EMR'13
Lille
Sept. 2013

Summer School EMR'13
"Energetic Macroscopic Representation"

Université Lille1 Sciences et Technologies

«Optimal synthesis of cascaded loop controllers with saturation using Ant Colony Optimization»

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GREI Groupe de recherche en électronique industrielle

UQTR ÉCOLE D'INGÉNIERIE Génie électrique et génie informatique

- Outline -

« Introduction »

Many methods and rules have been proposed for tuning Proportional-Integral-Derivative (PID) controllers;

- Ziegler-Nichols
- Frequency response methods
- Pole placement

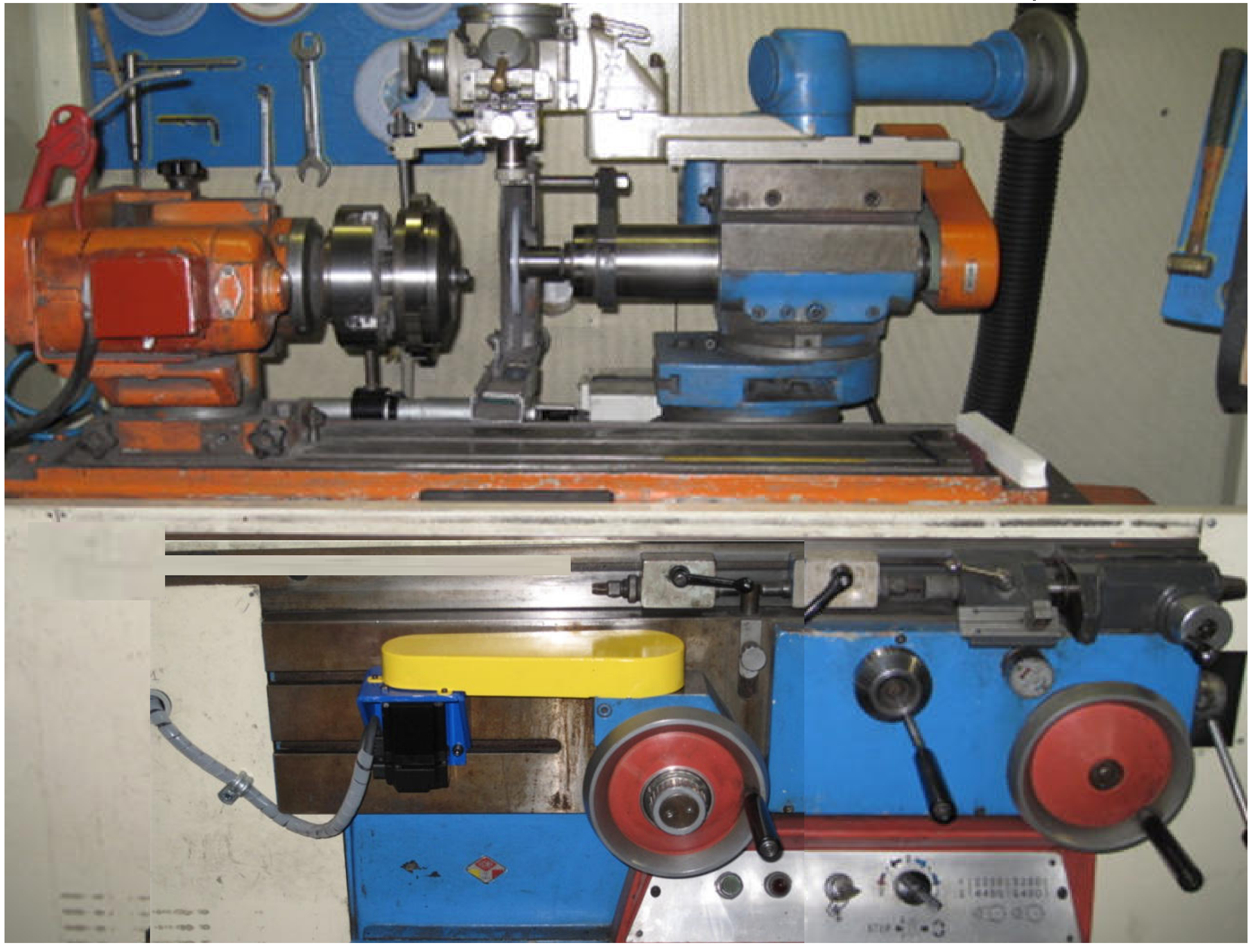
Problematic : Rules typically respond to particular performance criteria and do not take into account controller saturation, and rely on a time separation argument in complex systems.

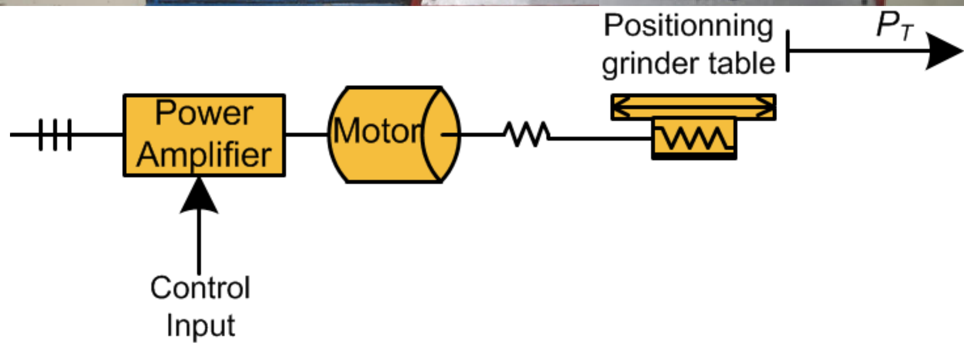
Proposition :

ACO based methodology applied to a motion system with flexible coupling **for tuning controllers in presence of saturation**.

