Modelling and Control of a Hydrogen Plant

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Outline

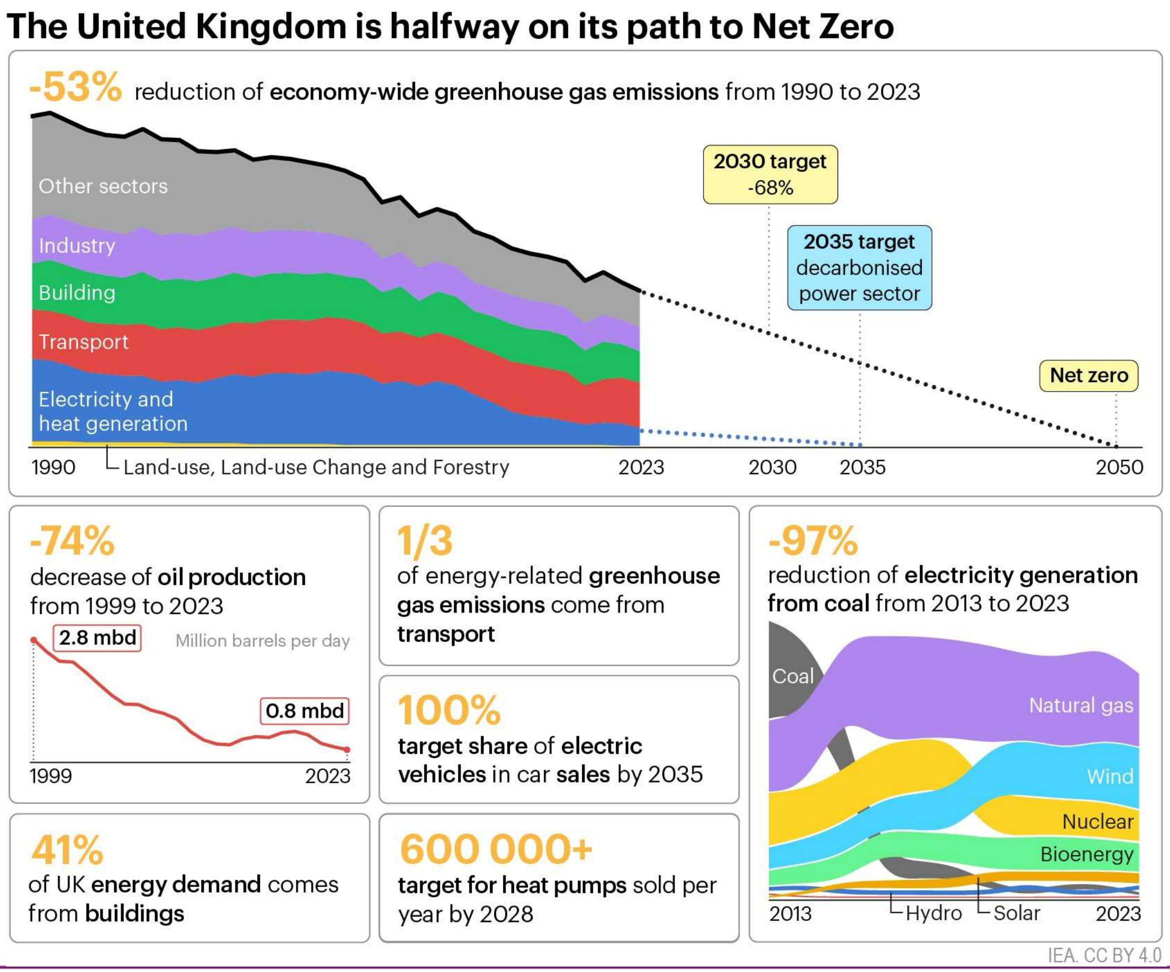
- **Background and why we are doing it**
  About Hydrogen / Why need dynamic model for hydrogen system

- Modelling and control of electrolyser
  About Electolyser modelling / Electrolyser system control

- Modelling and control of fuel cell
  About Fuel cell modelling / Fuel cell system control

- Electrolyser and Fuel Cell system for DIgSILENT/Power factory
  About realization of modelling and control for fuel cell and electrolyser system in DIgSILENT /Power factory

Background



- The UK government has planned the production of **10GW** low-carbon hydrogen by 2030 and **240-500 TWh** low-carbon hydrogen supply by 2050 [1].
- The British Energy Security Strategy set the target to **10 GW** by 2030, with at least **half** coming from **electrolytic hydrogen**, and up to **1 GW** of electrolytic hydrogen by 2025 [2].

Model requirements

- **Power factory:**

Do not have electrolyser model;
Fuel cell model is considered as static generator which only set P,Q value without detailed and BoP.

