FUNDAMENTALS OF ENERGY MANAGEMENT DEVELOPOMENT AS PART OF HYBRID AND ELECTRIC VEHICLE RESEARCH IN THE VEHICLE TECHNOLOGY DEPARTMENT OF KECSKEMET COLLEGE

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Basic research for the development of hybrid and electric vehicles

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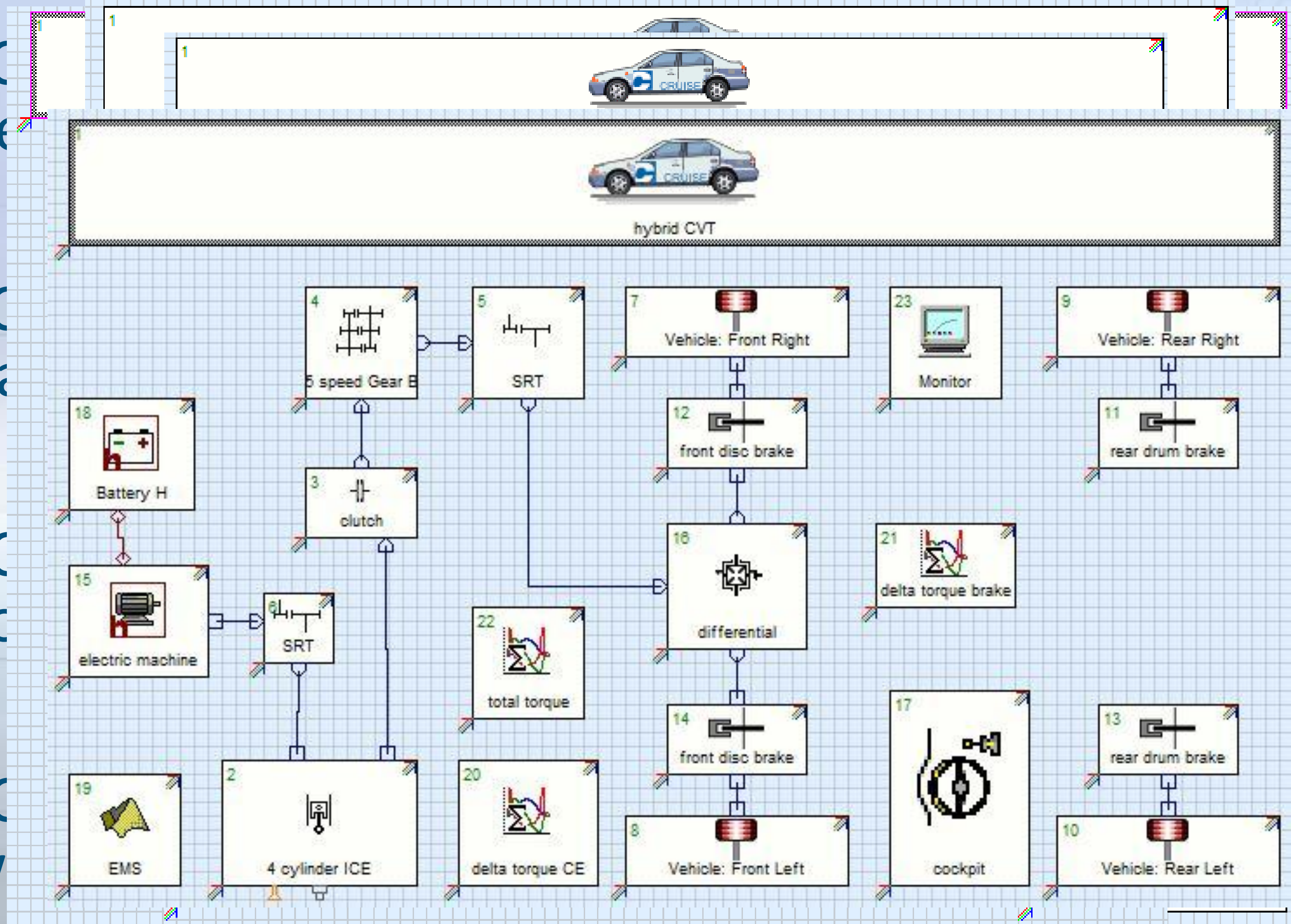
HYBRID CONCEPTS

The analyzed Concepts – AVL CRUISE environment

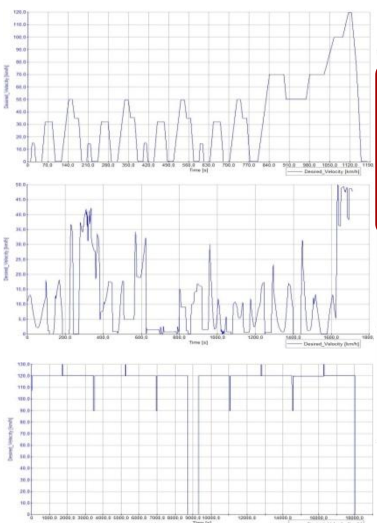
- „C… be…
- „C… as Ra…
- „C… co…
- „C… e w…



Choosing the best concept – decision matrix

Subjective Properties

Average weighted sum of:	C0	C1	C2	C3
- cost properties	30	33	27	25
- complexity properties	16	19	5	15
- weight properties	4	3	2	4
- flexibility properties	2	4	1	2
- dynamic properties	3	12	9	3
- comfort properties	26	14	25	25
Total Weighted Sum	93	92	71	83



		Concept 0		Concept 1		Concept 2		Concept 3	
NEDC	IM	5,16	[kWh]	0,00	[kWh]	6,41	[kWh]	3,95	[kWh]
	EM	0,00	[kWh]	0,97	[kWh]	0,46	[kWh]	0,03	[kWh]
	ΣE	5,16	[kWh]	0,97	[kWh]	6,87	[kWh]	3,98	[kWh]
	NOx	0,04	[g]	0,0001	[g]	0,11	[g]	0,04	[g]
	CO	0,13	[g]	0,0002	[g]	0,27	[g]	0,09	[g]
	HC	0,02	[g]	0,0001	[g]	0,04	[g]	0,01	[g]
HTDC	IM	5,12	[kWh]	0,00	[kWh]	1,32	[kWh]	4,07	[kWh]
	EM	0,00	[kWh]	0,31	[kWh]	0,19	[kWh]	0,03	[kWh]
	ΣE	5,12	[kWh]	0,31	[kWh]	1,51	[kWh]	4,1	[kWh]
	NOx	0,01	[g]	0,0009	[g]	0,01	[g]	0,027	[g]
	CO	0,10	[g]	0,0021	[g]	0,02	[g]	0,068	[g]
	HC	0,02	[g]	0,0011	[g]	0,00	[g]	0,008	[g]
LDDC	IM	231,79	[kWh]	500,14	[kWh]	714,78	[kWh]	431,69	[kWh]
	EM	0,00	[kWh]	0,29	[kWh]	0,55	[kWh]	0,03	[kWh]
	ΣE	231,79	[kWh]	500,43	[kWh]	715,33	[kWh]	431,72	[kWh]
	NOx	4,37	[g]	3,92	[g]	7,39	[g]	5,03	[g]
	CO	7,36	[g]	22,52	[g]	19,86	[g]	7,99	[g]
	HC	0,92	[g]	0,87	[g]	1,48	[g]	0,95	[g]