«Industrial grinder EMR and control structure»

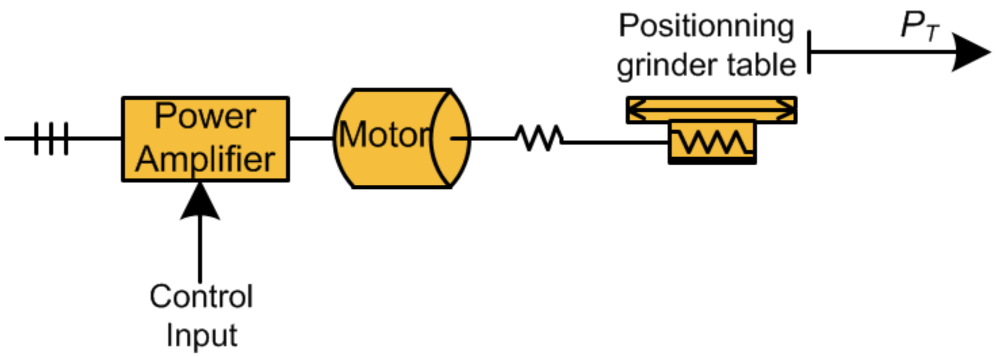
- Studied system -

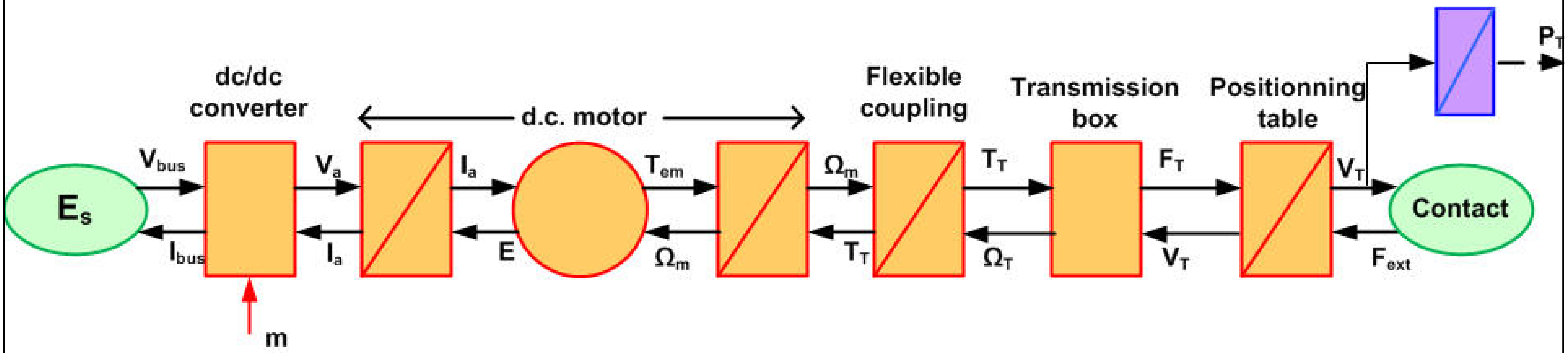




- EMR of the industrial grinder -

EMR #1

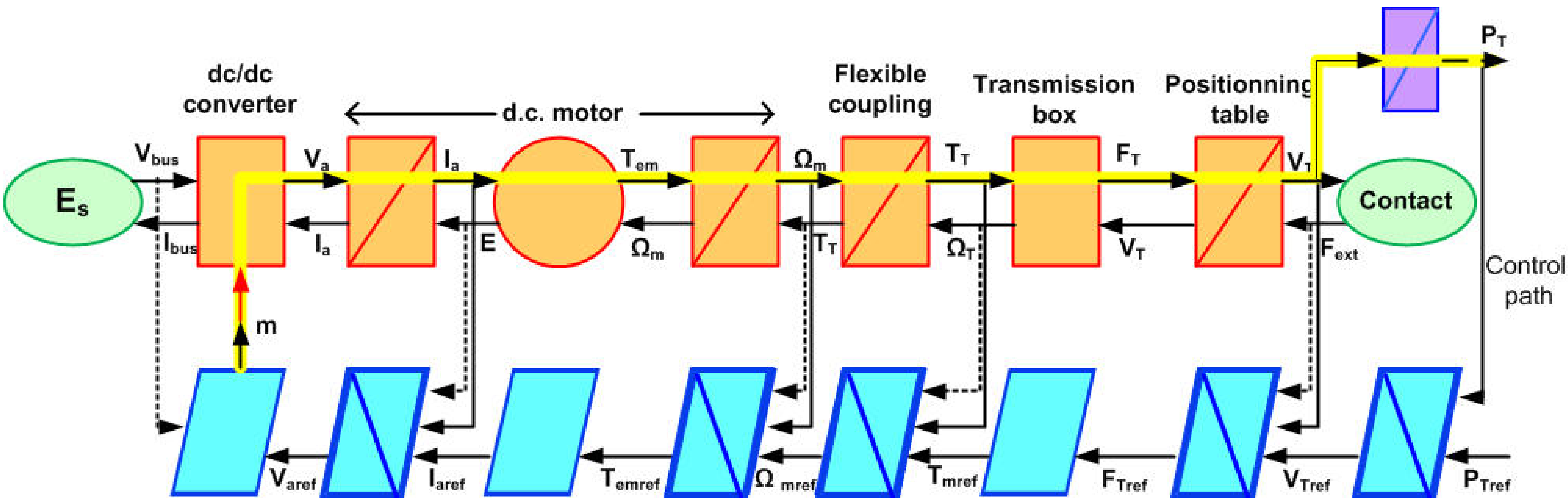




➔leads to a cascade control loop with 5 controllers

- EMR of the industrial grinder -

EMR #1



- EMR of the industrial grinder -

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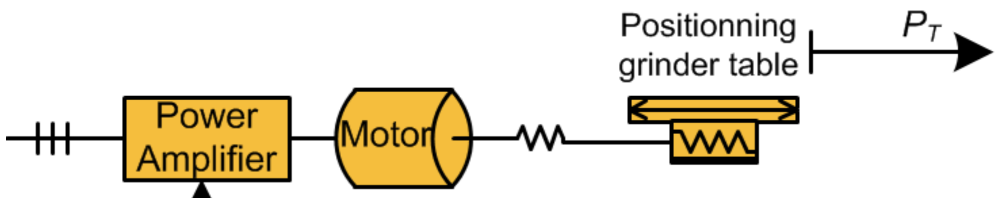
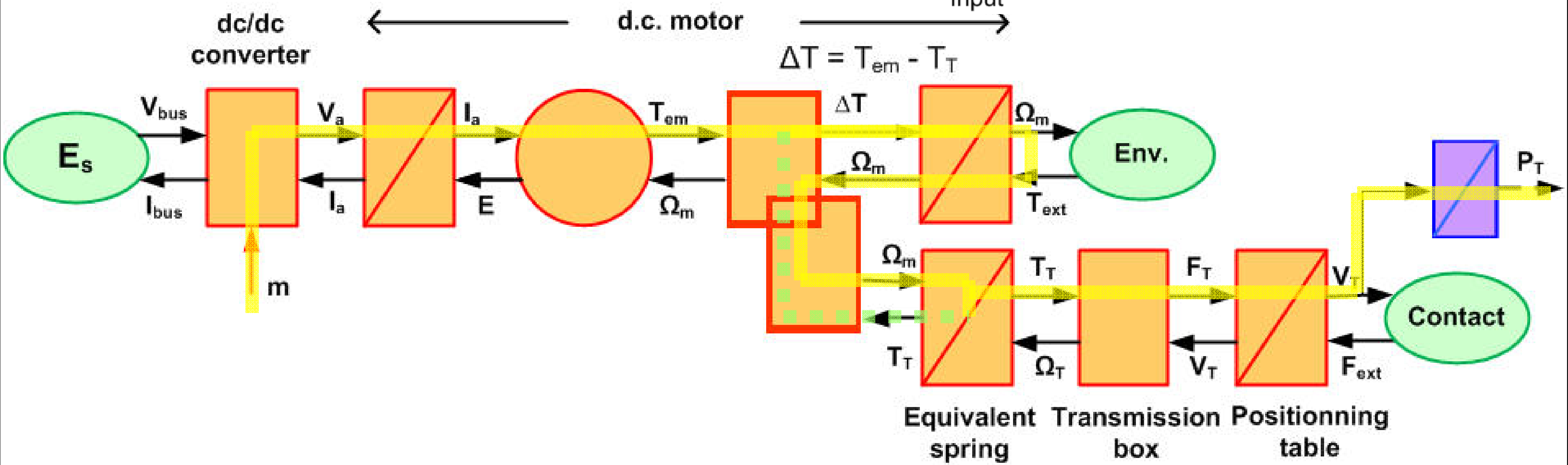
EMR #2