- **MATLAB:**

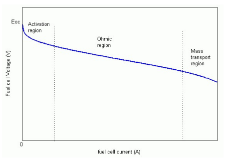
Closed library composition;
No direct path to PowerFactory

[1] British Energy Security Strategy, 2022, https://www.gov.uk/government/publications/british-energy-security-strategy
[2] IEA (2024), United Kingdom 2024, IEA, Paris https://www.iea.org/reports/united-kingdom-2024, Licence: CC BY 4.0

BoP: Balance of Plant

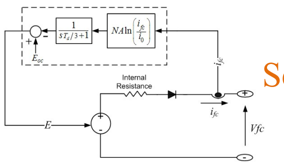
Background

Simple



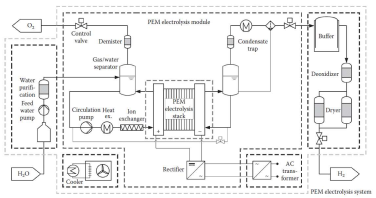
I-V curve

- ✓ Fast; Easy to integrate in grid tools
- ❑ Fits well only under exact operating point; No dynamics, thermal/hydration, or gas-path effects.



Semi-empirical

- ✓ Sensitivity to temperature and partial pressures is explicit
- ❑ Lacks dynamics (thermal, water, manifold); no BoP.



Lumped Dynamics with BoP

- ✓ Captures plant-level interactions; Suitable for grid service
- ❑ Requires multi-disciplinary data.

High-fidelity CFD (2D/3D, porous media)

- ✓ Highest physical resolution;
- ❑ Very high computational cost; unsuitable for system-level or long-horizon runs; Difficult to couple tightly with grid/EMS simulations

Complex

Why a dynamic model instead of a simple source/load model?

- Safety & constraints are invisible in a simple source/load model
- Efficiency & H_2 production are state-dependent
- No dynamics, thermal or gas effects

What fidelity is "enough" for power system simulation?

- State-dependent V–I/η and H_2 production/consumption
- Basic dynamics (mass flow, partial pressure, thermal).
- BoP interactions

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Modelling of electrolyser

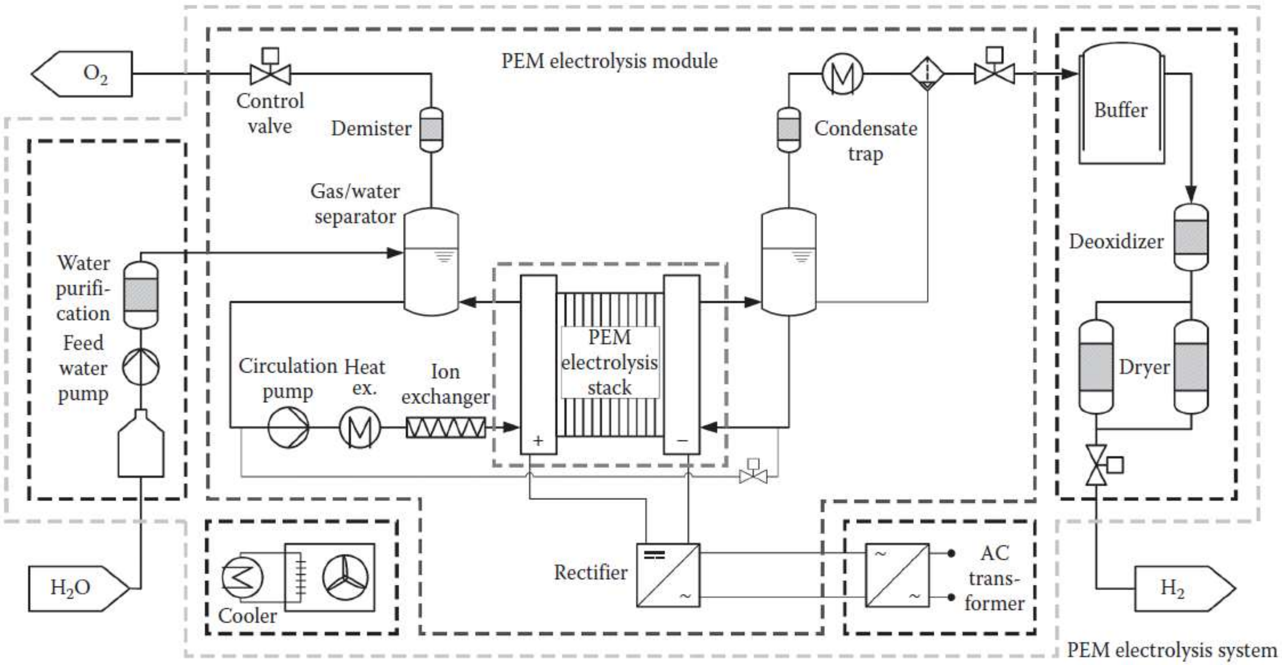

Fig.1 General layout of a PEM electrolysis system consisting of the PEM stack and module with power electronics and the EL subsystems for water purification, gas drying, and fine purification and cooling unit [1].

Modelling Points

- **PEM electrochemical stack model**

Inputs: Stack current, stack temperature, partial pressure of each components

Outputs: Stack voltage

- **Mass flow inside the cell**

Inputs: Stack current, stack temperature, partial pressure of cathode and anode, molar water flow

Outputs: Water flux, interface concentrations/mole fractions, partial pressure of each components

- **Thermal model of the stack**

Inputs: Stack current, environment temperature, molar water flow

Outputs: Stack temperature

[1] Bessarabov, Dmitri, et al., eds. *PEM electrolysis for hydrogen production: principles and applications*. CRC press, 2016.

