MPC: an Algorithm Improvement

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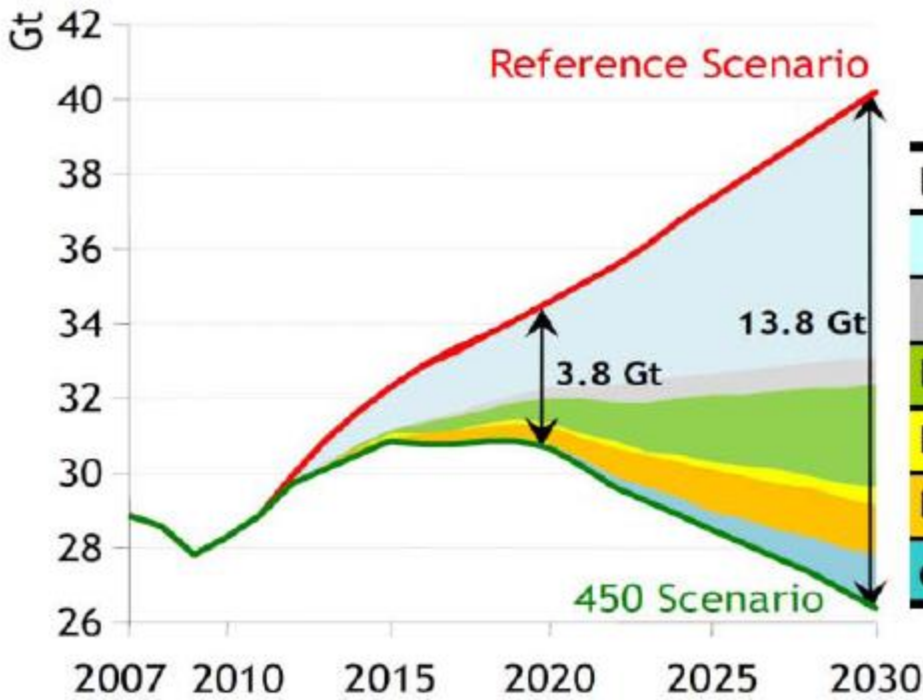
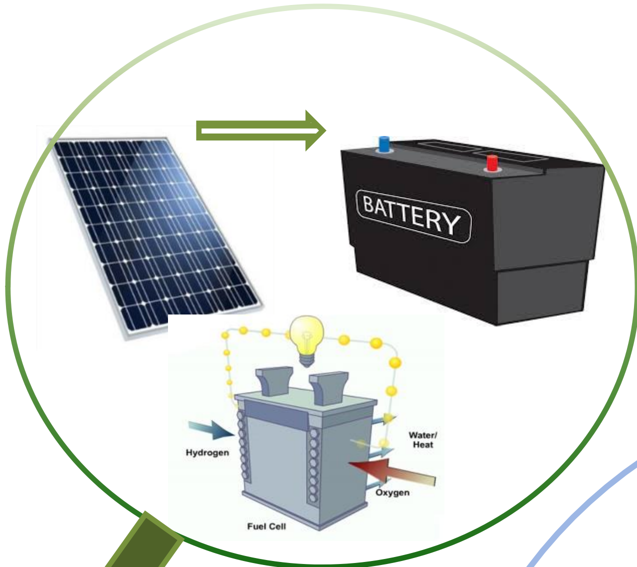
World energy-related CO_2 emission savings by technology in the 450 Scenario relative to the New Policies Scenario