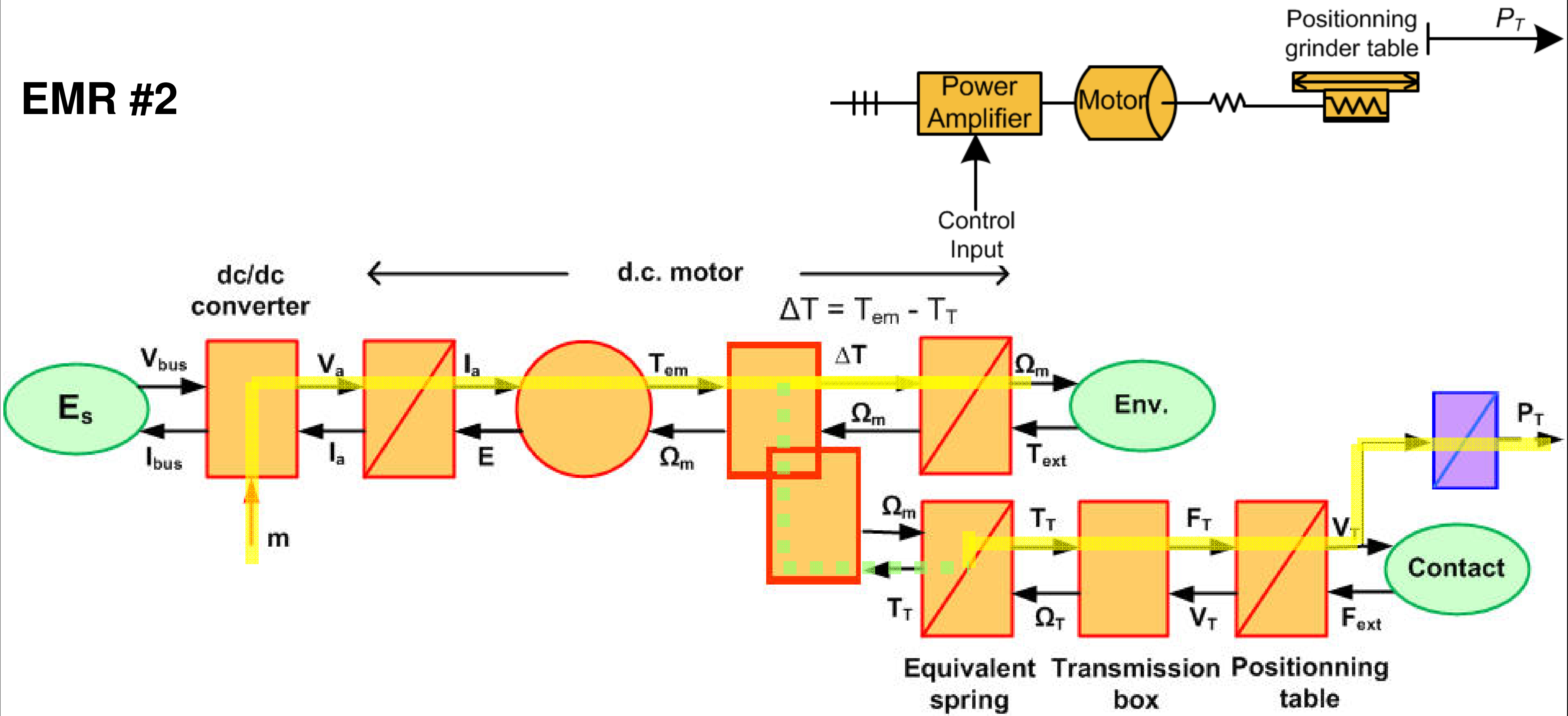




➔hypothesis are required to reproduce the standard 1½ axis industrial controller structure