Objective Properties

				Concepts			
Properties			Weight	C0	C1	C2	C3
tive Properties	NEDC	Electric consumption	2	4	1	2	3
		Fossil fuel consumption	2	1	4	3	2
		CO Emission	2	3	4	2	1
		HC Emission	2	2	4	3	1
		NO_x Emission	2	1	4	3	2
		Weighted sum of NEDC		22	34	26	18
	C	Electric consumption	4	4	1	2	3
		Fossil fuel consumption	4	1	4	3	2
		CO Emission	4	3	4	2	1
		HC Emission	4	3	4	2	1
		NO_x Emission	4	2	4	3	1
		Weighted sum of HTDC		52	68	48	32
		Electric consumption	1	4	2	1	3
		ossil fuel consumption	1	4	1	3	2
		CO Emission	1	4	1	2	3
		HC Emission	1	3	4	1	2
		NO_x Emission	1	3	4	1	2
		Weighted sum of LDDC		18	12	8	12
Total weighted Sum:				92	114	82	62

CONCEPT ANALYSIS

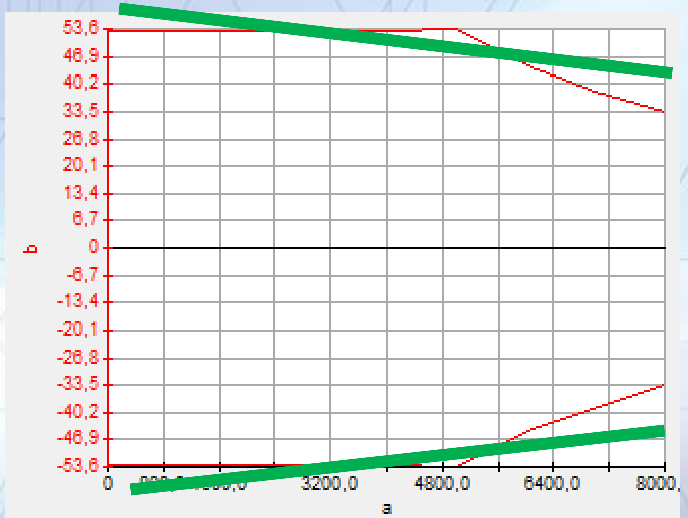
Simplified model, Validation

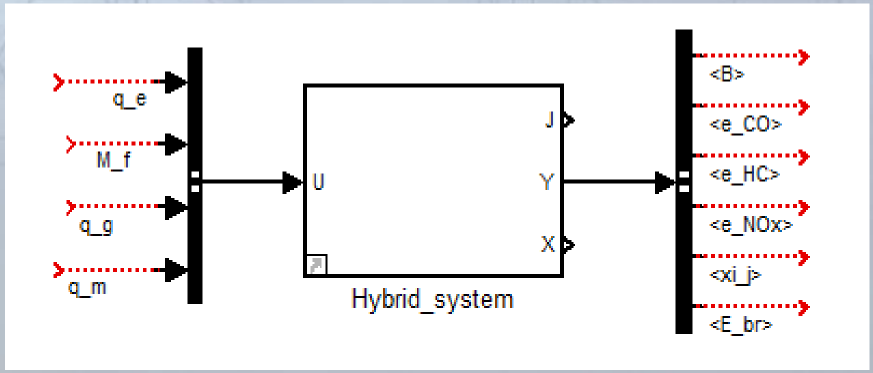
Simplified model

- The chosen concept was deeper analyzed
  - AVL CRUISE environment
  - Sensitivity study
  - More test cycles
- Also for controller design a simplified model was created

Simplified model in Simulink

- Linear characteristics,
- Input – power demand (q_e,q_m,q_g)
- States - Vehicle speed, Battery SOC, RE rpm
- Output – Fossile/Electr. consumption, emissions, vehicle acceleration
- Simulink environment





Simplified model in Simulink

$$v_j = k \cdot \int \frac{M_e - M_l}{\hat{\Theta}} dt$$

$$\omega_{mg} = \int \frac{M_m - M_g - M_v}{\Theta_{mg}} dt$$

$$E_b = E_{b0} + \int P_g \cdot dt - \int P_e \cdot dt$$

$$M_e = \min\left(M_e^{max} \cdot q_e \cdot \left(1 - a \cdot \frac{v_j}{k}\right), \frac{U_e \cdot I_e^{lim} \cdot k}{v_j} \right)$$

$$M_l = \frac{C \cdot v_j^2}{k} + \frac{D \cdot v_j}{k} + M_{l0} + M_f$$

$$M_m = q_m \cdot M_m^{max}$$

$$M_g = M_g^{max} \cdot q_g \cdot (1 - b \cdot \omega_{mg})$$

$$M_v = d \cdot \omega_{mg} + M_{v0}$$

$$P_e = I_e \cdot U_e$$

$$P_g = I_g \cdot U_e$$

$$I_e = \min\left(\left(\frac{M_e}{U_e} \cdot \frac{v_j}{k} \right), I_e^{lim} \right)$$

$$I_e^{lim} = I_g + I_b^{max}$$

$$I_g = \frac{M_g}{U_e} \cdot \omega_{mg}$$

$$I_b^{max} = R \cdot E_b$$

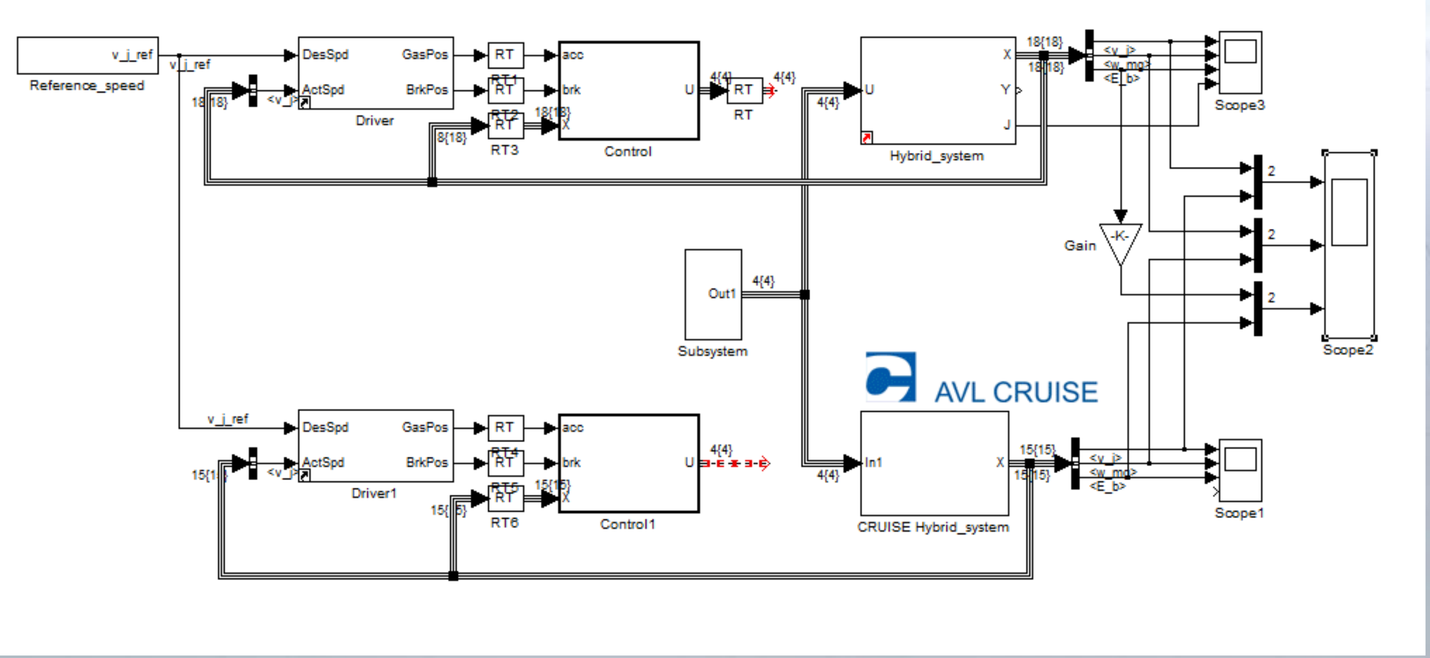
$$\mathbf{u} = [q_e \quad q_m \quad q_g]$$

