Gestione intelligente della domanda: prospettive e tecnologie per il controllo distribuito dei carichi in Bassa Tensione

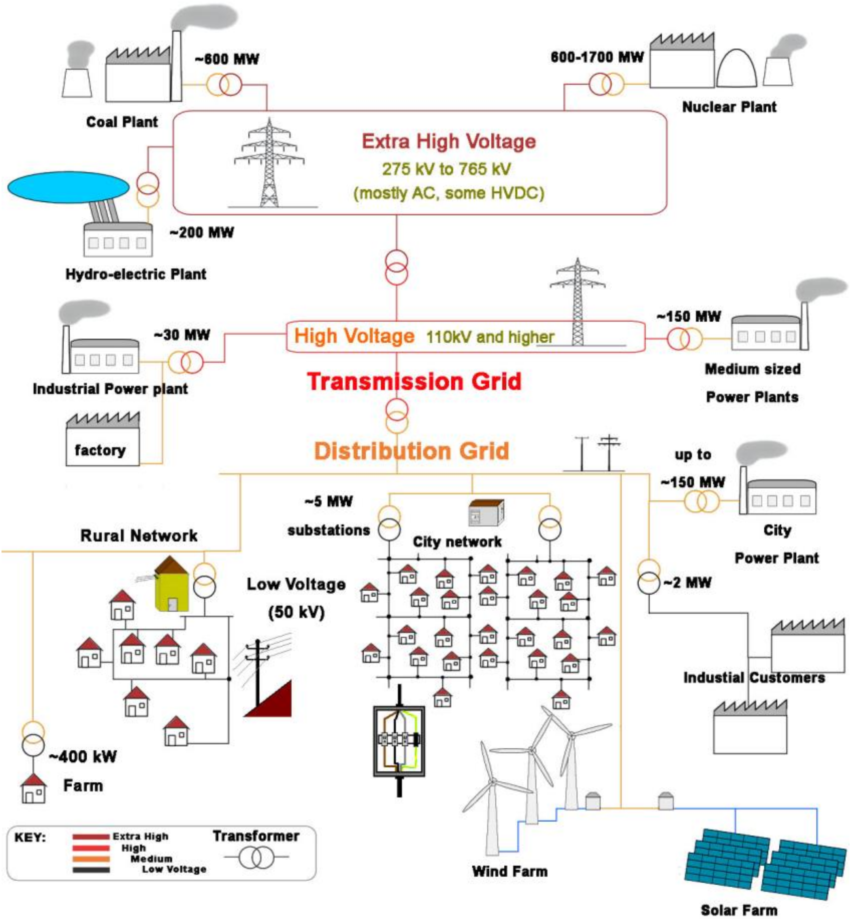
Federico Silvestro, *Università di Genova - DITEN*

Enrico Ragaini, *ABB*

Outline

- Short introduction on the state of the art
- Benefit of Demand Side management
- Example of a Shopping mall model implementation
- Predictive algorithm for load management
- Simulations
- Results
- Conclusions

Smartgrid challenges



- Distribution networks are Active (not "passive" systems) → new paradigms in their operation and control and planning.
- Ability to reduce system losses and improve grid efficiency → a major drive for smart Grid.
- Developments in automation and communications and ICT → Possible to implement centralized, coordinated volt control.
- Smart Grid involves dynamic network management with real time state-estimation

Demand Side Management

- DSM = deliberate alteration of electrical energy use
  - Load response
    - The end user agrees to be disconnected (with or without notice, if necessary, upon discount in tariffs).
  - Price response
    - The end user intentionally modify its demand according to its economical purposes

Active demand

- **Active Demand**” involves all types of equipment that may be installed at the consumers (or prosumers) premises:
  - electrical appliances
  - distributed generation
  - thermal or electrical energy storage systems.

- **Typically available DERs are:**
  - Non controllable loads
  - Smart shiftable loads
  - Smart loads with thermal inertia
  - Curtailable Loads
  - Electric vehicles
  - Non dispatchable generation sources
  - Dispatchable generation sources
  - Storage Systems

Possible roles for Loads

- Risk Management. Energy Providers can use demand response to substantially reduce their risk and their customers' risk in the market.
- Environmental. Demand Response (DR) can help reduce environmental burdens placed on the air, land and water by reducing the need to operate polluting plants.
- End user. Many customers welcome opportunities to manage loads as a way to save on energy bills and for other reasons such as improving the environment.
- Market Power Mitigation. DR programs help mitigate market power of traditional and new energy suppliers. This is especially the case when DR can operate essentially coincident (i.e., in near real time) with tight supplies and/or transmission constraints that might lead to market power.