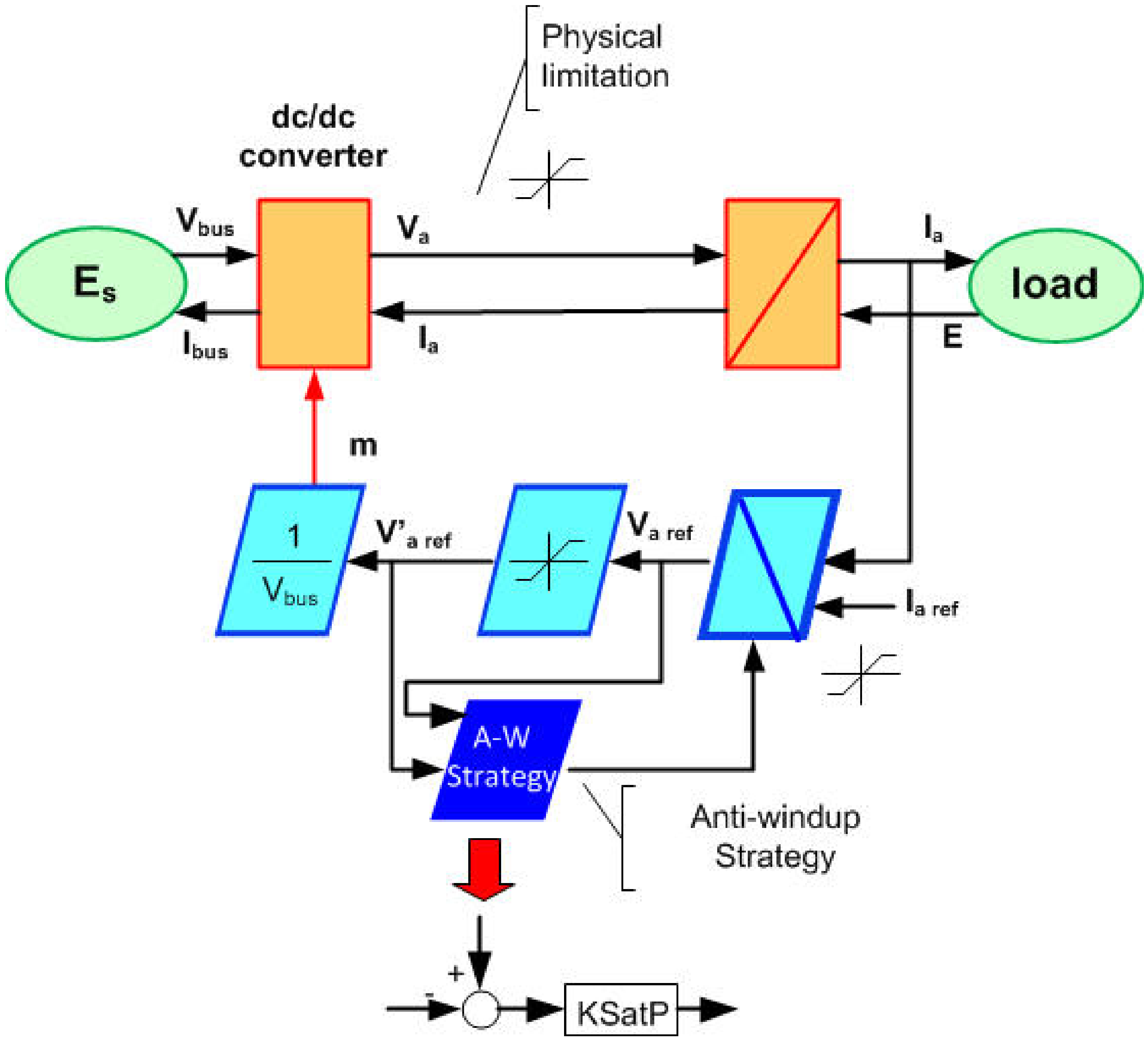
- EMR of the industrial grinder -

EMR #2



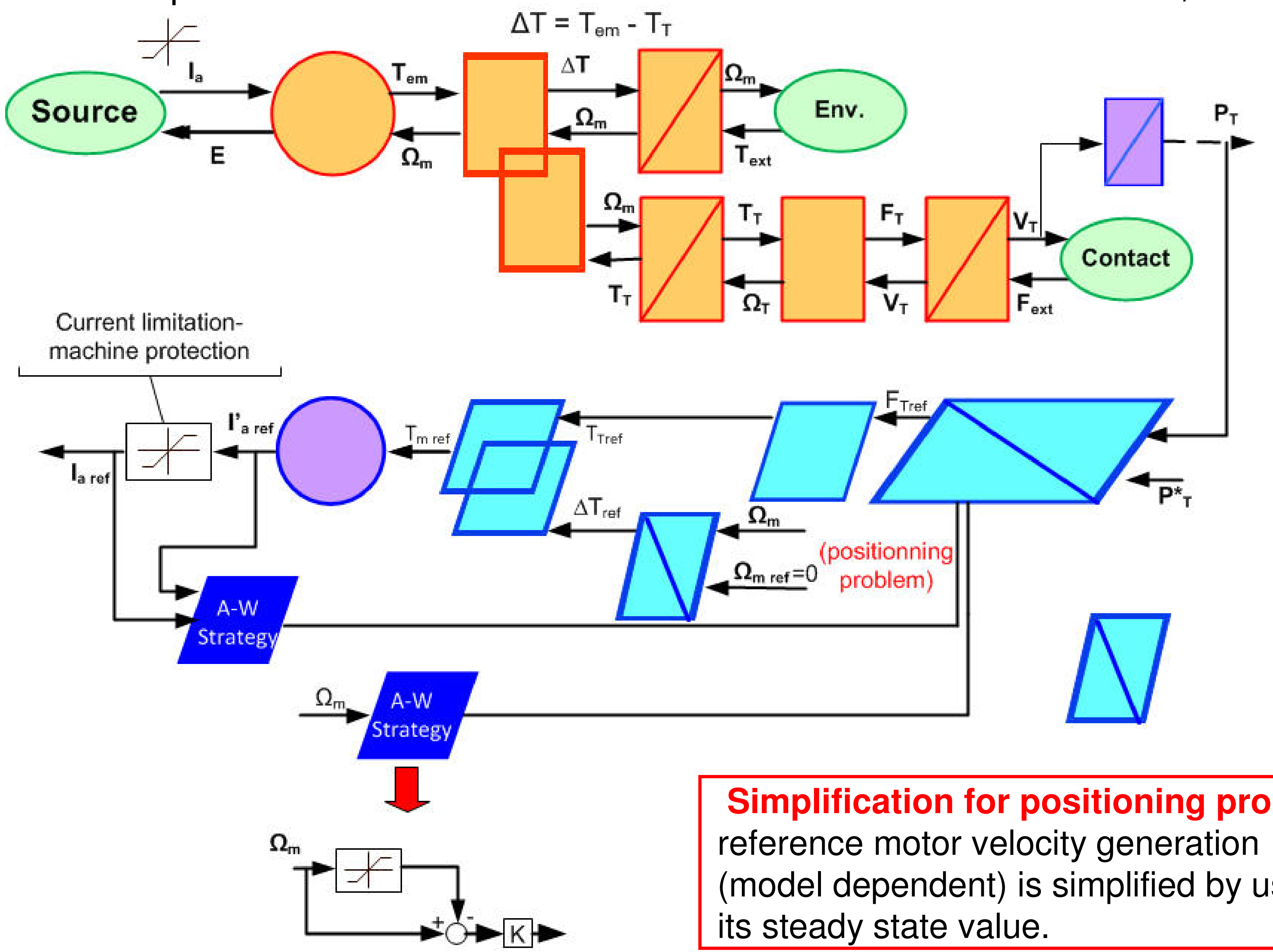
➔we evaluate independently driving torque T_T and ΔT; we assume external motor velocity reference, set to its final value.

PI current practical control structure



- Inversion-based control of the system -

Position practical control structure



Simplification for positioning problem:
reference motor velocity generation (model dependent) is simplified by using its steady state value.

«Ant Colony Optimization (ACO)»

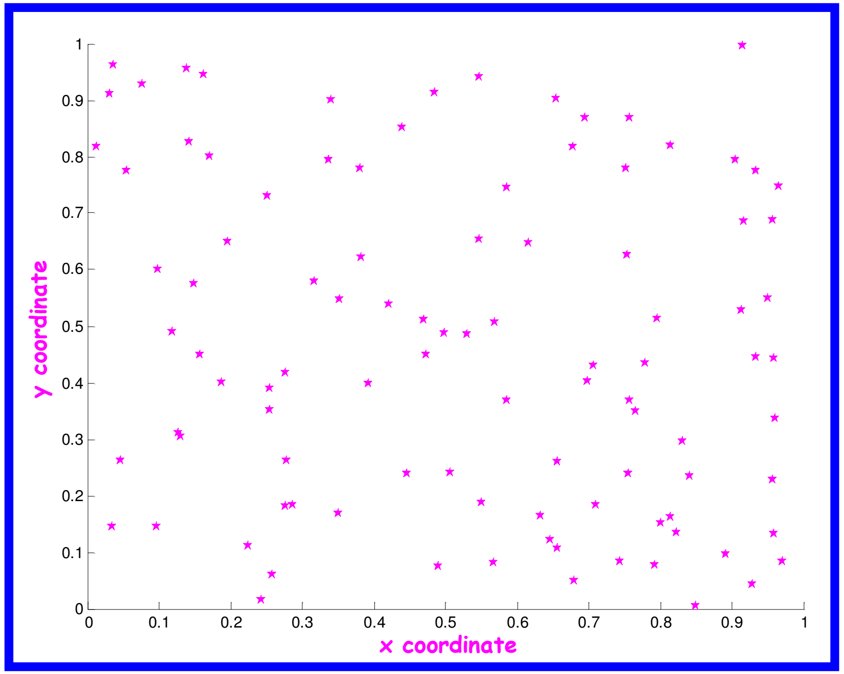
Inspired by the behavior of ants

•Tendency of taking the shortest road facing multiple paths to a food source

•Communication via their environment by depositing traces of pheromones

Illustration of ACO with Traveling Salesman Problem:

Find the shortest path connecting several cities



100 cities with random coordinates

Decison rule:

probability of ant k located in city i to choose city j

$$P_{ij}^{k}(t) = \frac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]^{\beta}}{\sum_{l \in N_i^k}\left[\tau_{il}(t)\right]^{\alpha}\left[\eta_{il}(t)\right]^{\beta}}$$