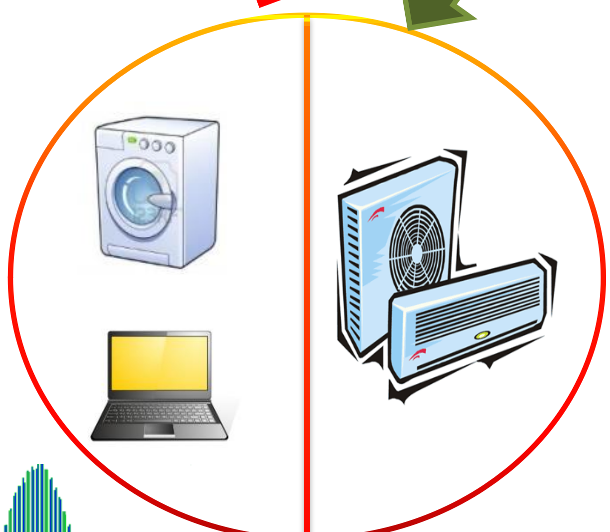


Share of abatement %

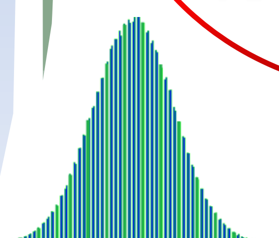
	2020	2030
Efficiency	65	57
End-use	59	52
Power plants	6	5
Renewables	18	20
Biofuels	1	3
Nuclear	13	10
CCS	3	10

The System





Distributed Generation	Energy source *(by Priority)*
Off grid Hybrid system	*Pv panel* *Battery* *Fuel Cell*
Energy load	Goal
Electric load + Thermal load (HVAC system)	*Optimal Management with renewables sources*



RULE BASED CONTROL

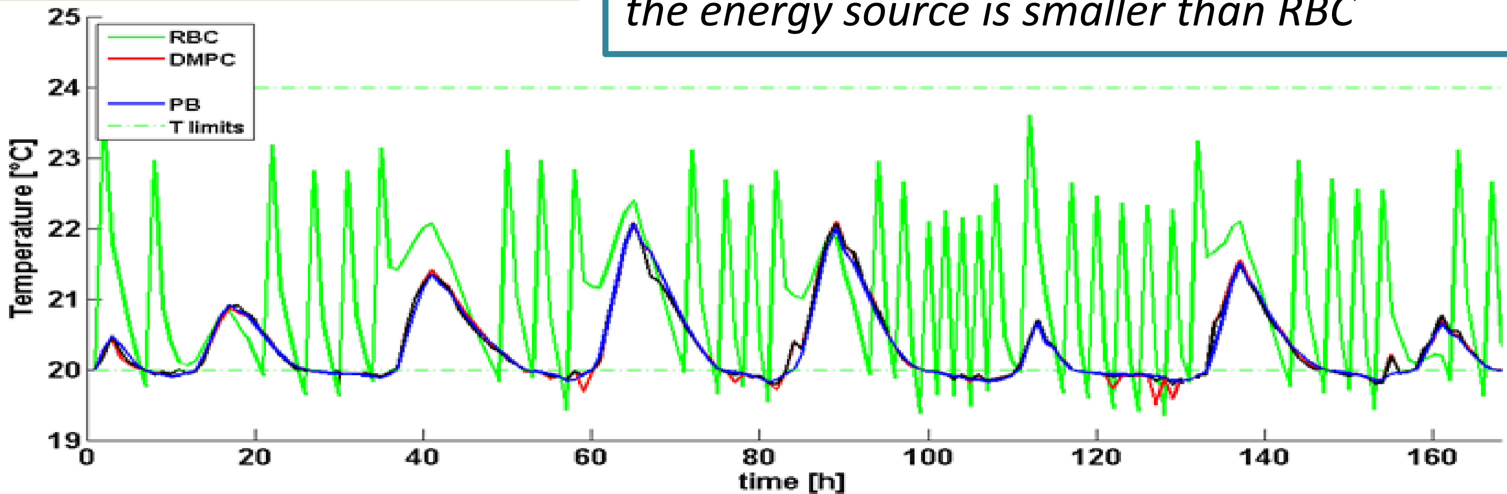
- **USES ONLY** current state
- START and STOP of FC and HVAC
- It works with an ***if condition then action*** sequence of commands using some threshold parameter (temperature or voltage)