Loads as active player

- This kind of flexibility, in general, is required to power plants at High Voltage (HV), but with the introduction of liberalized electricity markets and new requirements related to the concept of SmartGrid.
- The Authority for Electricity and Gas (AEEG) in Italy has recently launched a survey to apply the DLC to Small Medium Enterprises (SMEs).
- Therefore, shopping centers, office buildings, medium sized manufacturing industries with interruptible loads, in a power range between 0.5 and 1.5 MW can play an important role.

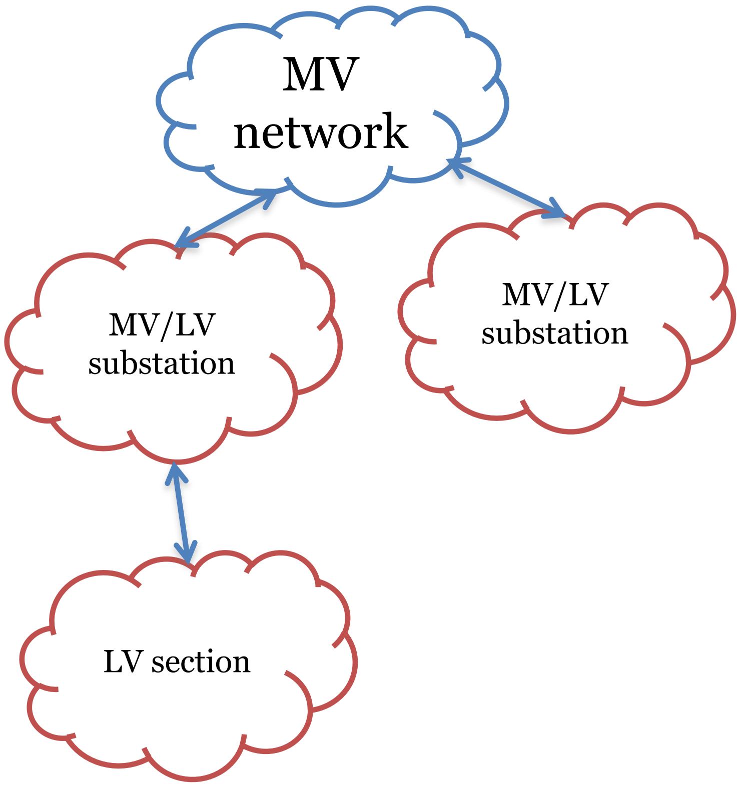
Type of loads

- The effectiveness of load management measures depends on the degree to which it is possible to increase, decrease, or reschedule loads.

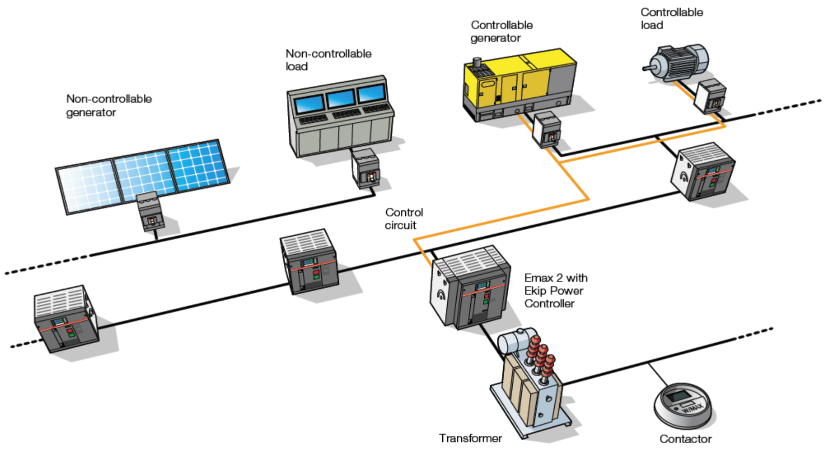
- In general for DSM, loads can be classified into:
  - thermal and refrigeration loads (i.e. HVAC, ovens, etc.)
  - Fixed cycle loads (industrial process, etc.)
  - Other loads (lighting, elevators, etc.)