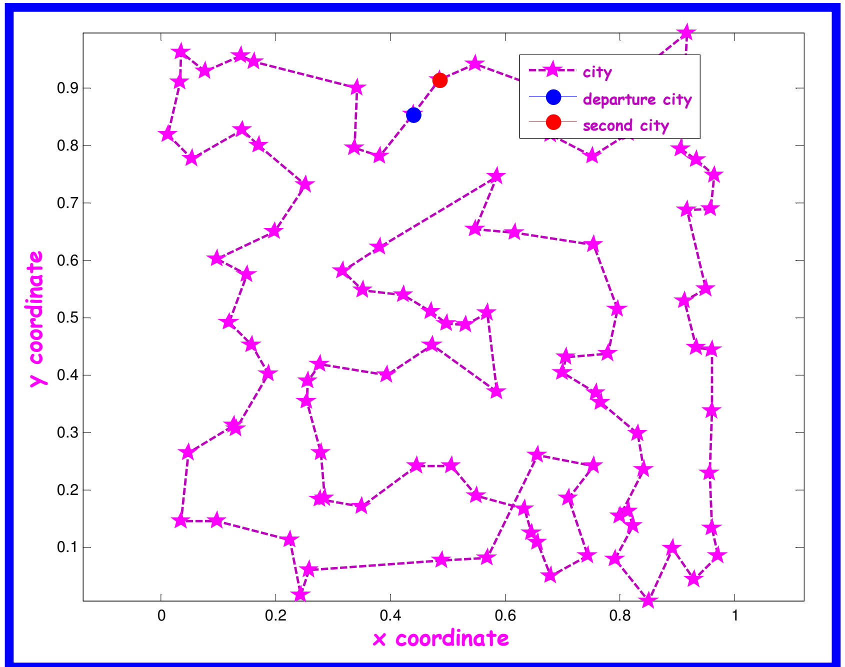
η_{ij} is the inverse distance between cities i and j

Update of pheromone matrix

$$\tau_{ij}(t+1) = \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\,\tau_{ij}^{k}(t) \qquad \forall\,(i,j) \in L$$

Quantity of deposited pheromones is function of the quality of the solution (total length L of path):

$$\Delta\,\tau_{ij}^{k}(t) = \begin{cases} 1/L^{k} & \forall\,(i,j) \in L \\ 0 & \text{otherwise} \end{cases}$$



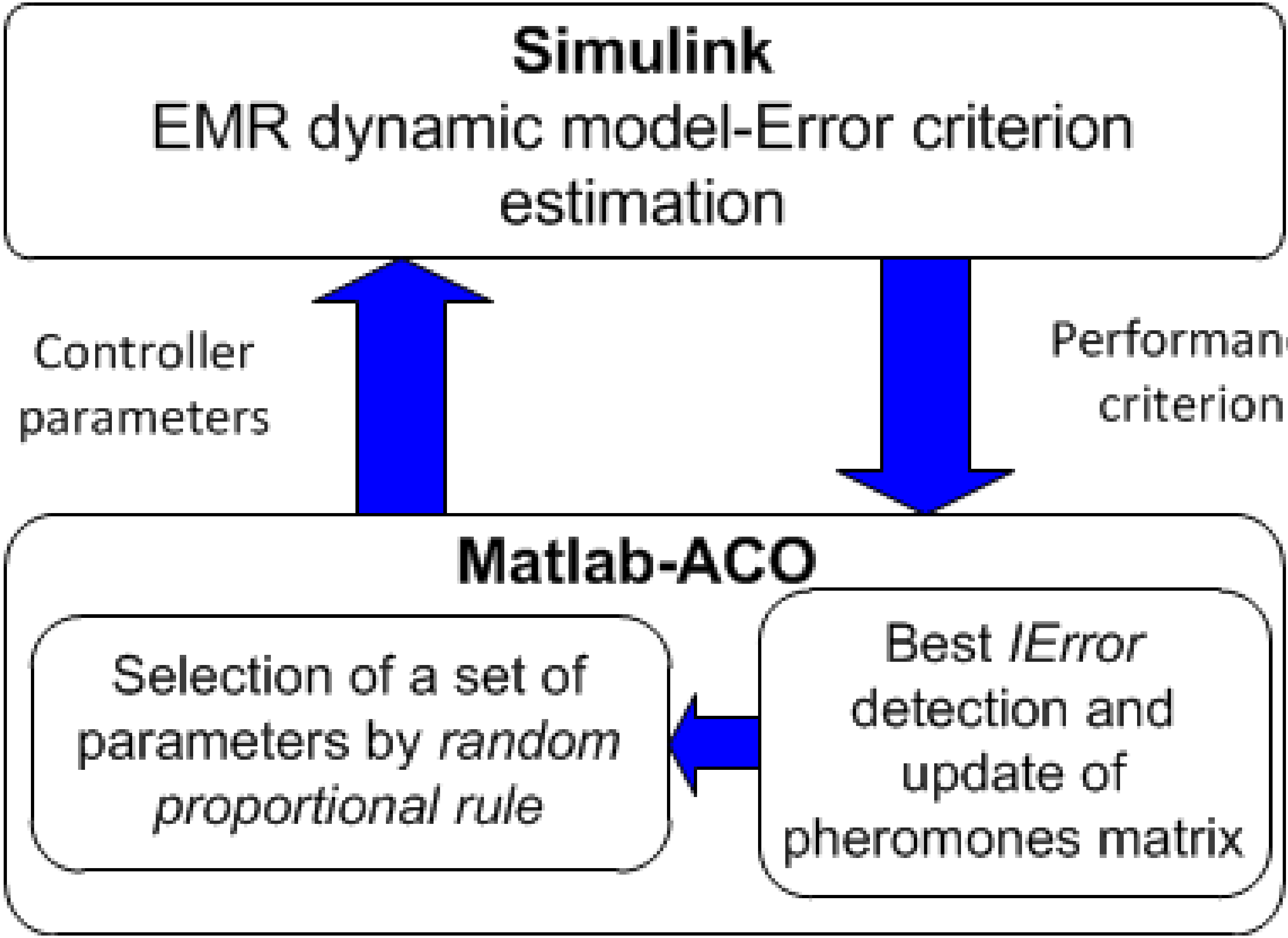
Shortest path found (L=8.2244 units)