$$\mathbf{x} = [v_j \quad \omega_{mg} \quad E_b]$$

$$\mathbf{y} = [B \quad e_{CO} \quad e_{HC} \quad e_{NOx} \quad \xi_j \quad E_{br}]$$

Simplified model in Simulink

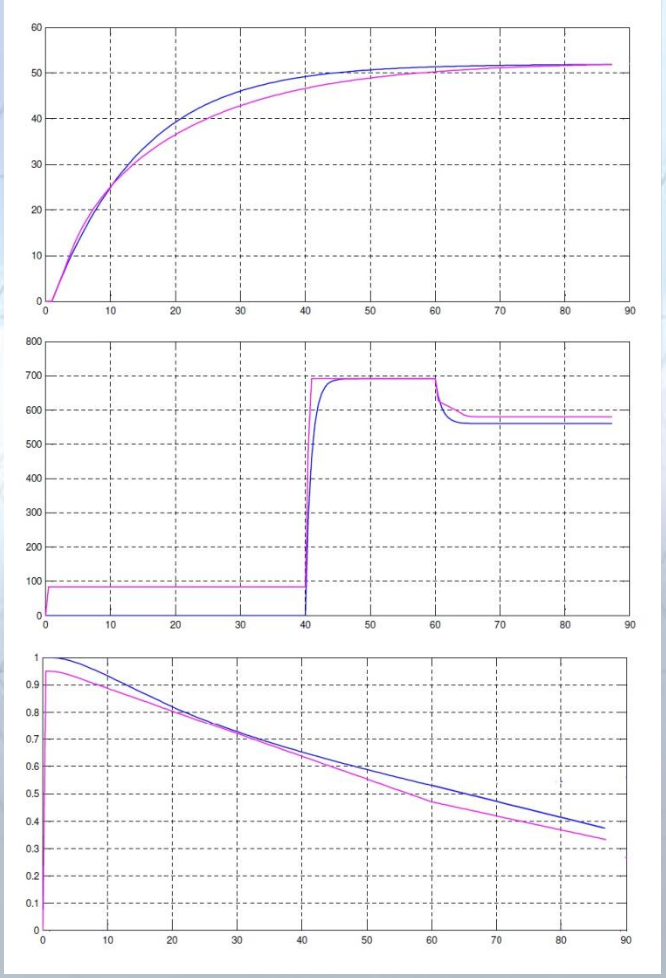
- The simplified model was compared to the more detailed one created in CRUISE
- For the comparison, the CRUISE and Simulink environments had to be merged.



Simplified model in Simulink

- Comparing the behavior of the two models
  - Vehicle speed
  - RE rpm
  - Battery SOC

- The simplifyed model follows the CRUISE model within the allowed error



ENERGY MANAGEMENT STRATEGIES

Energy Management controllers

- 4 Controller logics are investigated that are based on
  - Neural networks
  - Fuzzy logic rules
  - Genetic algorithms
  - State machine
- To compare the performance of the different controllers a „Cost function" had to be created

The cost function

- It has to be formed such as
  - Smaller value is better
  - It punishes the high value of
    - Emissions, fossil fuel consumption
    - Electric energy consumption
    - Lack of dynamics

Cost function

- The chosen cost function is basically an integral average:

$$J = \frac{1}{T}\int \sqrt{f_1 \cdot \left(\frac{B}{B^{\max}}\right)^2 + f_2 \cdot \left(\frac{e_{CO}}{e_{CO}^{\max}}\right)^2 + f_3 \cdot \left(\frac{e_{HC}}{e_{HC}^{\max}}\right)^2 + f_4 \cdot \left(\frac{e_{NOx}}{e_{NOx}^{\max}}\right)^2 + f_5 \cdot \left(\frac{\xi_j}{\xi_j^{\max}}\right)^2 + f_6 \cdot \left(\frac{E_{br}}{E_{br}^{\max}}\right)^2}\, dt$$

- Where:
  - f_i – weighting constants, /sum(f_i)=1/
  - B – Fossil fuel consumption
  - $e_{CO,HC,NOx}$ – Emission values
  - ξ – Vehicle dynamic behavior error
  - E_{br} – Electric energy consumption
- ^{max} – the maximum possible value of the given variable