Basic idea for ILM

- The objective is to keep power demand at the Point of Common Coupling (PCC) controllable:
- The basic idea is to have a circuit breaker with Intelligent Load Management (ILM) equipped with a specific algorithm that can manage the power flow across the main interconnection and can also coordinate *different LV breakers underneath.*
- Each load has a priority in terms of availability to be switched off and on. This allows to rank loads that have to be switched off in order to minimize the impact on installation functionality.

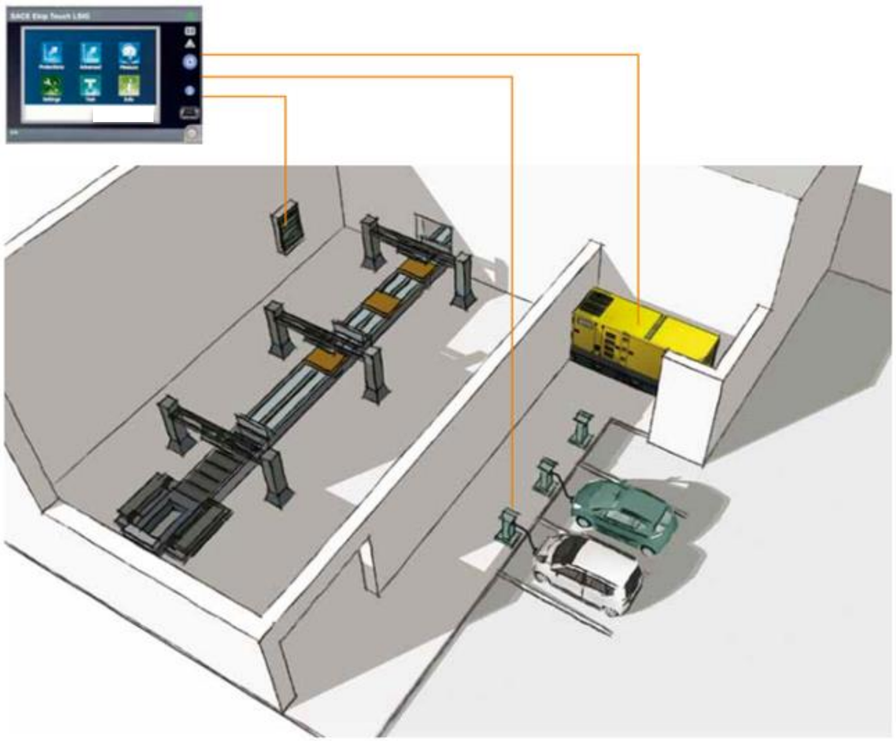


Benefit of ILM



- Peak reduction plans are already in place in several countries (UK, USA, S.Korea)
- Algorithms of Power Controller fit very well with energy market practice (e.g., power average on fixed time slots)
- If applied on large scale, it can ease solution of peak demand issues

Benefit: Improved efficiency



In addition to limiting peaks, ILM can contribute to energy efficiency in several ways:

- if peaks are limited, usage of less efficient generators can be reduced
- limiting load fluctuations help keeping generators close to optimum operation
- designing power distribution infrastructure with built-in control capability leads to a more rational use of energy (e.g., increased modularity)