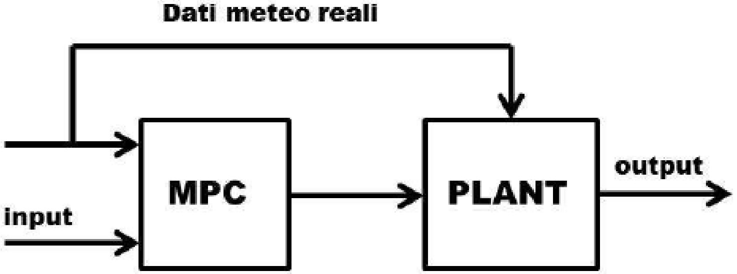
Expected Behaviour :*very high variability of internal condition and not optmal use of Fuel Cell(FC).*

MODEL PREDICTIVE CONTROL

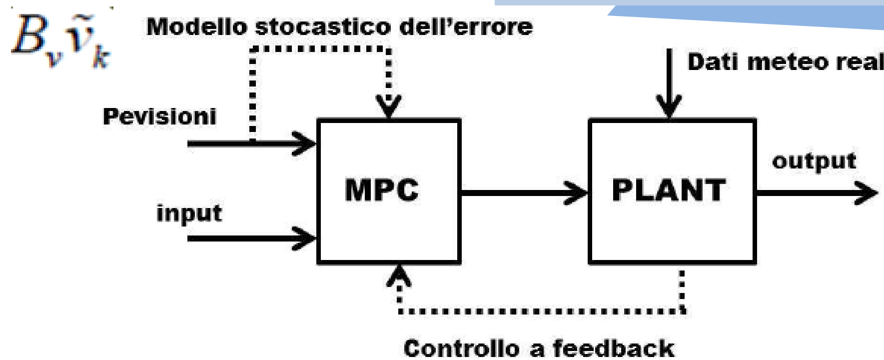
- **USES weather forecasts**
- REGULATES both FC and HVAC
- It works modelling our system and launching an optimization function w.r.t. pre-setted weights.

Expected Behaviour: *low variability of condition and in FC use. Power needed from the energy source is smaller than RBC*