ENERGY MANAGEMENT – NEURAL NETWORKS

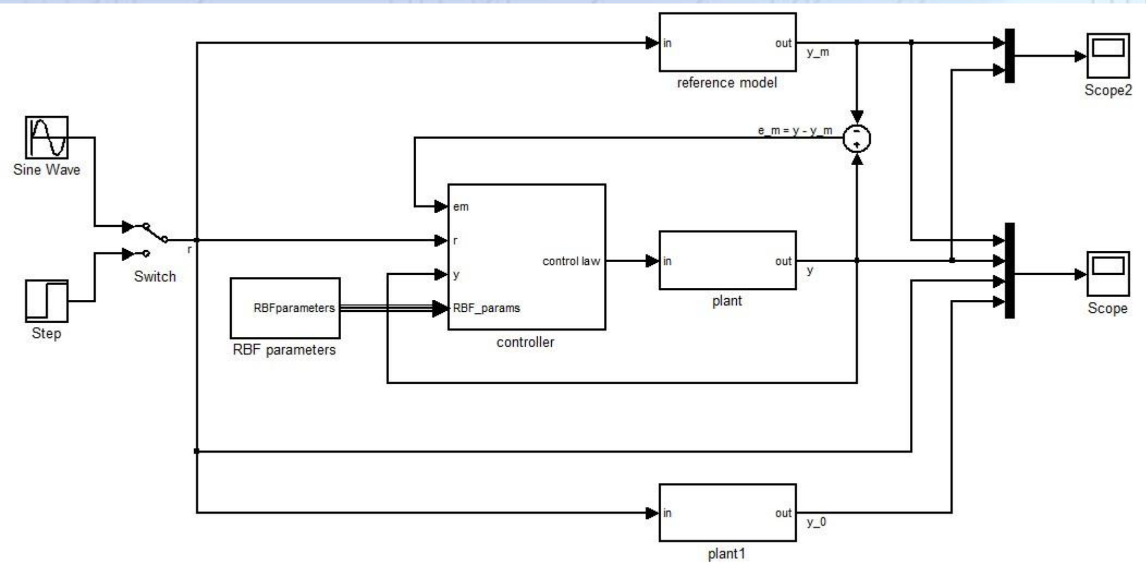
Dr. István Pintér

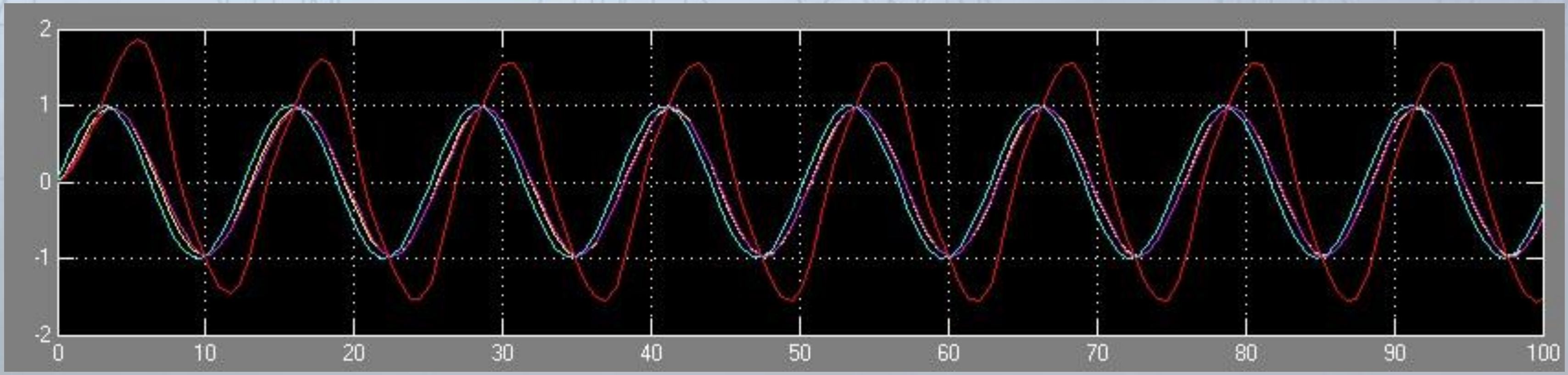
Neural Network Background

- NN are widely used for handling nonlinearities in phisical systems.
  - Keeping an ICE air/fuel rate at optimum level
  - Minimze fuel consumption at a given battery SOC level
- In control, they can be used for reference model following. This model can be created
  - By learning of the NN
  - By experts, using technical knowledge
- In our case
  - The used NN method is, Radial Base Function (RBF) method
  - The reference model is given by expert

Using Neural Network for Energy management

- RBF-MRAC controller implementation in MATLAB-ban, 4th Runge-Kutta
- MATLAB/Simulink block





Using Neural Network for Energy management

- The RBF method with expert created reference model has great advantages but also there are some challenges too
  - No good support in Simulnik environment,
  - Small number of MIMO system usecases
  - It’s performance greatly depend on the reference model

ENERGY MANAGEMENT – GENETIC ALGORITHM

Dr. Norbert Csík

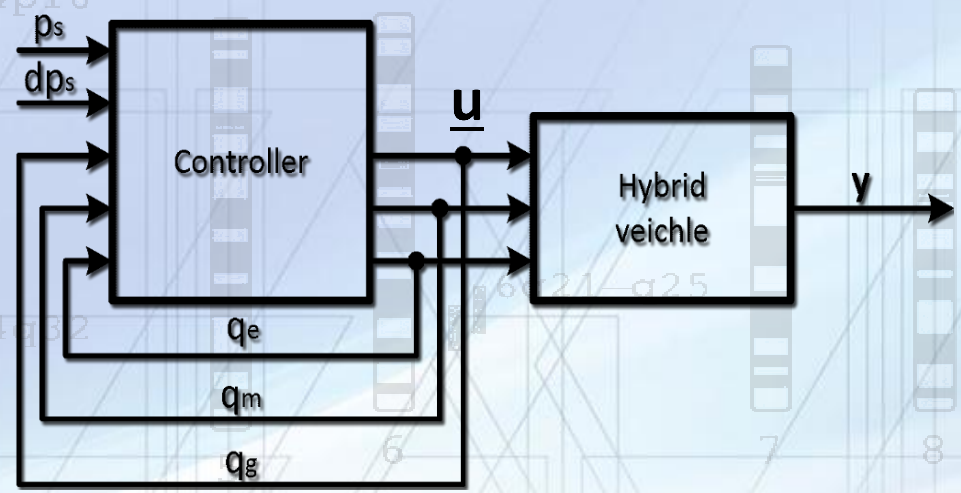
Using evolution algorithm for Energy management

- Advantages
  - Robust searching features
  - Pre-knowledge from the problem is not needed
  - Efficent working in extreme cases (deficient, infinite, discrete searching space, etc.)
  - It is able to give a set of solutions
- Disadvantages
  - Search for global optima
  - The speed of evolution cycle depends on problem-oriented calculations
  - It gives just an approximation, without terminating conditions there is no final state.
  - Usually for efficeint working hibridization needed.
  - Choosing suitable polimorf chromosome structure usually hard

Chromosome design

Input ($\underline{x}$) is:

The control output signals ($\underline{u}$), the state of pedal (ps) and the signed changing state of pedal (dps).