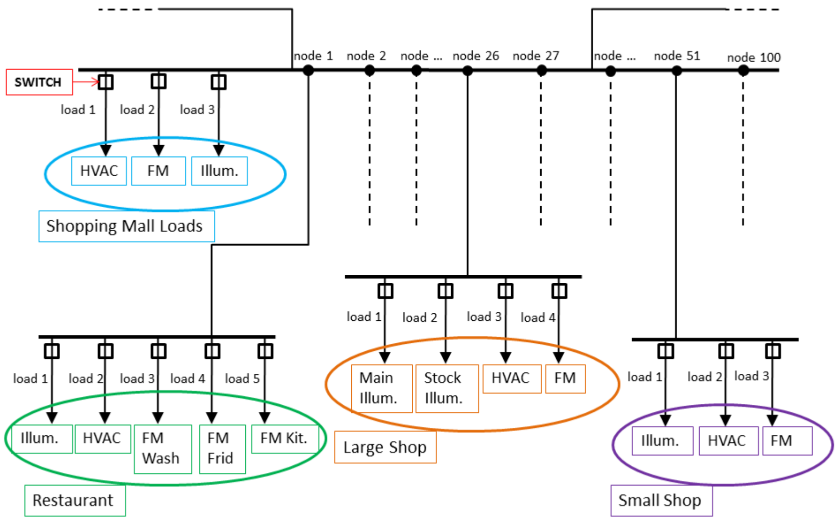
Application: Shopping mall model*

- The model is composed by 100 main users shared among 3 different categories (25 Restaurants, 25 Large Shops and 50 Small Shops). For each category some different loads are assigned:

- **Restaurants** *(Illumination, Kitchen, Dishwasher, Fridge, Heat Ventilation and Air Conditioning (HVAC))*

- **Large Shops** *(Main Illumination, Stock room illumination, Power wiring, HVAC)*

- **Small Shops** *(Illumination, Power wiring, HVAC)*



*F. Adinolfi, A De Danieli, A. Fidigatti, S. Massucco, E. Ragaini, F. Silvestro, " ***Intelligent Load Management for a Shopping Mall Model in a Smartgrid Environment*** ", Powertech Conference, June 2013 Grenoble

Load Profiles

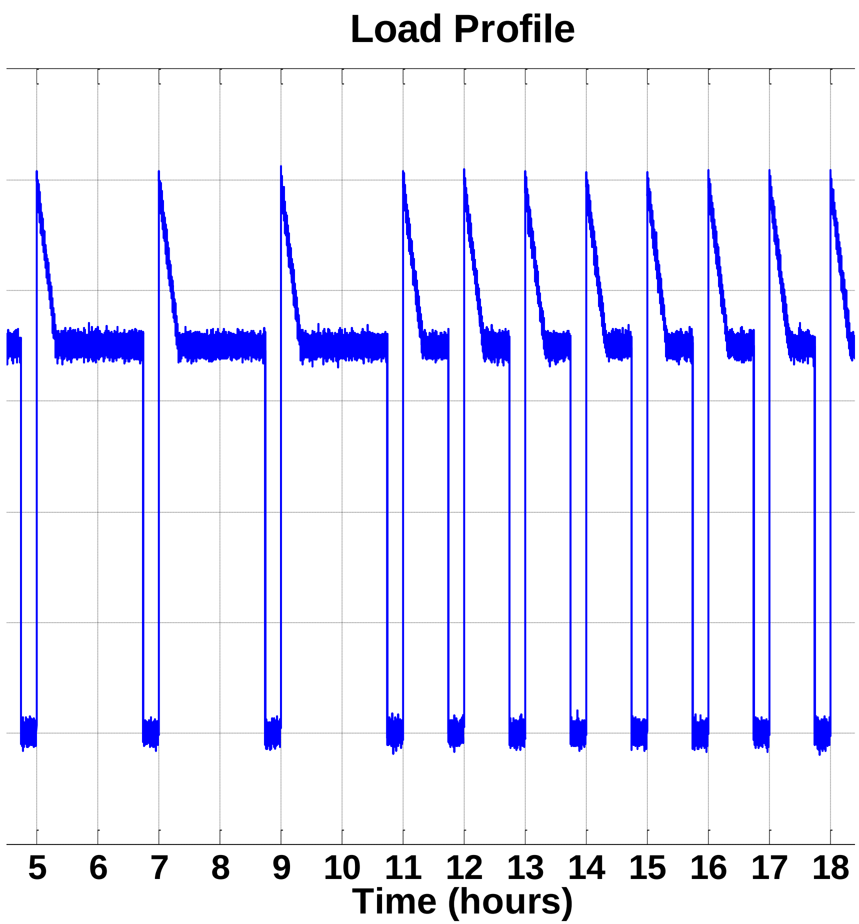
- Three loads (illumination, Power and HVAC), that represent the power need to the mall operation, are added.
- Totally there are 378 electrical loads and each load has its own reference switch.
- Measures:
  - Some consumption profiles are derived from a previous real measurement campaign (e.g. the energy absorption profile of the fridge), instead some others are modeled with a procedure that starts from operating points with samples at 15 minutes and adds a random noise respecting the mean consumption rate.