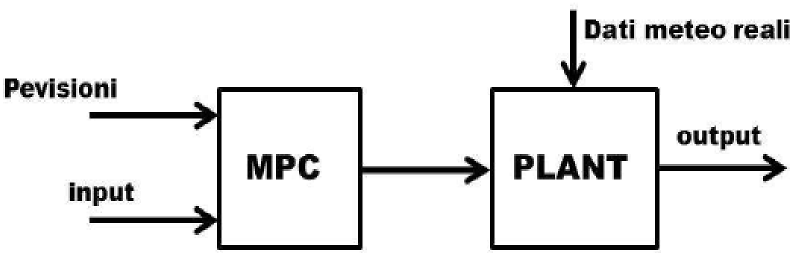


Performance Bound: *Forecast used are the same than future disturbances.*

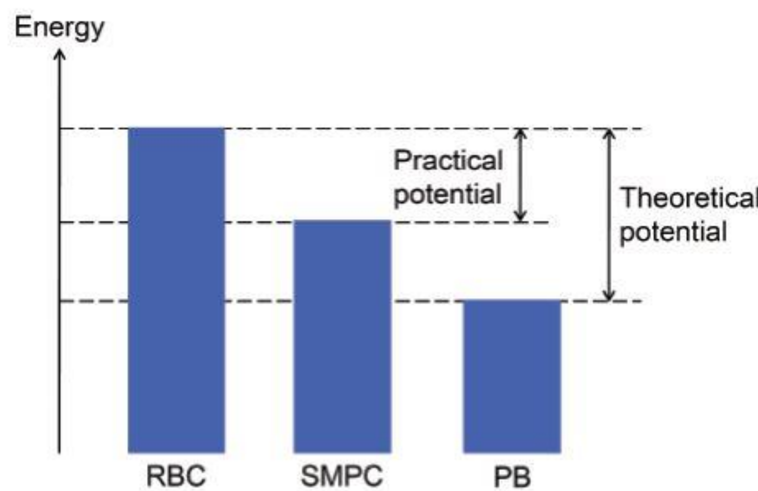


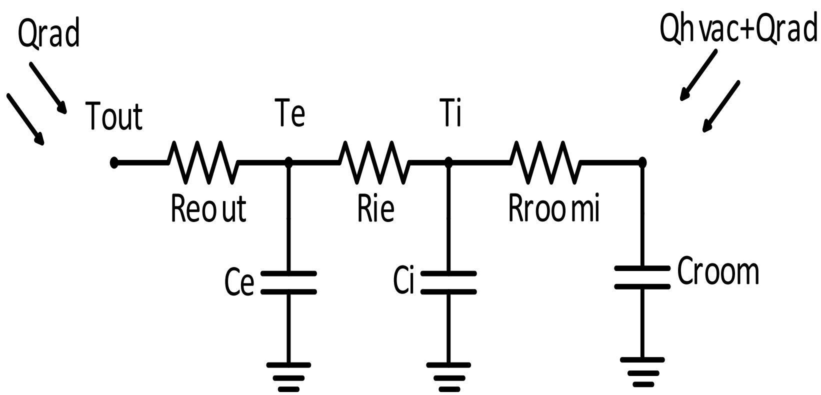
$$\{u\}_t = [M]_t \cdot \{w\}_t + \{h\}_t$$

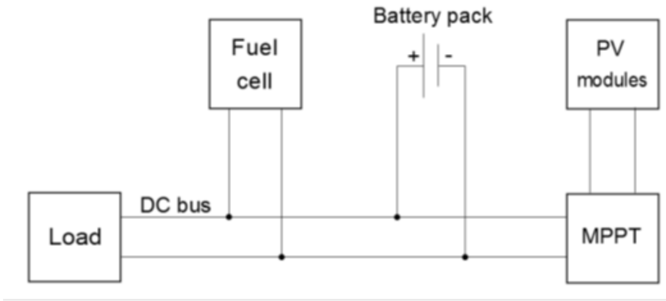
STOCASTIC: *we construct a model of the uncertainty to reach better performances.*



DETERMINISTIC: *the uncertainty between forecast and real disturbances gives us an error in the control .*







Discretized Thermal Power balance (ex.)

$$T_{e_{k+1}} = T_{e_k}\left(1-\frac{R_{eout}+R_{ie}}{R_{eout}\cdot R_{ie}}\cdot\frac{t}{C_e}\right)+\frac{t}{C_e R_{ie}}T_i+\frac{t}{C_e R_{eout}}T_{out}+\frac{t}{C_e}Q_{rad}$$

Discretized Balance of Power

$$G_{k+1}=G_k+\left(P_{pv}+P_{fc}-\frac{Q_{HVAC}}{cop}-P_{load}\right)_k\cdot t$$

- **Electric modeling** (DC bus with battery voltage as reference)
- **Thermal Modeling** (lumped parameter model with validation through EnergyPlus Thermodynamic Model)

$$\{x_{t+1}\} = [A]\{x_t\} + [B]\{u_t\} + [B_d]\{d_t\} + [B_v]\{\tilde{v}\}$$
$$\{y_t\} = [C]\{x_t\}$$

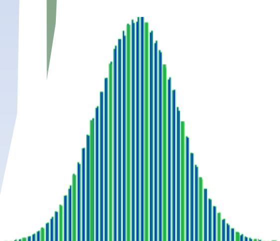
System dynamics

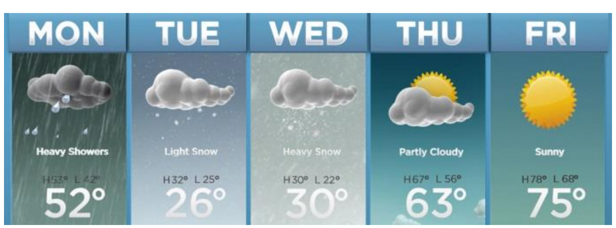
$$U_{min} \le U_0 \le U_{max} \qquad Y_{min} \le Y \le Y_{max}$$
$$J_0(Y,U_0) = (Rf - Y)'\tilde{Q}(Rf - Y) + U_0'RU_0$$