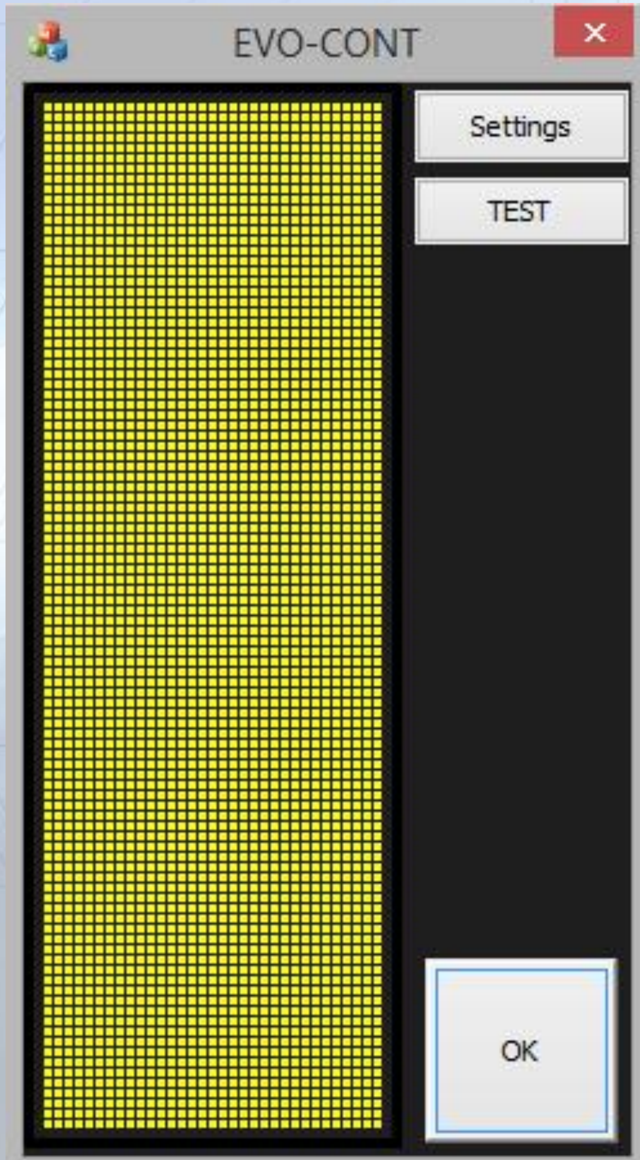
The control outputs are derived from the power-products of input signals. The parameters of this approximation produce the matrix of chromosome.

$$u_{i=1,2,3} = \sum_{j=1}^{N} \left(A_{j0} \cdot \prod_{k=0}^{4} \left(x_{jk} - B_{jk} \right)^{C_{jk}} \right)$$

$$\begin{bmatrix} A_{00} & B_{00} & C_{00} & \cdots & B_{04} & C_{04} \\ A_{10} & B_{10} & C_{10} & \cdots & B_{14} & C_{14} \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ A_{N0} & B_{N0} & C_{N0} & \cdots & B_{N4} & C_{N4} \end{bmatrix}$$

Other features

- Visual C/C++ MFC technology
- Simple GUI
- One lifespace, one population, 12 entity
- Self-controlling inner mechanism:
  - Using predisposition in chromosomes
  - Terminating conditions based on the age of the best entity



Expectations

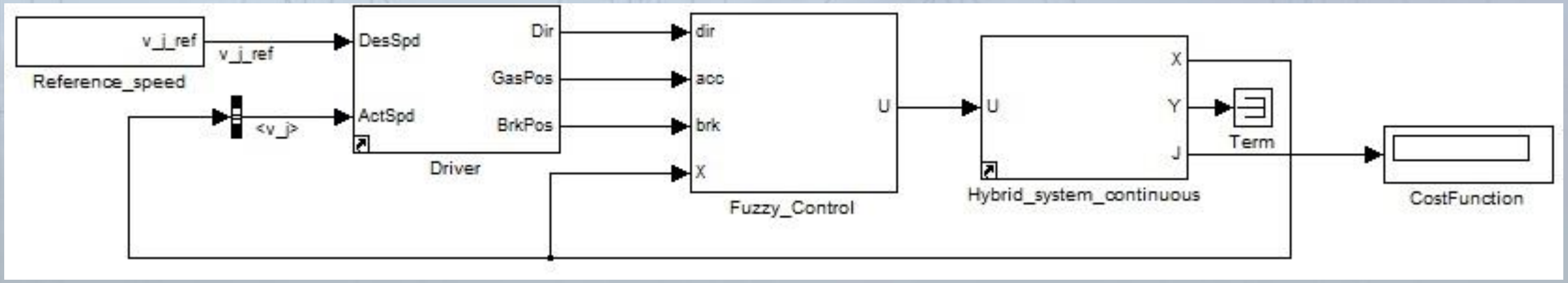
- Robust searching features
- Avoidance of early convergence
- Strong evolution rate
- Stop after 10^5-10^6 step near optimum