Modelling of electrolyser

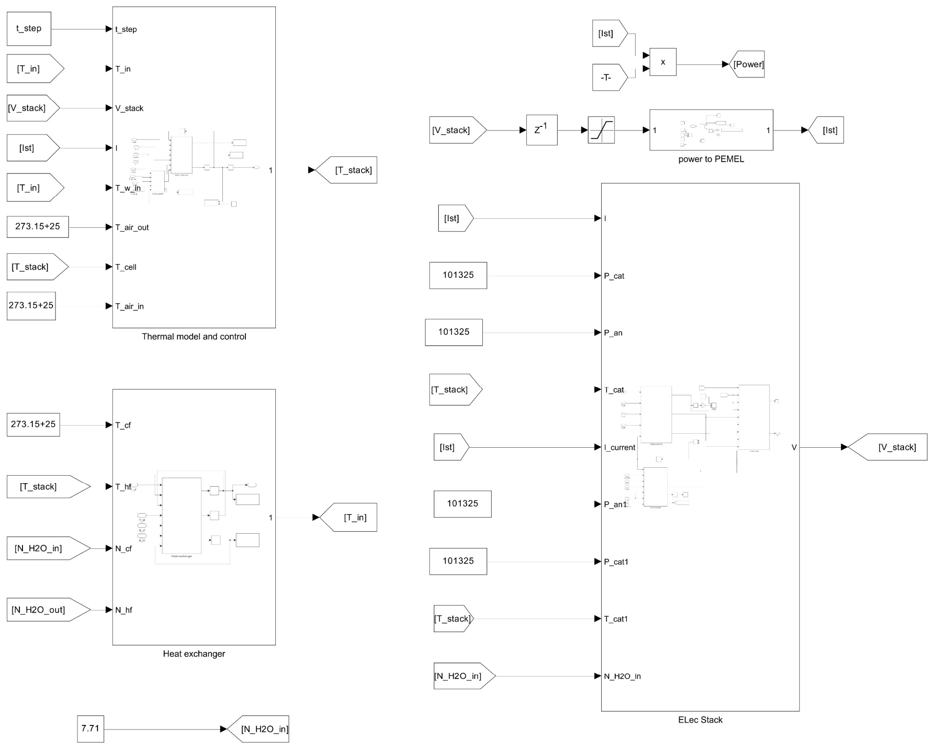

Fig. 2 PEM electrolyser system model in MALAB/Simulink

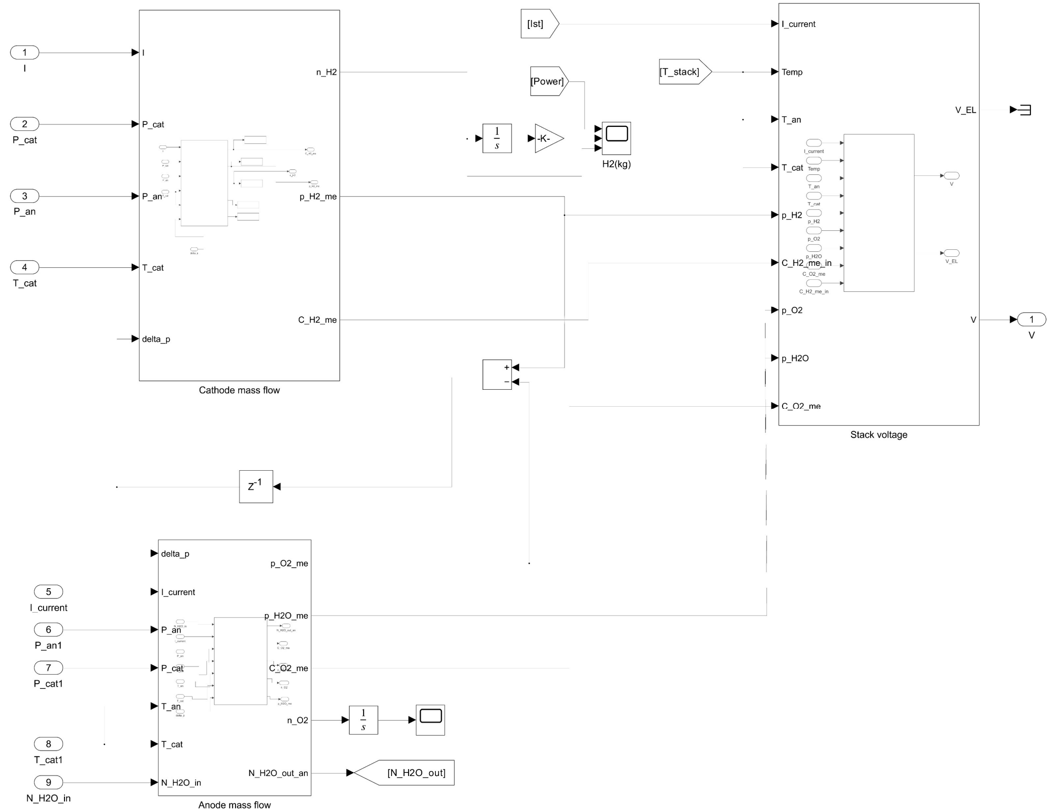

Fig. 3 Electrolyser stack model in MATLAB/Simulink

Thermal control of electrolyser

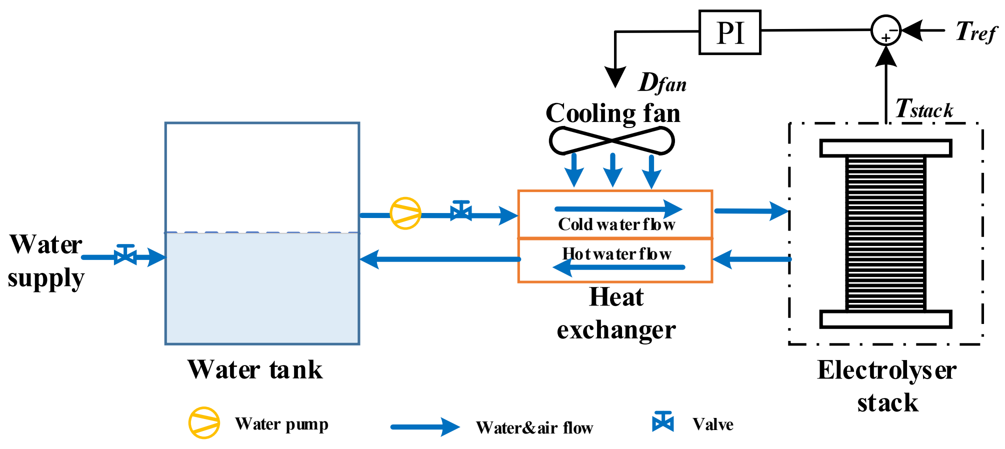

Fig. 4 PEM stack temperature control with BOP of the model.

Why Thermal Control Is Essential for Electrolyser

Thermal control is mandatory to keep the stack in its efficiency–lifetime optimal spot, preserve hydration, respect safety limits.

Control objectives:

Track temperature set-point with small steady-state error.

Inputs & Outputs:

Inputs: Molar Water flow, environment temperature, Stack current and voltage

Outputs: Duty cycle of the fan

Constraints:

Hard limits: Maximum and minimum temperature.

Actuator limits: fan duty ∈[0,1]

