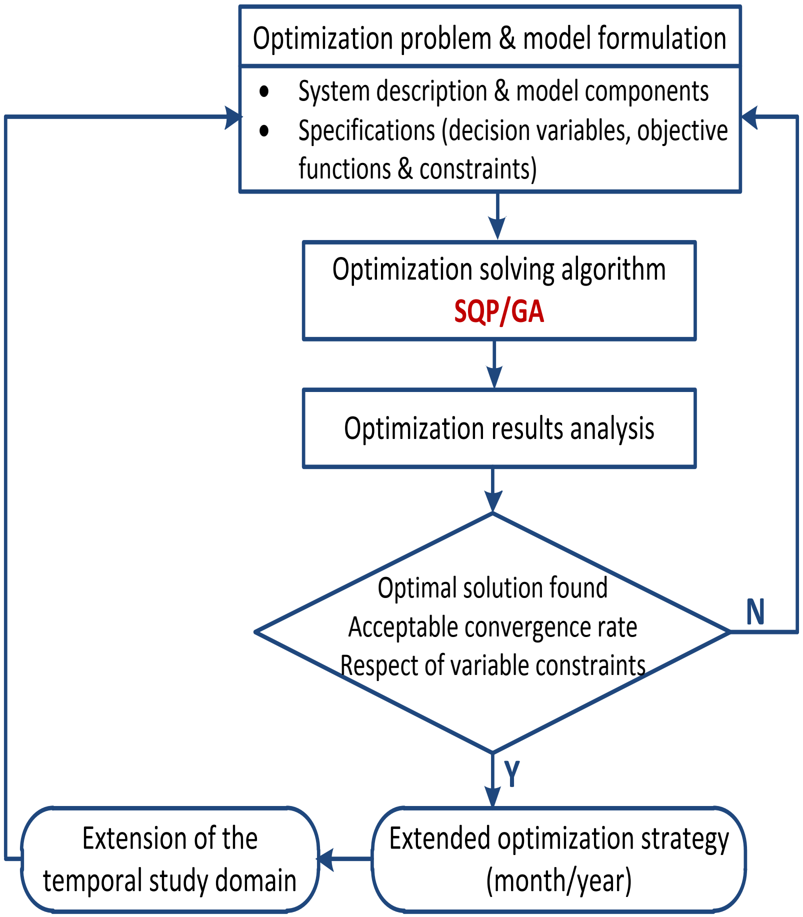
- Power flow identification in HRPS system
- Energy management objectives definition in order to satisfy energy and economic constraints

Case study 2 : Design and supervision of a hybrid railway power substation

Design with explicit nonlinear optimization:

Optimizing the size of renewable sources and the size of the storage system.
Energy management predetermined.

Method based on a dynamic system simulation associated with an optimization algorithm:



Organization chart of IFTEH sizing optimization method

Case study 2 : Design and supervision of a hybrid railway power substation

Design with explicit nonlinear optimization:

Description of optimization problem with SQP algorithm

Variables	Constraints	Objective function
S_{PV}, with $0 < S_{PV} < S_{PV\_max}$ S_w, with $0 < S_w < S_{w\_max}$ P_{max_sto}, with P_{sto_i}, $i = 1..24$ $-P_{max\_sto} \leq P_{sto\_i} \leq P_{max\_sto}$ E_{max_sto}	$E_0 = E_f$ $E_{min\_sto} > 0$	Minimizing total cost Min(C)

Description of optimization problem with genetic algorithm

Variables	Objective function
S_{PV}, with $0 < S_{PV} < S_{PV\_max}$ S_w, with $0 < S_w < S_{w\_max}$ P_{sto_i}, $i = 1..23$ with $P_{sto\_24} = -\sum_{i=1}^{23} P_{sto\_i}$ and $-P_{max\_sto} \leq P_{sto\_i} \leq P_{max\_sto}$	Minimizing total cost Min(C)

Numerical results of optimization

	Optimization variable (Spv)	Cost function (C)	Evaluations
SQP	200000m²	39736k€	5351
GA	221500m²	42342k€	26100

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Methodology for HRPS energy management

STEP 1
Work specifications

STEP 2
Design of the supervisor

STEP 3
Chart representation of operating modes
- Functional graphs -

STEP 4
Determination of the membership functions

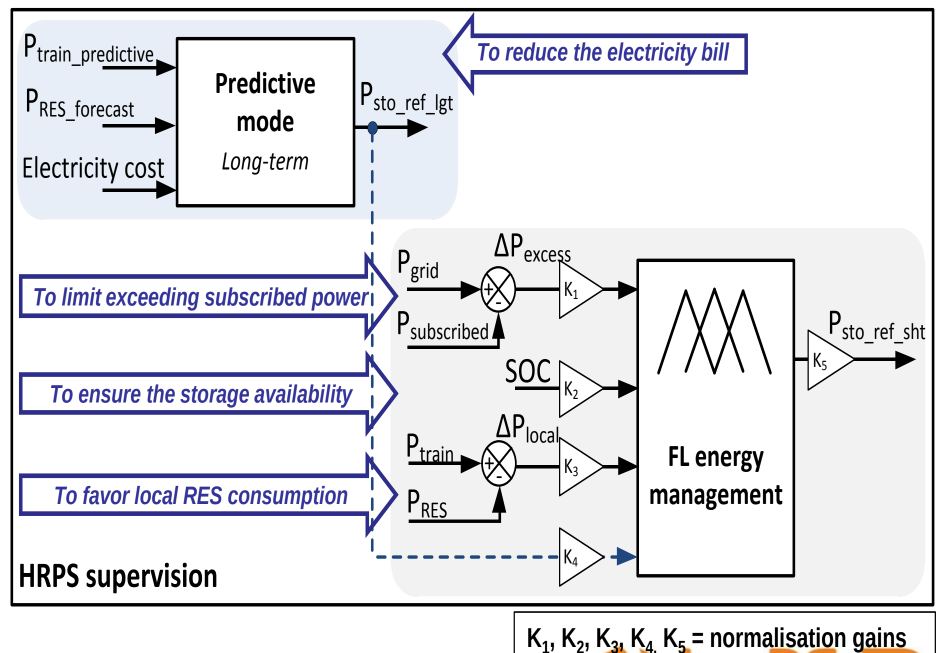
STEP 5
Chart representation of fuzzy operating modes
- Operational graphs -