ENERGY MANAGEMENT – FUZZY LOGIC

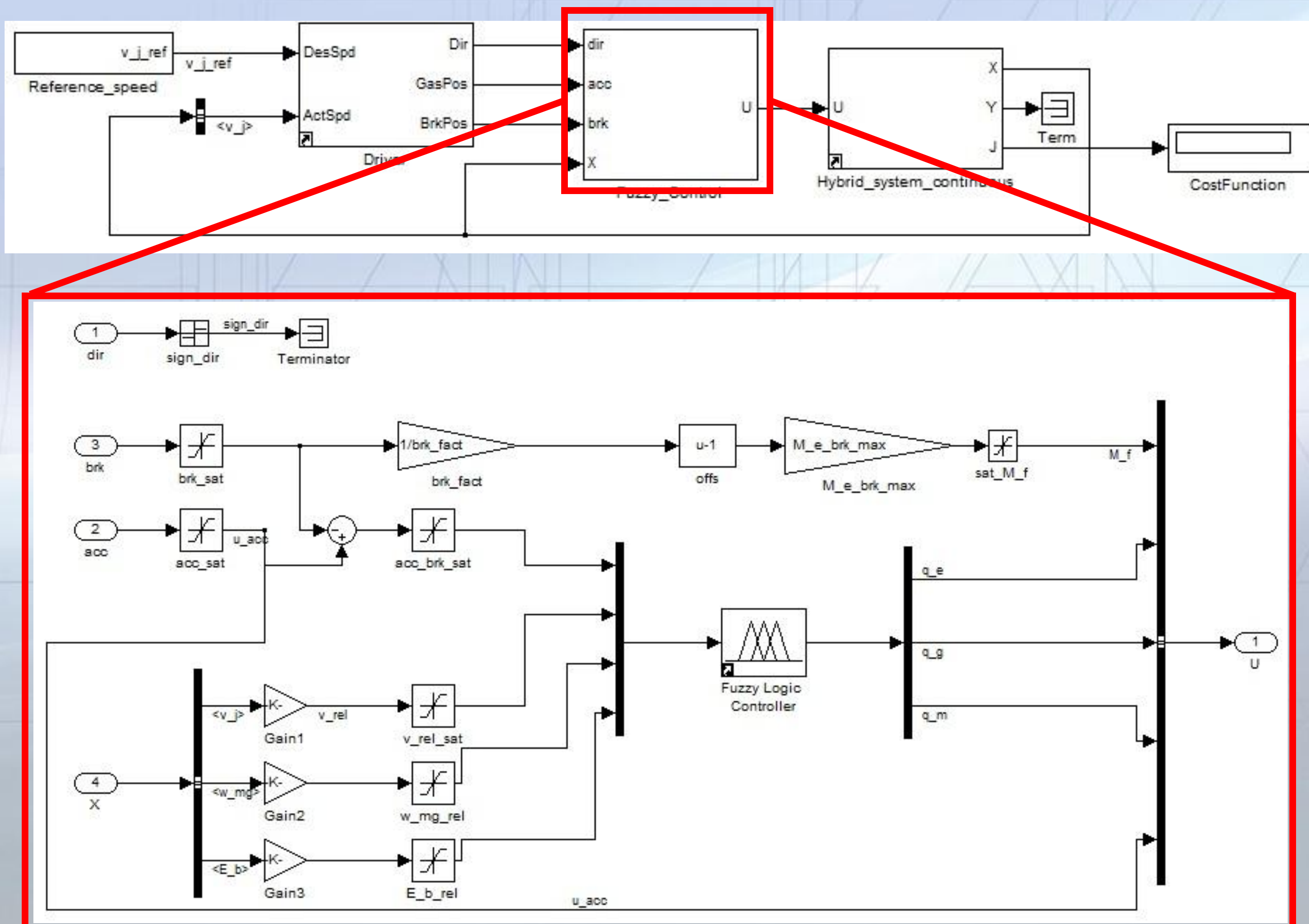
Dr. Zsolt Csaba Johanyák

Fuzzy logic based energy management control of hybrid vehicle

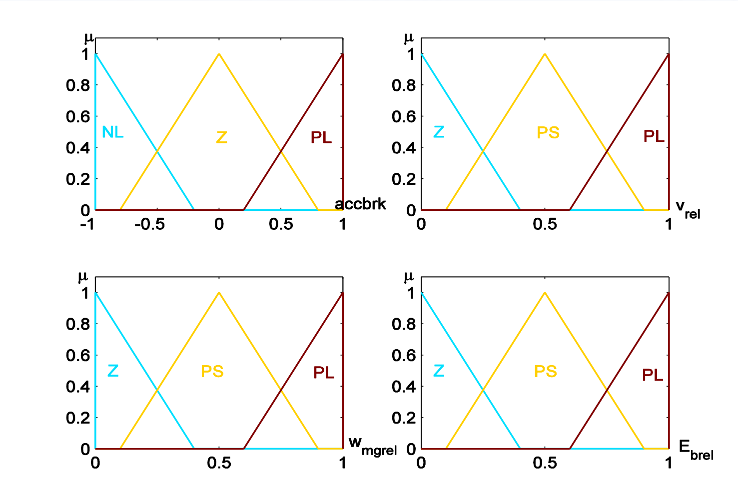
- Inputs and outputs
- Preprocessing operations
- Postprocessing operations
- Operational characteristics of the fuzzy system
- Input and output membership functions
- Initial (rough) rule base
- Performance evaluation
- Tuning of the fuzzy system's parameters

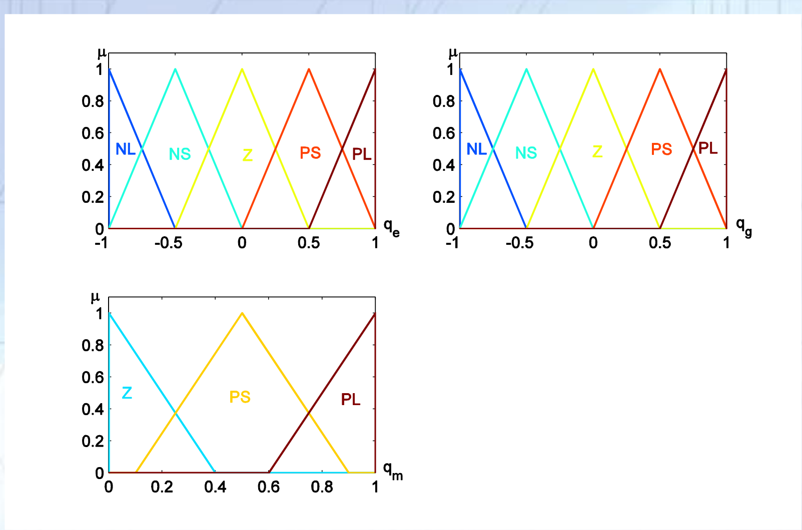


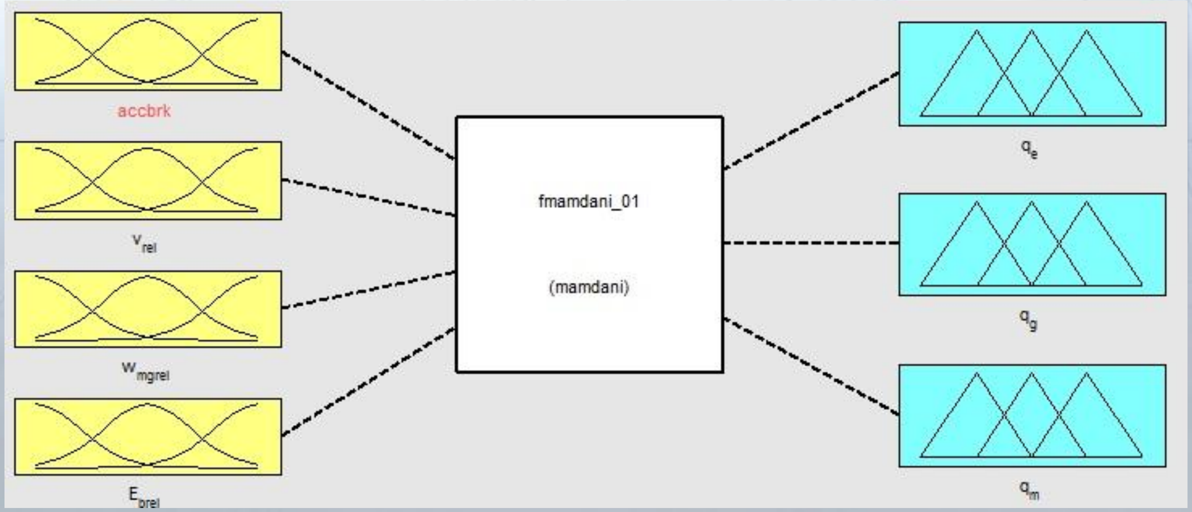
Using Fuzzy logic algorithm for Energy management