Simulation results

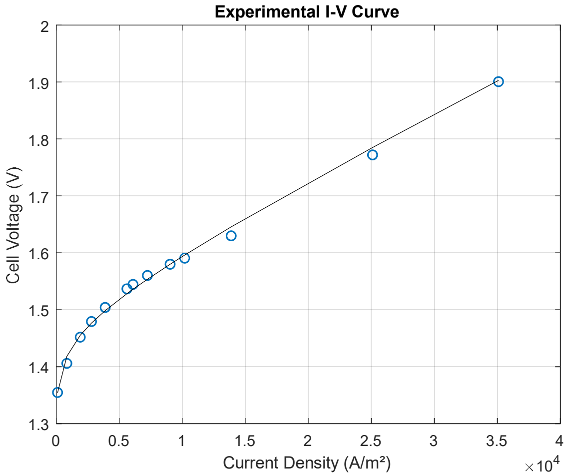

Fig. 5 V-I curve fitting results

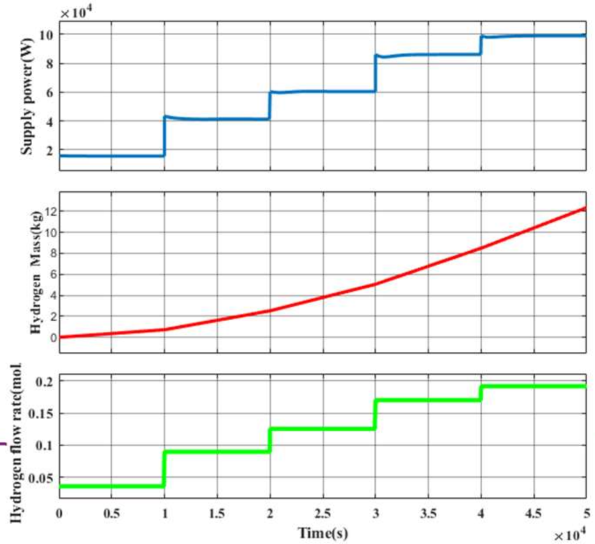

Fig. 6 Hydrogen generation curve

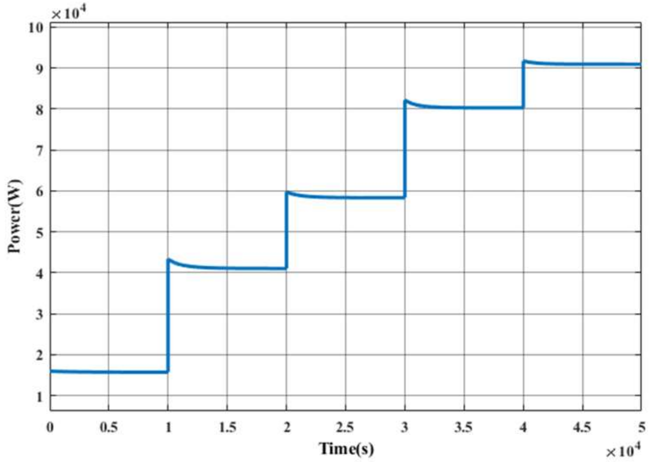

Fig. 7 Variation of power supply

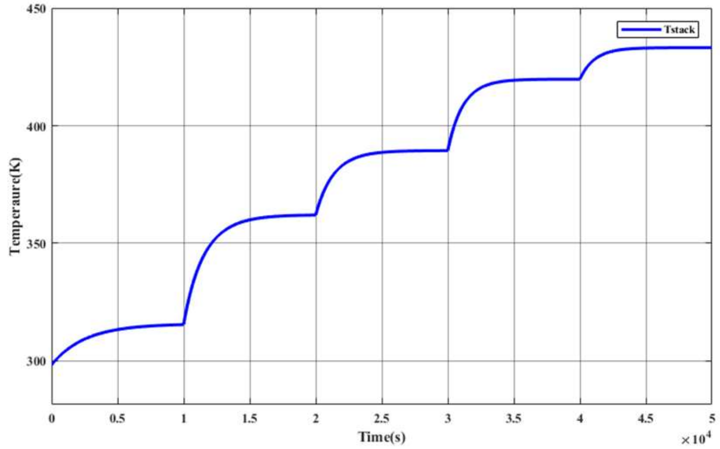

Fig.8Temperature performance of PEM electrolyser stack without thermal control of the Simulink

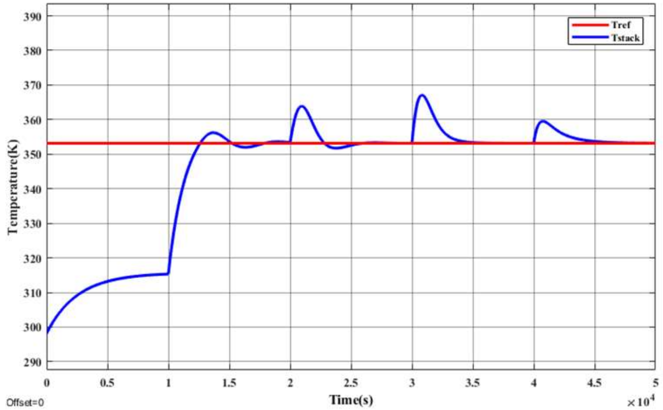

Fig. 9 Thermal control when the supply current changes

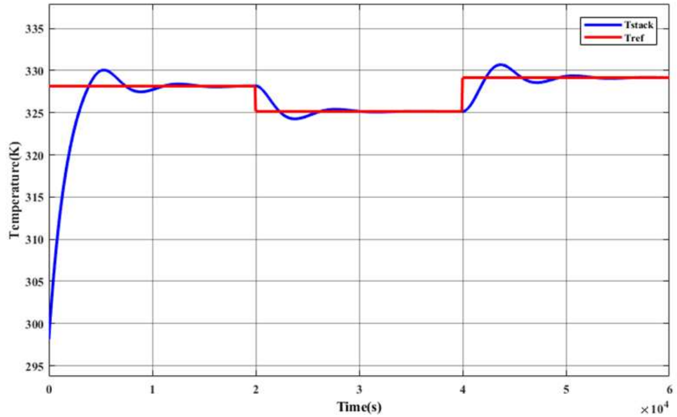

Fig. 10 Thermal control when the reference of temperature change under constant current