STEP 6
Determination of the fuzzy rules

STEP 7
Determination of indicators to measure the achievement of objectives

Case study 2 : Design and supervision of a hybrid railway power substation

Combination of explicit method for predictive management and implicit method for real-time management



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Case study 2 : Design and supervision of a hybrid railway power substation

Comparison of different supervision cases

Subscribed power is reduced five times in HRPS supervision

Study case	*CMDPS*	I_{RES}
Reference case	5338 €	0%
Case 1 (Predictive mode – explicit optimisation)	1024 €	96,5%
Case 2 (Real time management – implicite optimisation)	1036 €	95,5%
Case 3 (Combination of predictive and real time management)	942 €	96,9%

well performance of real time strategy compared to predictive mode results

RES is locally consumed almost in totality

Objectives:

- Reduce the cost of exceeding the subscribed power
- Promote local consumption of renewable energy

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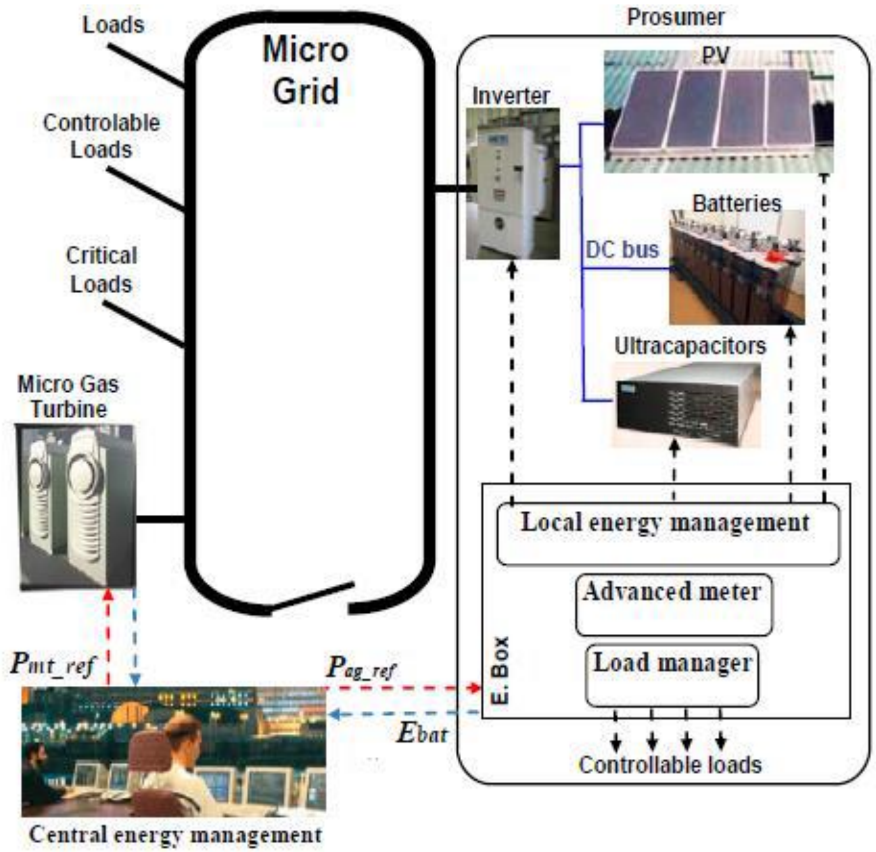
Case study 3 : Day-ahead Optimal Operational Planning of Generators



Pre-dimensioning by a non-linear optimization method.

Predictive management with an explicit method: dynamic programming.

Discontinuous system due to the commissioning of a turbine or its shutdown.

- Focus on the design of the Micro Grid Central Energy Management (MCEMS) under particular constraints.
- Uint commitment problem with dynamic programming is developed in order to reduce the economic cost and/or CO_2 equivalent emissions.

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Conclusion : recommandations

Design optimization and supervision of multi-source energy systems is a relevant issue and becomes more and more common.

Recommandations

- An optimized and well-managed system leads to better reliability and lower costs.

- The choice of the optimization method depends mainly on the following criteria : reliability or overall convergence, rate of local convergence, precision and implementation

.

- It is possible to combine implicit and explicit optimization for design and supervision of multi-source energy systems (for example : optimizing fuzzy logic member functions with GA or SQP).

- It is necessary to adapt system models for optimization (simple and representative models for fast simulation).

- It is important to improve convergence and rapidity of optimization algorithms.

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