Antecedent and consequent partitions

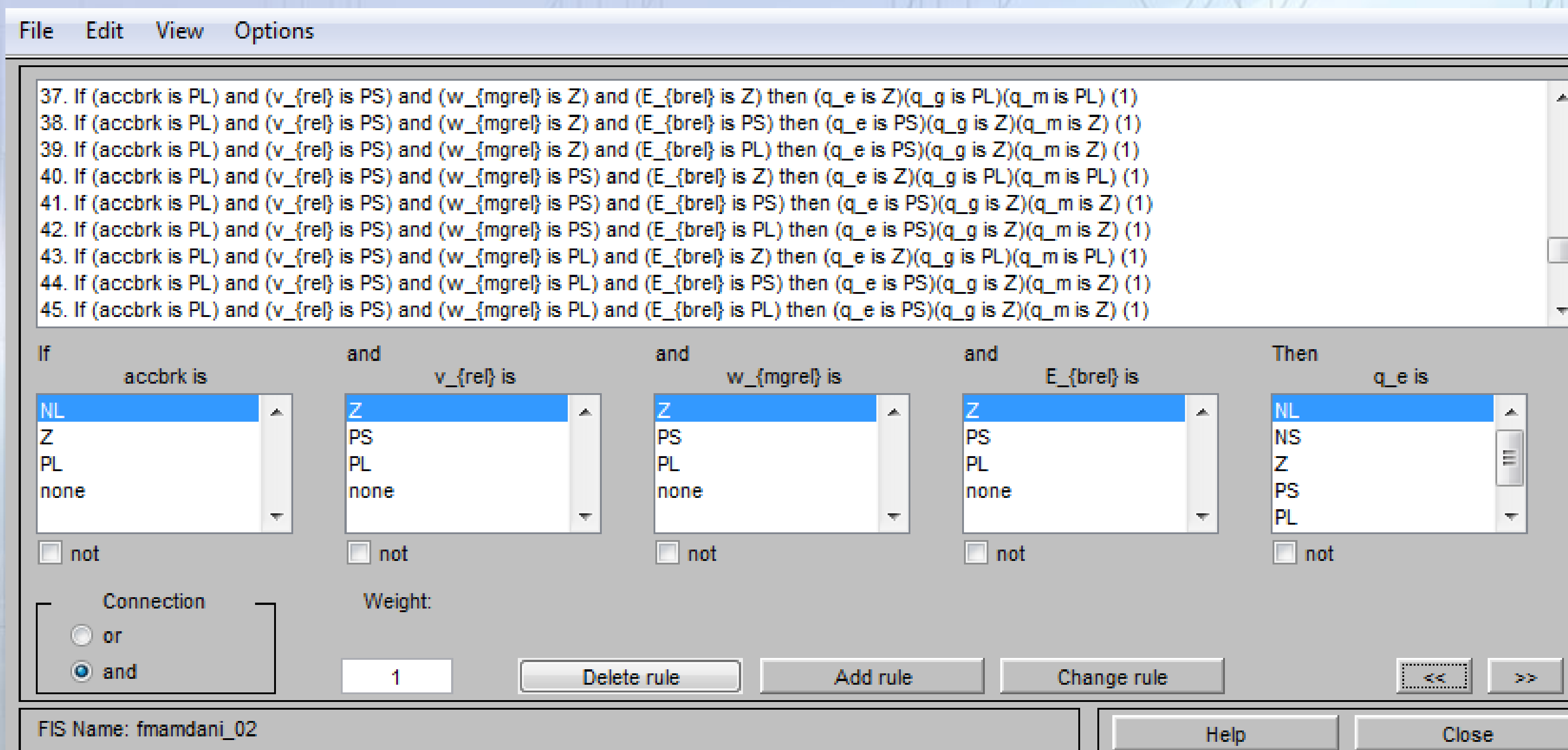






Initial Rule base

- 81 rules



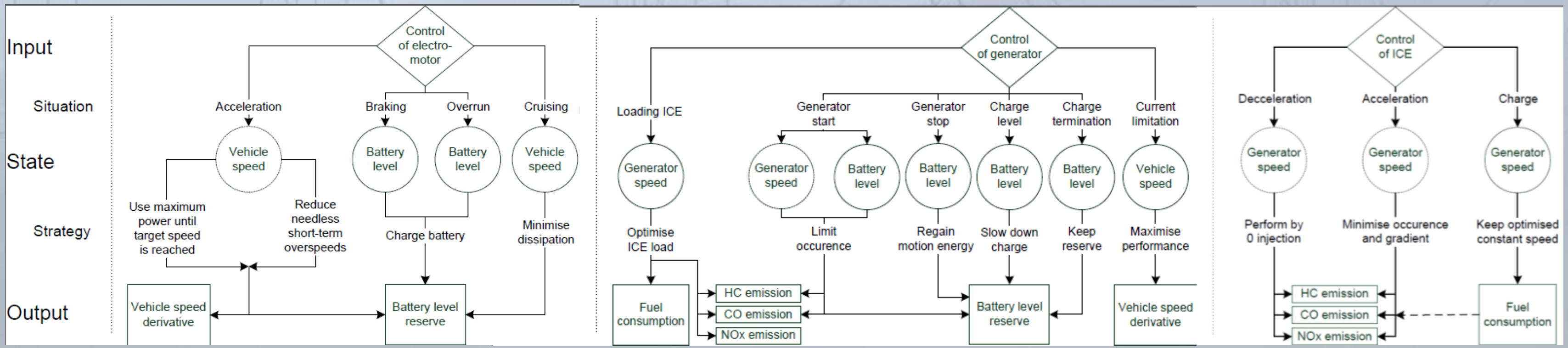
ENERGY MANAGEMENT – STATE MACHINE

Dr. Levente Balogh

State machine based energy management control of hybrid vehicle

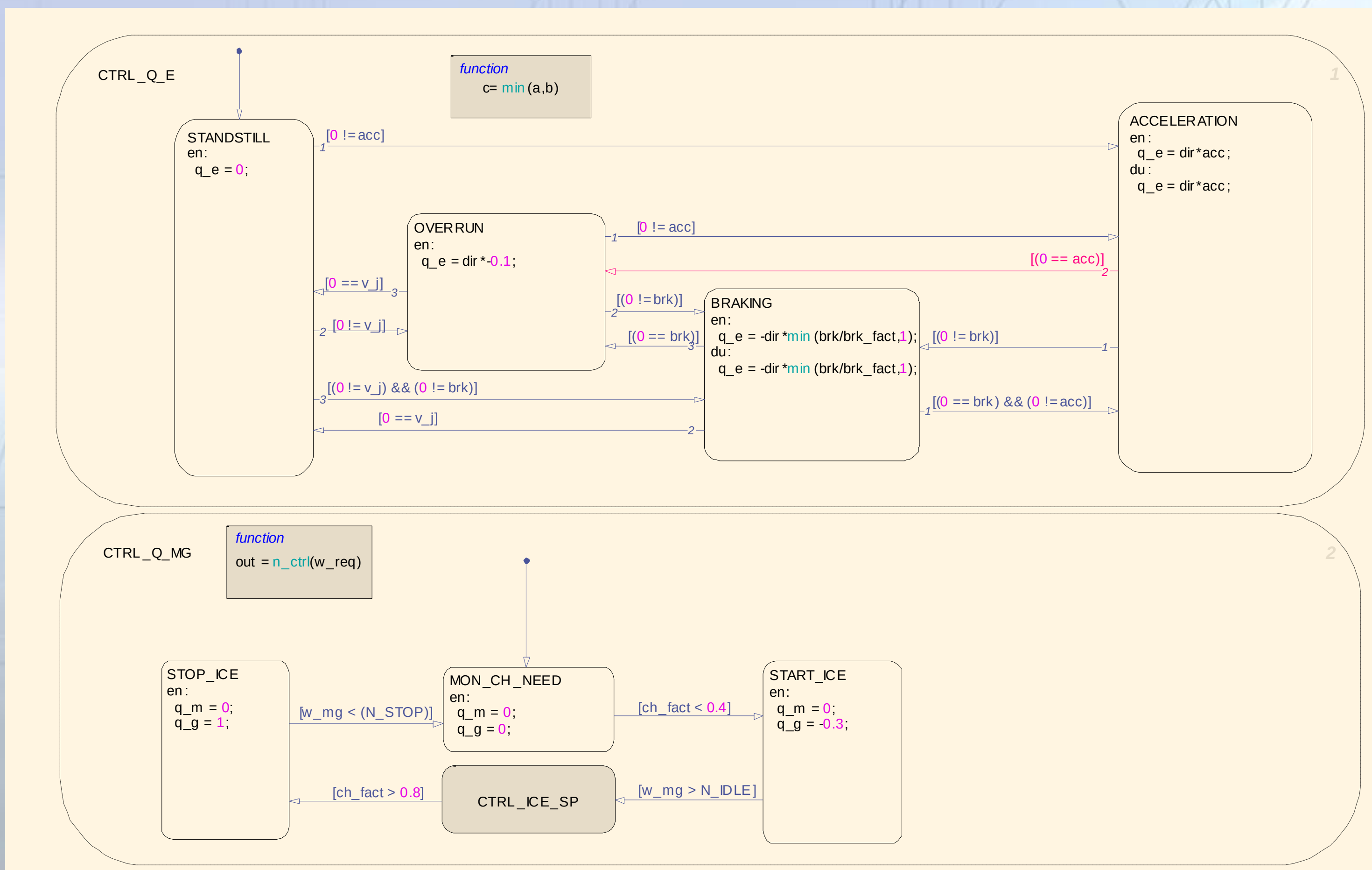
Design

- Method steps of controller design:
  - Definition of control strategies based on vehicle model inputs, state variables and optimisation outputs
  - Design of state machine based on strategies:
    - Definition of controller states
    - Assignment of control outputs related to states