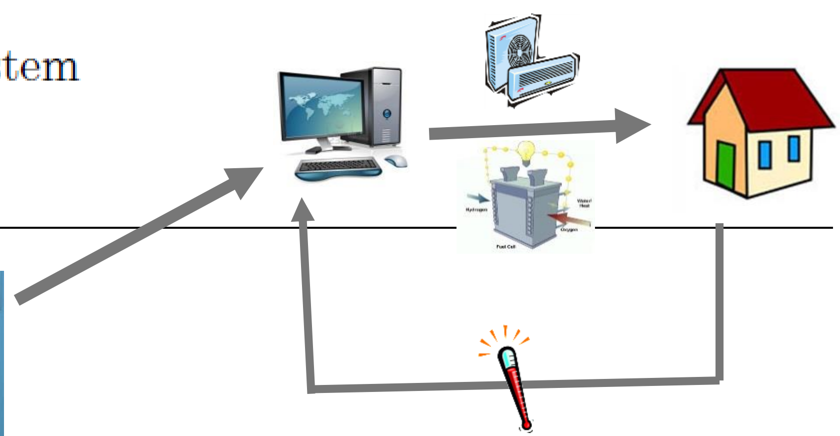
Function to be minimized with constraints

Algorithm 1 Receding horizon control

1. measure the state x_t at time t
2. obtain $\mathbf{u}_t^*(x_t) := \{u_{t|t}^*, u_{t+1|t}^*, ..., u_{t+N-1|t}^*\}$ by solving an optimization problem with horizon N
3. apply the first element $u_{t|t}^*$ to the system
4. proceed to time step $t+1$
5. go to 1.







THE PROBLEM

$$x_{k+1} = Ax_k + B_u u_k + B_d d_k + B_v \tilde{v}_k$$

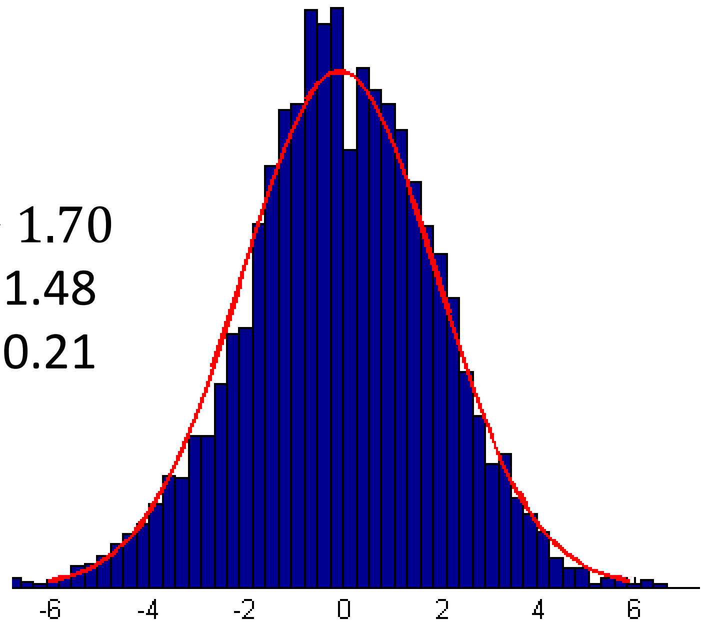
uncertainty of the forecast. It exists only in the SMPC

First Idea!

$$v_k = \bar{v}_k + \tilde{v}_k$$

T_real (v_k), *T_prevision* ($\bar{v}_k$), *T_err: gaussian nature* ($\tilde{v}_k$)

σ=~ 1.70
μ_1=1.48
μ_2=0.21



IF:Model t_err with a single gaussian.
THEN: High variability of results.