Evaporation process is used to avoid unlimited accumulation of pheromones and to allow forgetting previous bad decisions :

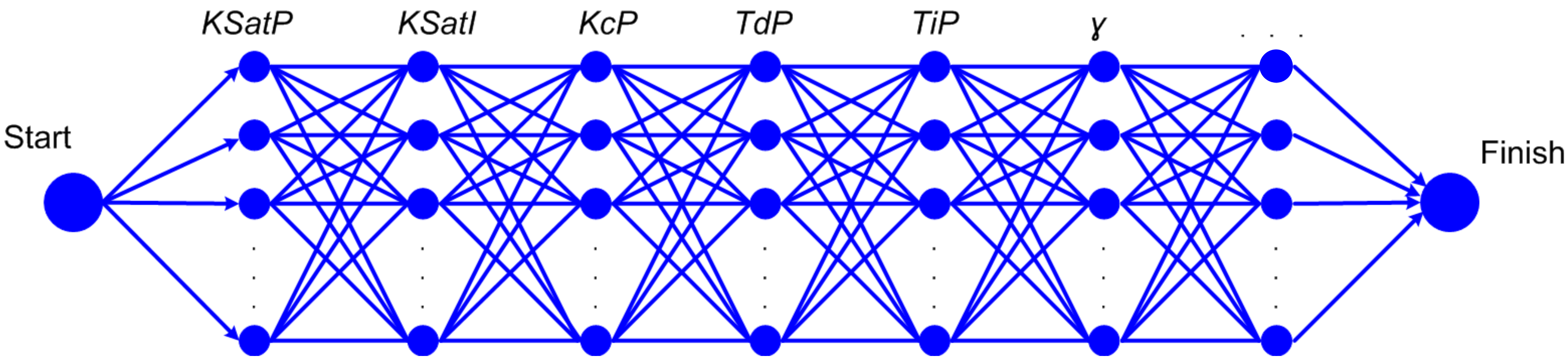
$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}\ (t+1) \qquad \forall\,(i,j) \in L$$

«ACO application for PID parameter tuning with anti-windup management»

- Simulation environment -



- controller tuning ➡ combinatorial optimization problem -



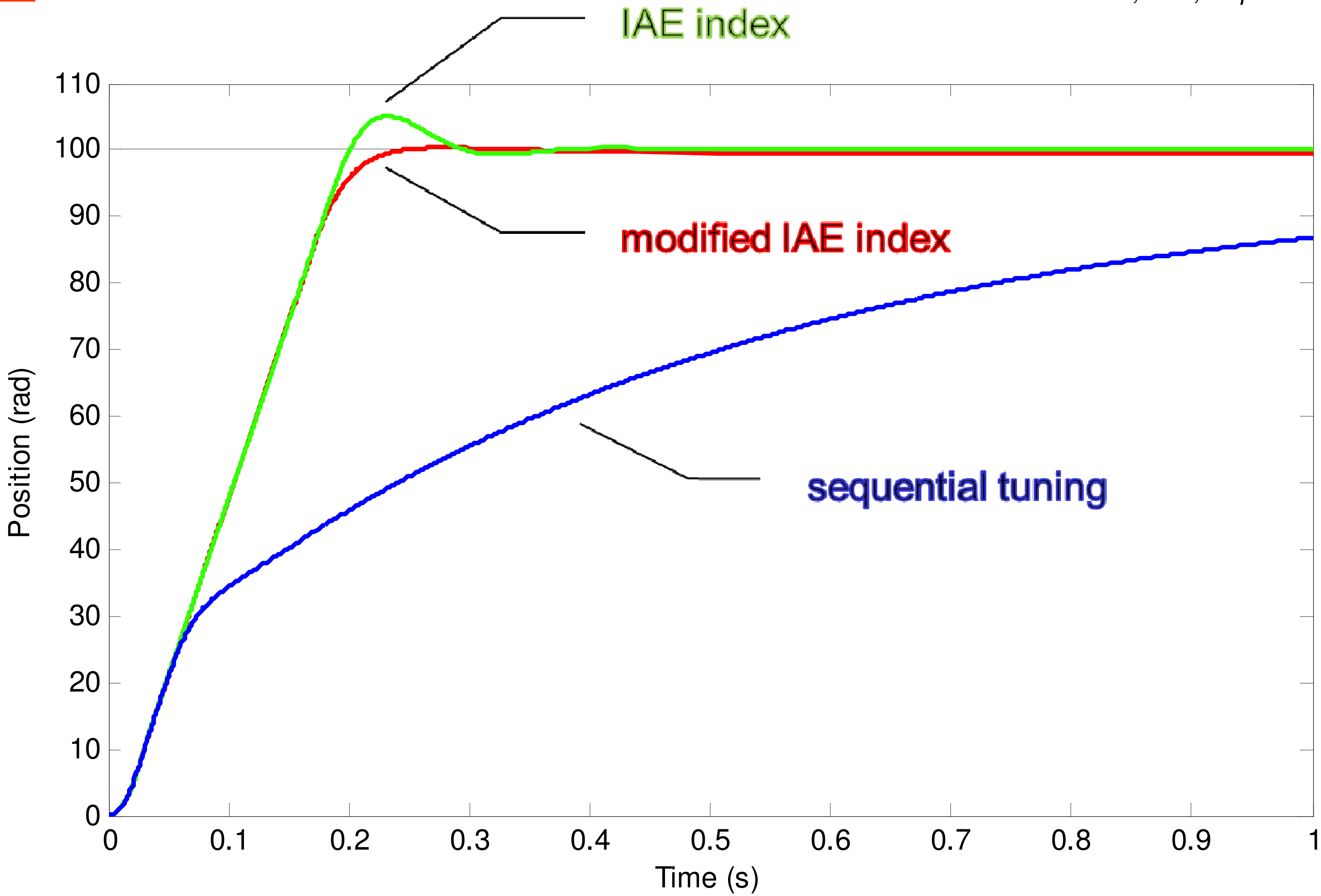
Performance criterion = f(y*, y, u, t)