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Modelling of fuel cell

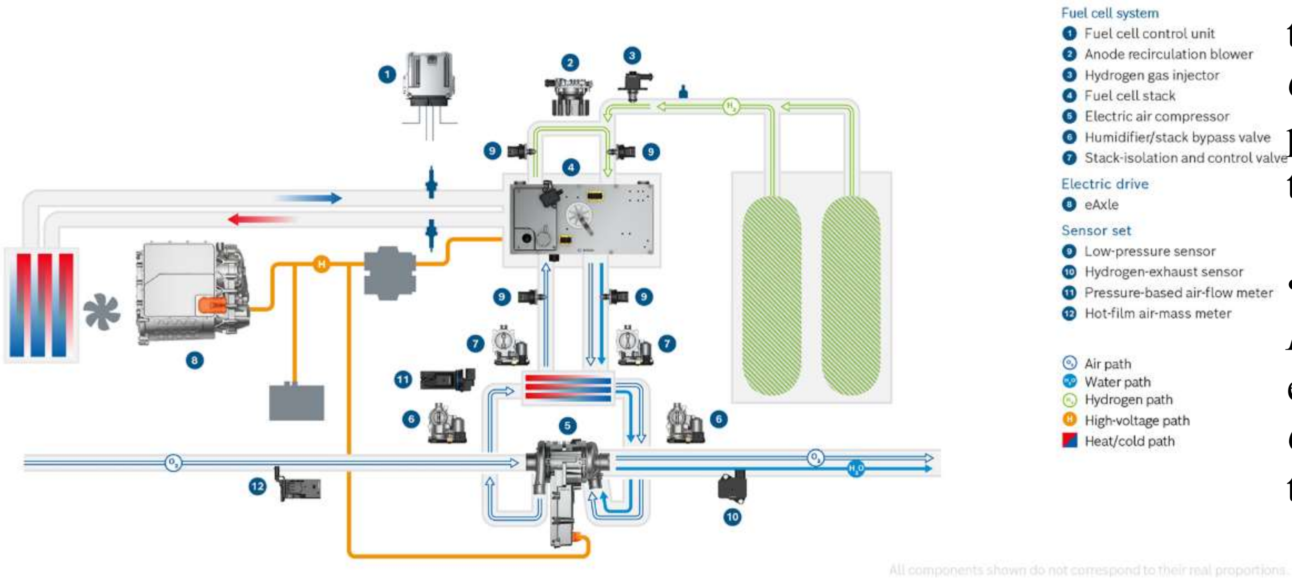

Fig. 11 PEM stack with BoP [1].

Modelling Points

- **Fuel cell stack model**

Inputs: Mass flow rate of vapor, partial pressure, temperature of cathode, exit flow relative humidity

Outputs: Stack voltage, OER, cathode partial pressure, cathode mass flow, cathode output temperature

- **Oxygen Supply model**

Inputs: Cathode partial pressure, compressor voltage, environmental temperature

Outputs: Mass flow rate of vapor, partial pressure, temperature of cathode, exit flow relative humidity

- **Cathode return manifold**

Inputs: cathode mass flow, cathode output temperature

Outputs: return manifold partial pressure

[1] Bessarabov, Dmitri, et al., eds. *PEM electrolysis for hydrogen production: principles and applications*. CRC press, 2016.