Payback Effect

- To model the payback effect the absorption profile of these loads is increased to the maximum value every time that a thermal load is switched on after a previous disconnection in order to model the restoration of the target temperature (thermostatic behavior).

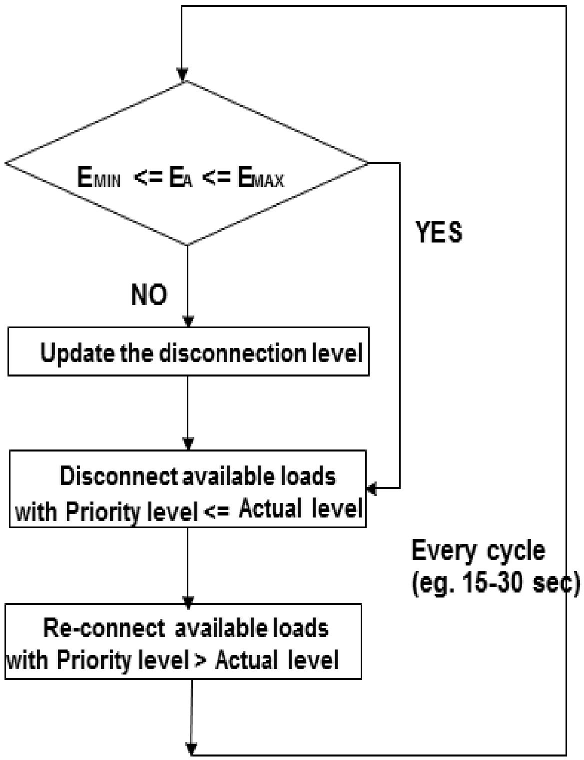
- The change in the power demand lasts less for the fridges (one minute) than for the air conditionings (three minutes) because it is assumed that the thermal capacity of the fridge is lower than the room space.

Load Profiles: pay back effect



- Thermostatic loads:
  - The fridge absorption profile has been modeled starting from real measures, it is characterized with a number of cycles of power consumption due to the assumed use of this device during the day.

Algorithm for the ILM

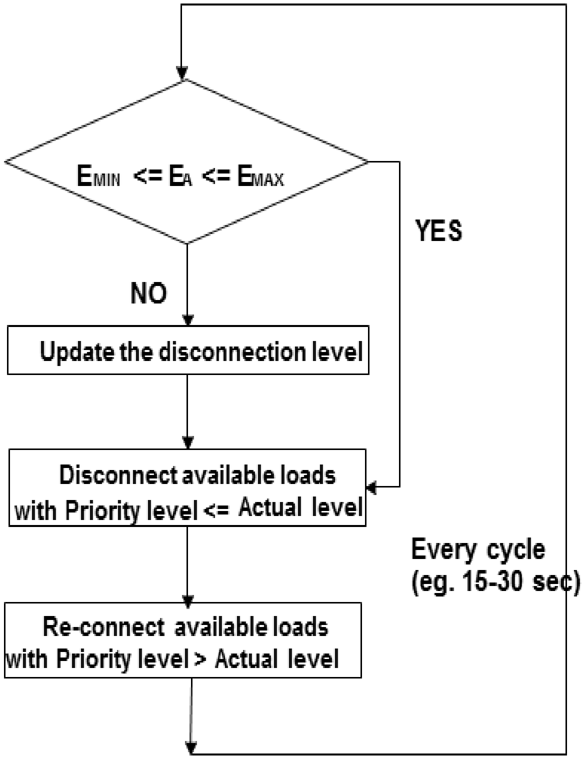


The object of the algorithm is to contain the energy consumption below of a predetermined threshold.

Once defined a **target power MP** (*Mean Power*) as the average value in the **range of time T**, the objective of these controller is to ensure that <u>the final energy at the end of the period T is equal to or less than MP * T.</u>

The proposed predicted rate controller measures the expected slope of average energy consumption at a regular sampling interval and compares it with the instantaneous energy consumption at that particular time.

Algorithm for the ILM



If the predicted line indicates that the desired value E_{max} can be exceeded the controller commands a disconnection, while if the predicted consumption is lower than E_{max} other loads can be connected. **Therefore the controller acts on the instantaneous power, switching on/off the loads according to the inputs received from the algorithm.**

A **priority level** is attached to each breaker by means of a look-up table previously defined. The priority level is update at each cycle and the operation of disconnection and reconnection of each load is actuated in accordance to this level.