$$IError = \int_0^{Ts} |e(t)|\, dt + \sigma \int_0^{Ts} e_d(t)\, dt$$

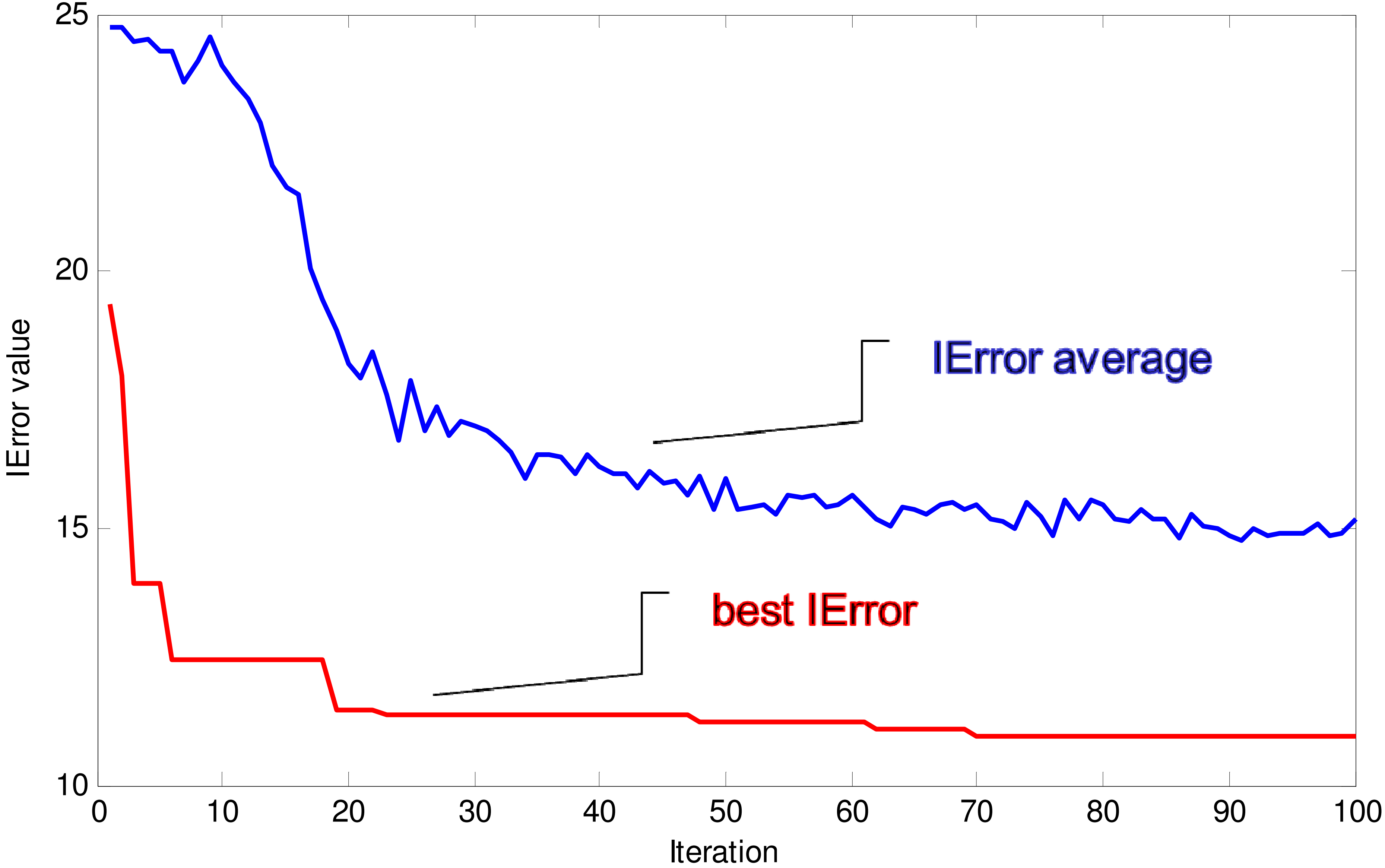
$$e_d(\mathrm{t}) = \begin{cases} |e(t)| & \text{during response overshoots} \\ 0 & \text{otherwise} \end{cases}$$

« Results»

- ACO results -


IAE index
modified IAE index
sequential tuning
Position (rad)
Time (s)
0
10
20
30
40
50
60
70
80
90
100
110
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

- Convergence rate of ACO for the modified IAE with saturation -



«Conclusion»

EMR representation :

❖two EMRs of the same system may lead to very different control structures

❖the 1 ½ axis control structure can be improved with other choices for the distribution criterion

❖EMR allows to highlight anti-windup management strategies

ACO method :

❖fills a gap for adjusting control structures with saturation and multi-loop control structures, for various types of controllers

❖performance criterion can be adapted to a specific application and constraints

❖can handle a large number of parameters to be adjusted

«New developments»

- New developments -

- development of performance criteria for handling hard and soft constraints [M.-J. Blondin and P. Sicard, EPE 2013]
- development of strategies for multi-degrees of freedom controllers [M.-J. Blondin and P. Sicard, EPE 2013]
- strategies to reduce the execution time of the ACO : combine ACO with local search algorithm (Nelder-Mead) [M.-J. Blondin and P. Sicard, IEEE IECON 2013]

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« Biographies and References »

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