highest variability of the values! we need to decrease the uncertainty of the model by a Statistical Analysis of the data.

$$x_{k+1} = Ax_k + B_u u_k + B_d d_k + B_v \tilde{v}_k$$

$$\tilde{v}_{k+1} = F\tilde{v}_k + Kw_k$$

$$\{u\}_t = [M]_t \cdot \{w\}_t + \{h\}_t$$

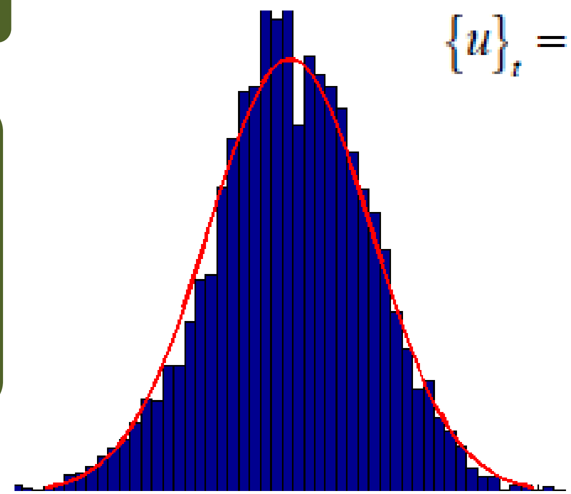
<u>ASSUMPTION</u>: T_error is treated as an HISTORICAL SERIES

1 Computation of auto-correlation coefficients ; (***ρ***)

WE WANT A LINEAR Auto-Regressive MODEL!

2 Least square methods (OLS); for finding best linear coefficient

3 Modelization and check the gaussianity of the residual



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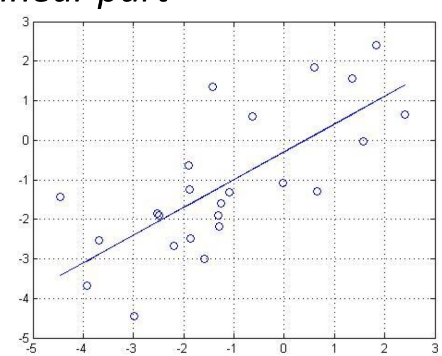
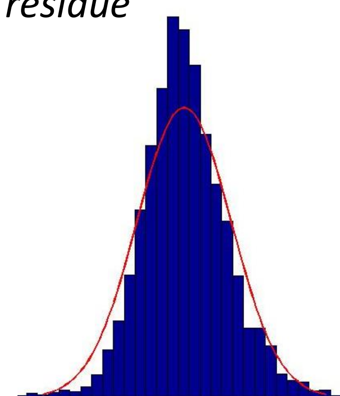
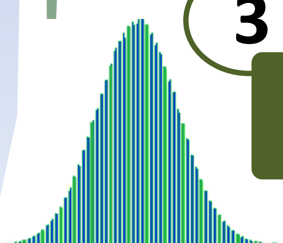
F is the coeff. of the linear part



+

K is the deviation of the residue





$$\tilde{v}_{k+1} = F\tilde{v}_k + Kw_k$$

Our new uncertainty

SET 1

Hourly data

Characteristic of t_err:

μ=1.48 °C (very high systematic error; low quality of data)

σ=1.67

Results

ρ_mean=~ 0.84

F_mean=~0.84

K=0.80

q(costant coeff.)=0.27

SET 2

data every 3 hour, linearized at every hour.

Characteristic of t_err

μ=0.2 °C

σ=1.74

Results

ρ_mean=~ 0.80

F_mean=~0.80(in historical series F it is almost equal with ***ρ***)

K=0.88

q(costant coeff.)=~0

- Weather forecasts with 1 h detail show very good autocorrelation coefficients.
- The statistic procedure can be replied with high robustness with different weather forecasts sources .
- The MPC algorithm faces less uncertainties (smaller value of w): higher SMPC performances are expected through the feedback controll with respect to the Deterministic MPC.

THANKS FOR THE ATTENTION!