Simulations

The simulations are one day long and they cover three different scenarios, in which the effects of the predictive controller are evaluated. The analysis starts from a scenario called **Base Case** so composed:

- 378 loads with a peak absorption of **1639 kW** totally
- Each load has its own breaker with a defined level of priority within 1 and 9
- The time period for the main controller T (I_{CTRL}) is equal to **900** seconds (15 minutes), the cycle time for the priority level is **50** seconds.
- The parameter E_{max} is equals to 275 kWh/15 minutes → **1100 kW**

Shopping Mall Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
HVAC	2	7
Power	6	30
Illumination	9	45
Restaurant Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Illumination	9	45
HVAC	Random (1-3)	Random (1-5)
Dishwasher	7	35
Fridge	5	25
Kitchen	6	30
Large Shop Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Main illumination	9	45
Stock illumination	6	30
HVAC	Random (1-3)	Random (1-5)
Power	8	40
Small Shop Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Illumination	8	40
HVAC	Random (1-3)	Random (1-5)
Power	4	20

Simulations

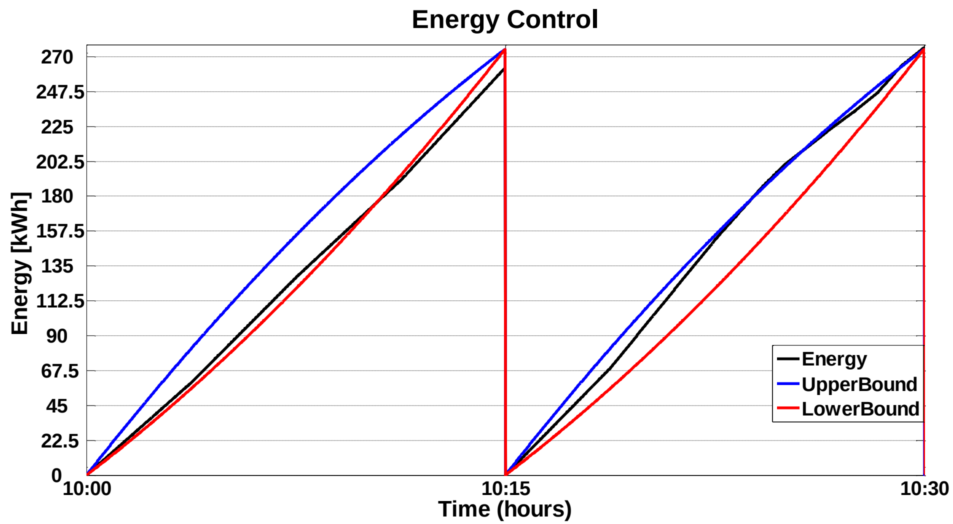
The other two scenarios are so defined:

- In <u>**Case 1**</u> the breakers are characterized with a more detailed **level of priority within 1 and 45**, moreover the cycle time of the algorithm is reduced to 5 seconds.
- In <u>**Case 2**</u> the **logical operation of the controller is changed**: when the forecasted energy consumption oversteps the upper limit, the algorithm tries to estimate directly the priority level below which all the loads have to be disconnected immediately to meet the target consumption in the end of the period T.

Shopping Mall Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
HVAC	2	7
Power	6	30
Lithing	9	45
Restaurant Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Lithing	9	45
HVAC	Random (1-3)	Random (1-5)
Dishwasher	7	35
Fridge	5	25
Kitchen	6	30
Large Shop Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Main Lithing	9	45
Stock Lithing	6	30
HVAC	Random (1-3)	Random (1-5)
Power	8	40
Small Shop Loads		
Load Name	**Priority Value (Base Case)**	**Priority Value (Case 1-2)**
Lithing	8	40
HVAC	Random (1-3)	Random (1-5)
Power	4	20

Results

- Every time that the black line (the energy consumed) oversteps the upper limit (blue line) the controller increases the priority level reached by one and all the breakers with that priority value are opened.
- Then the energy consumed reduces its slope, if the lower bound (red line) is crossed the controller reduces the priority level reached and all the breakers with that priority value are reclosed.