    - Definition of possible state transitions
    - Evaluation of transition conditions



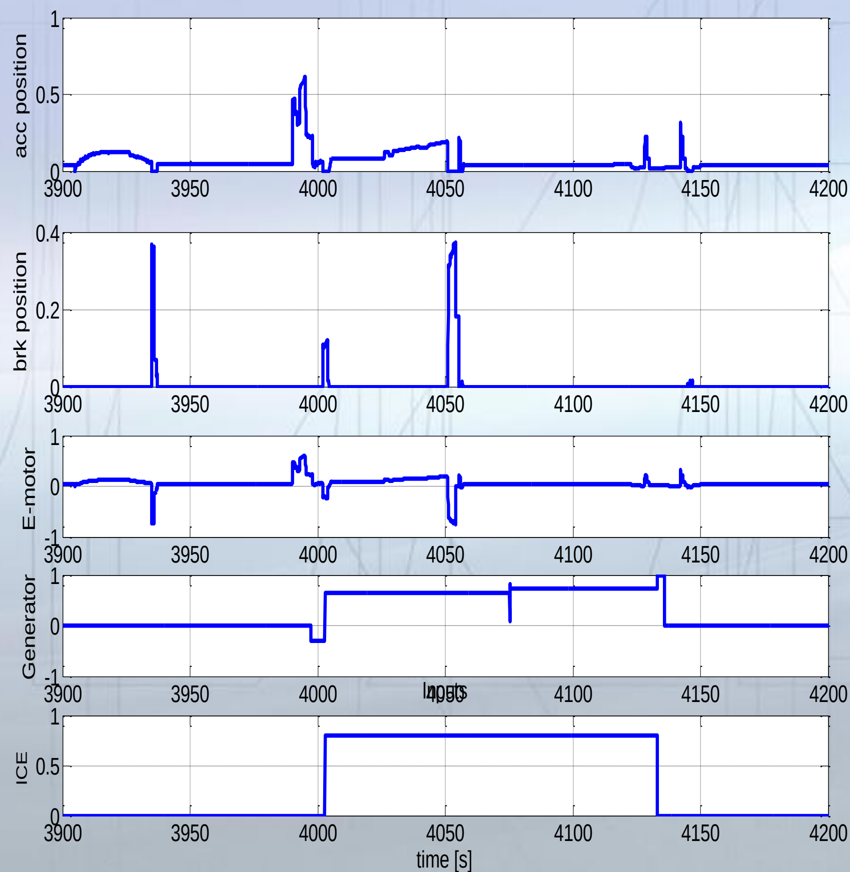
State machine based energy management control of hybrid vehicle

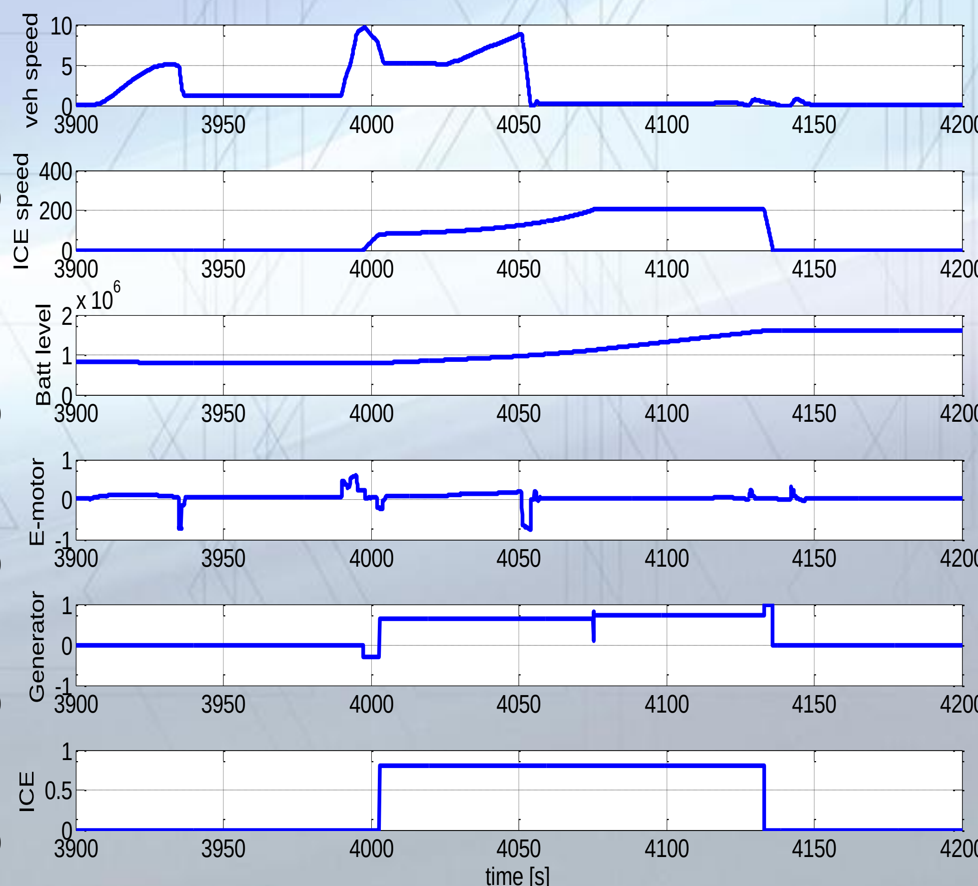
Implementation



State machine based energy management control of hybrid vehicle

Verification





THANK YOU FOR YOUR ATTENTION.

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BASIC RESEARCH FOR THE DEVELOPMENT OF HYBRID AND ELECTRIC VEHICLES

TÁMOP-4.2.2.A-11/1/KONV-2012-0012

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HUNGARY'S RENEWAL

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