Modelling of Fuel Cell

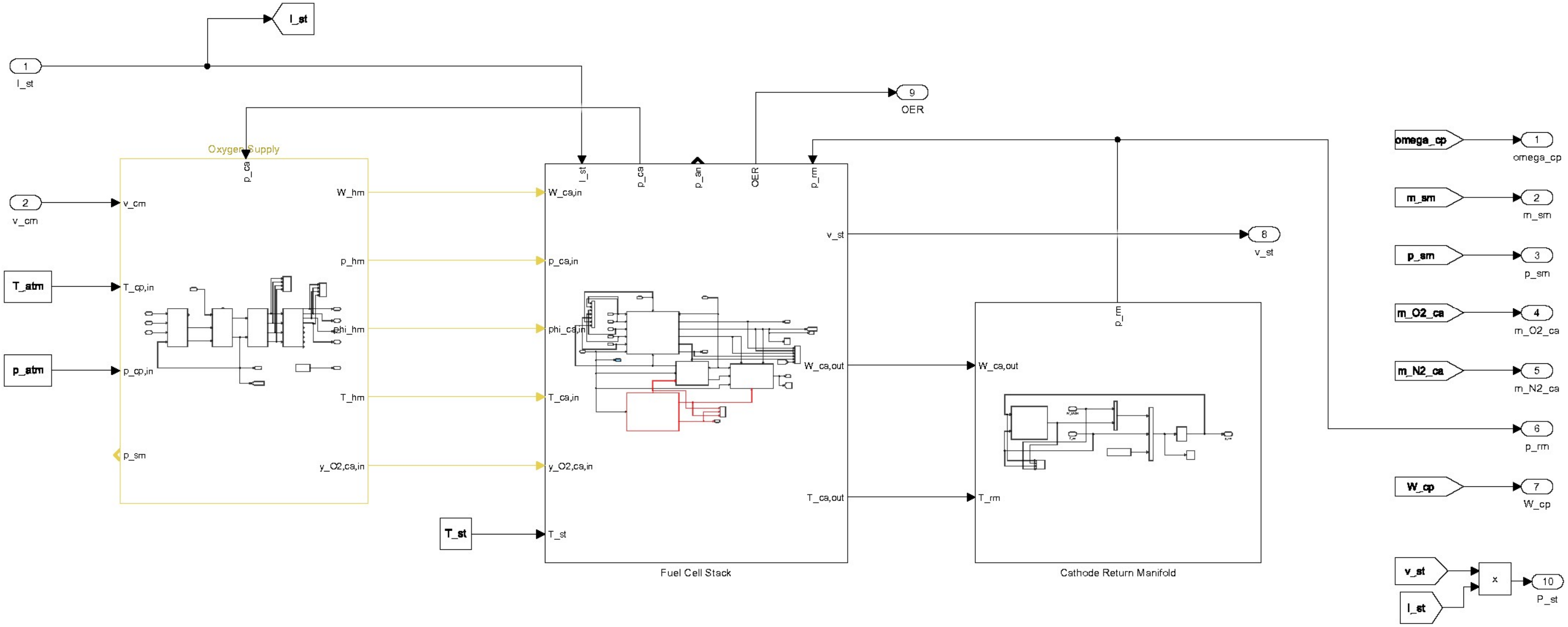

Fig. 12 FC system model in MALAB/Simulink

Modelling of Fuel Cell

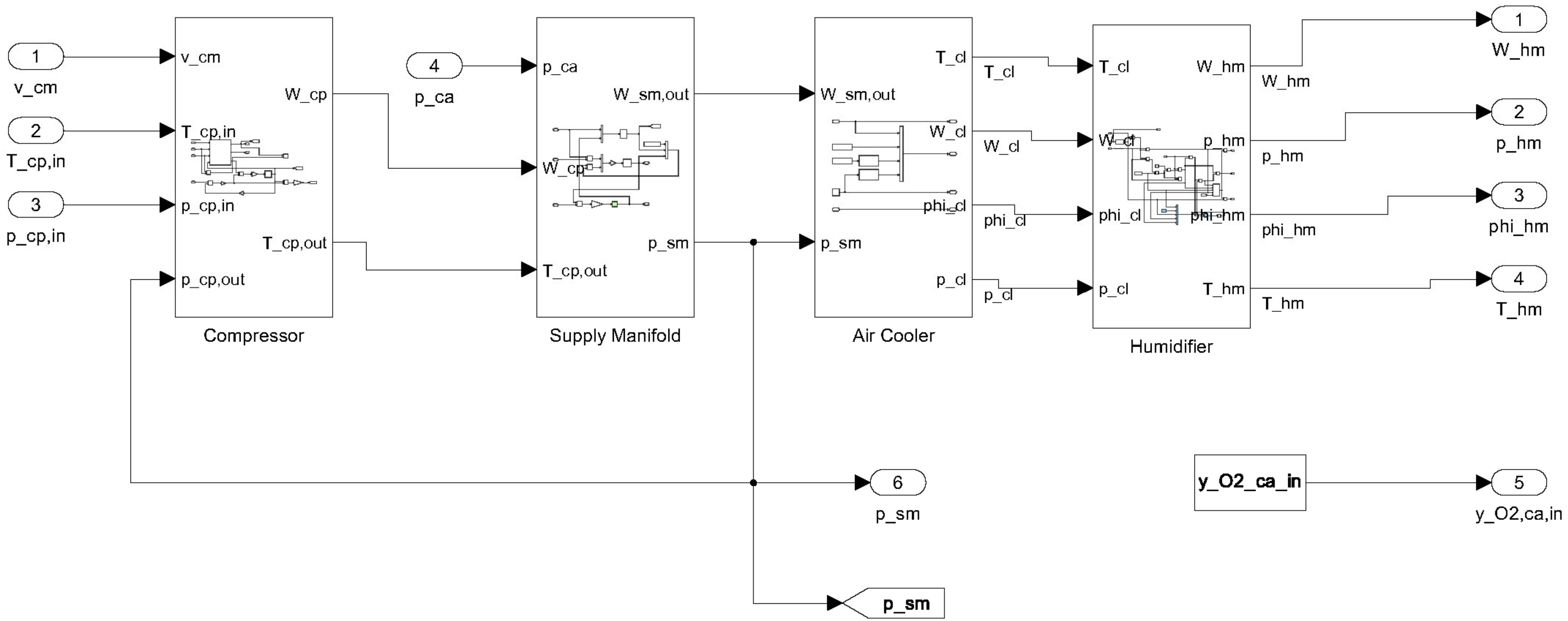

Fig. 13 Oxygen supply model in MALAB/Simulink

Modelling of Fuel Cell

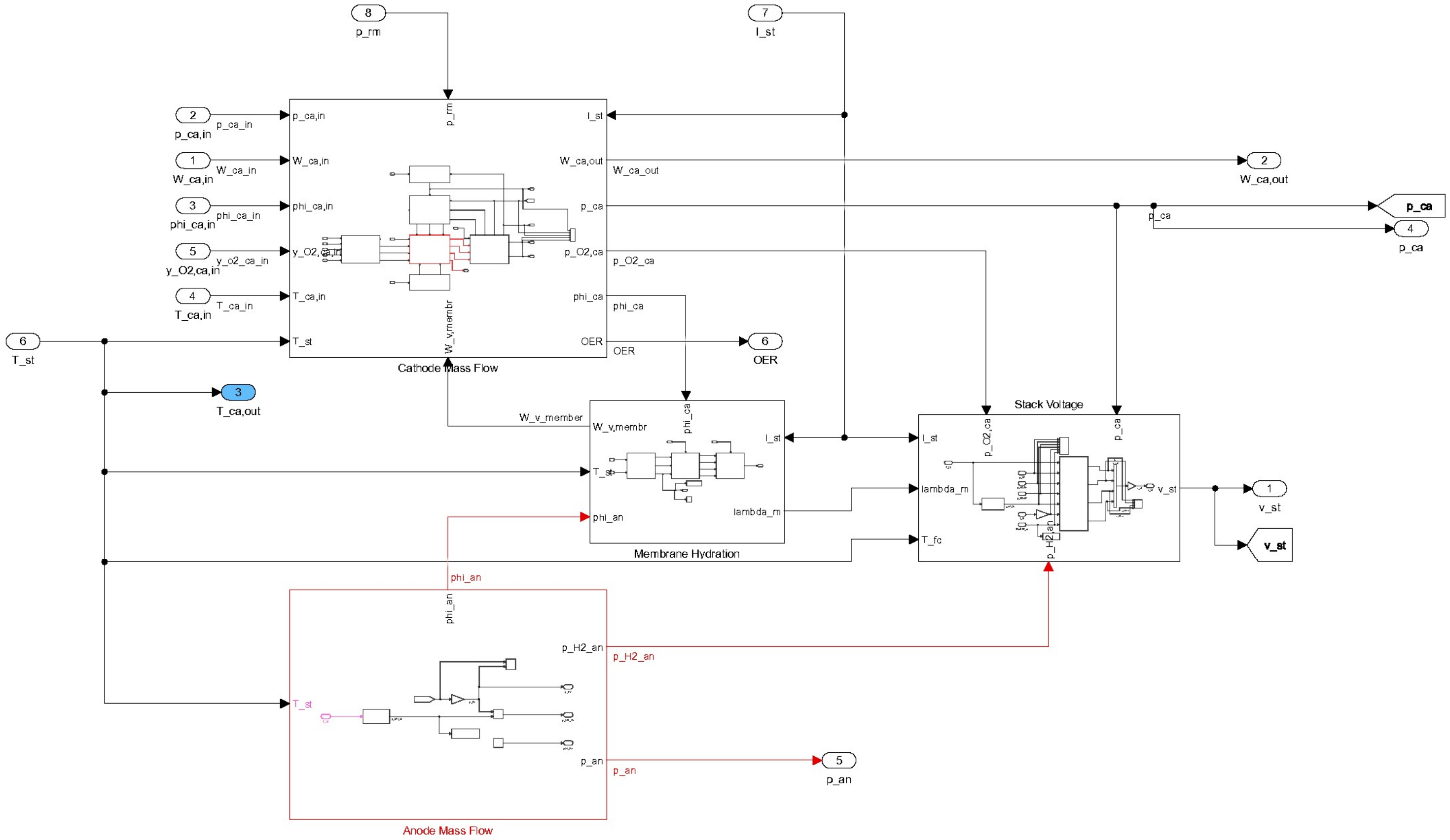

Fig. 14 Fuel cell stack model in MALAB/Simulink

Control of Fuel Cell

There are **three** major control subsystem loops in the fuel cell system: air/fuel supply, water and heat management.