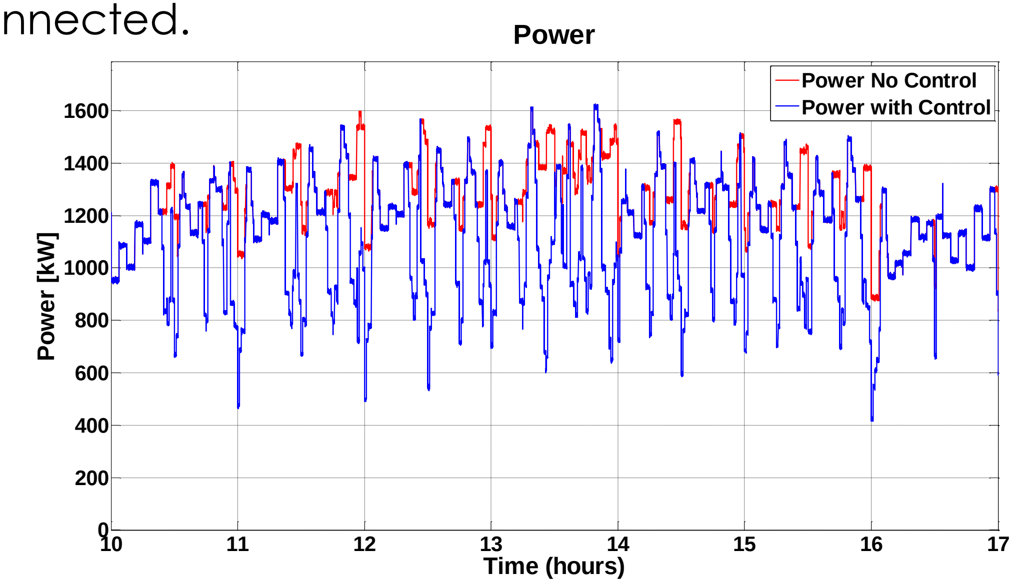


Results

Base Case

The Controller operates only in the central hours of the day when the energy demand grows up significantly. Sometimes the operation of the controller is <u>not sufficient</u> and the energy consumed exceeds the limit, some other times the controller actions are <u>oversize</u> and more loads than necessary are disconnected.

E_{ns} [MWh]	1,124 MWh
T_{disc} [hh:mm:ss]	341:00:00
$T_{disc\%}$ [% of T_{global}]	3.76%
N_{int}	252
e_{max} [%]	3.75%
E_{tot} [kWh]	449,2 kWh



- E_{nd} is the amount of energy not dispatched to the loads due to the operation of the Controller
- T_{disc} measures the overall disconnection time of the loads
- N_{int} is the number of loads disconnected during the simulation
- e_{max} is the maximum percentage error committed
- E_{tot} is the sum of the errors committed in each period T expressed in energy (kWh)

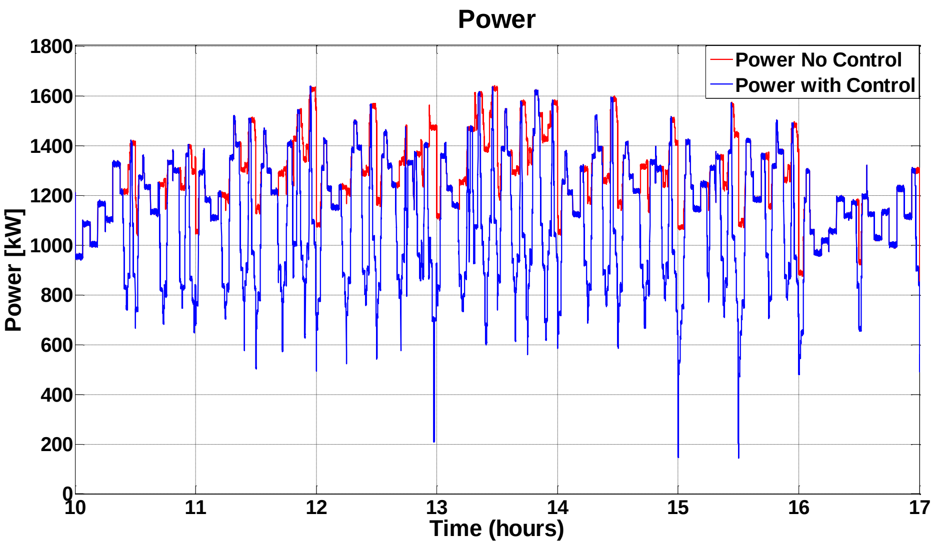
Results

Case 1

In Case 1 in order to make more performing the Controller by pushing the energy consumed closer to the target value to better describe the variability of the loads the **priorities assigned to each switch spread between 1 and 45**.

A comparison with the Base Case permits to evaluate the better behavior of the algorithm and the better results achieved in term of energy consumption, here reported using plots and numerical values.

E_{ns} [MWh]	1,244 MWh
T_{disc} [hh:mm:ss]	375:30:30
$T_{disc\%}$ [% of T_{global}]	4.14%
N_{int}	327
e_{max} [%]	3.64%
E_{tot} [kWh]	251 kWh



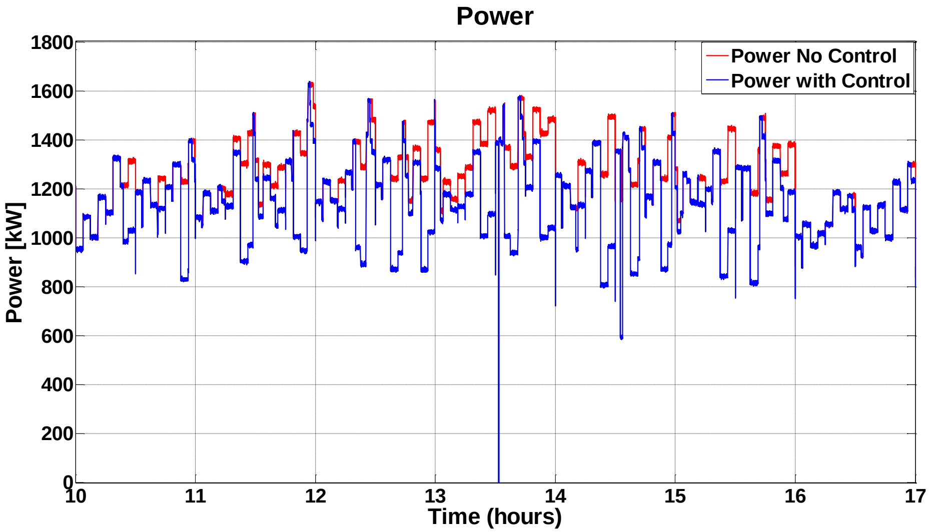
Despite the number of disconnected loads is increased the total error has been reduced to 251 kWh

Results

Case 2

<u>The controller algorithm has been modified</u> to obtain better performances in terms of runtime of the algorithm. When the consumed energy oversteps the upper limit the algorithm tries to estimate how much power has to be disconnected to respect the energy target in the ongoing period. This estimation is based on the assumption that the power demand remains constant during the period. The controller detects up to which priority value is necessary to remove power to obtain the desired result and disconnects all the loads that have a lower priority value.

E_{ns} [MWh]	0,826 MWh
T_{disc} [hh:mm:ss]	249:34:08
$T_{disc\%}$ [% of T_{global}]	2.75%
N_{int}	378
e_{max} [%]	9.67%
E_{tot} [kWh]	1258 kWh



Despite all the loads have been disconnected the error committed is increase and the energy consumed is 1,26 MWh more than desired.

Conclusions and Developments

- The methodology proposed for ILM allows to achieve good results in term of peak shaving and respect of the target consumption for tertiary sector buildings, opening the pace of ILM and indirect load control from DSO in future active distributions networks.
- Using more priority values to characterize the loads it is possible to better contain the energy consumption because the controller has a large variability of priority between which choose the loads to disconnect
- The behaviour of the algorithms is very sensitive to application specific load profiles, and therefore they require some tuning to provide a good response without shedding too many loads
- Future studies will regard the exploration of the control logic (used in Case 2) and the implementation of the “standard” controller (proposed in Case 1) in a more complex model by introducing hierarchy levels for the switches and using also the market price to decide the loads status.

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Federico Silvestro

federico.silvestro@unige.it

University of Genova - DITEN (Department of Electrical, Electronic,Telecommunication Engineering and Naval Architecture)
via all'Opera Pia, 11a, I-16145 - Genova, Italy
Ph. +39-010-353.2380
mobile +39 3292106167