- **Humidifier control and thermal control**

Until extensive experimental data become available, it is more appropriate to assume that the membrane is always fully humidified by other passive means.

The large separation of time scales justifies the assumption that temperature is well controlled compared with the fast oxygen dynamics.

- **Hydrogen Valve control**

It is assumed a fast proportional feedback controller on the hydrogen valve that keeps the anode pressure equal to the cathode pressure almost instantaneously.

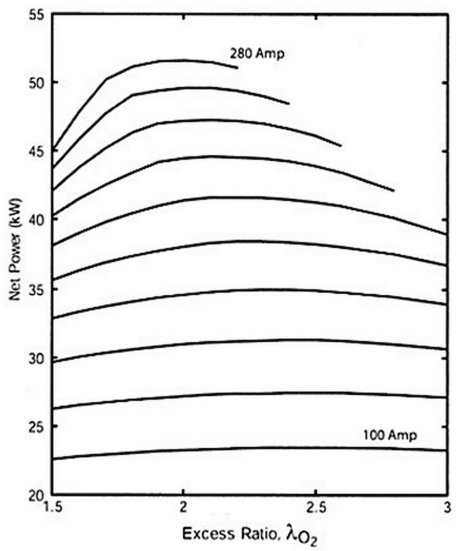

Fig. 15 System net power at different stack currents and oxygen excess ratios

- **OER control**

The oxygen excess ratio (OER), i.e., $\lambda_{O_2} = \frac{W_{ca_{in}}}{W_{ca_{react}}}$. Maintaining an optimal OER ensures sufficient oxygen supply during varying load demands, protecting the fuel cell stack and prolonging its lifespan.

Simulation results

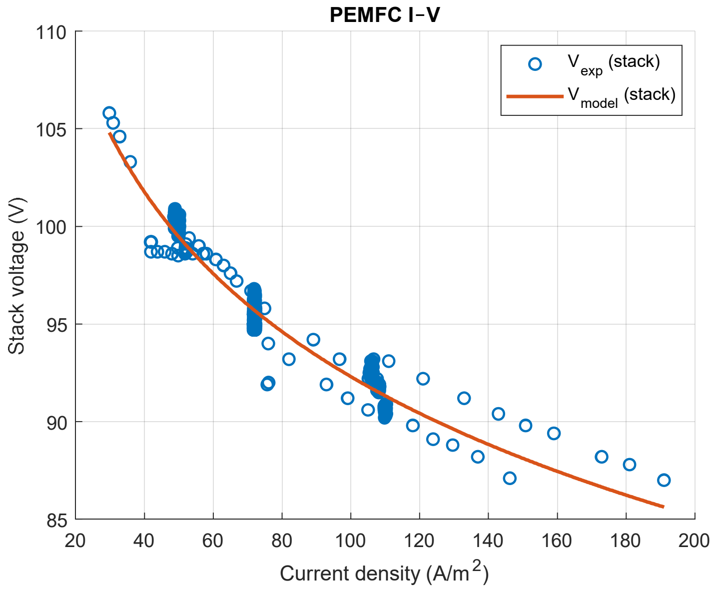

Fig. 16 V-I curve fitting results

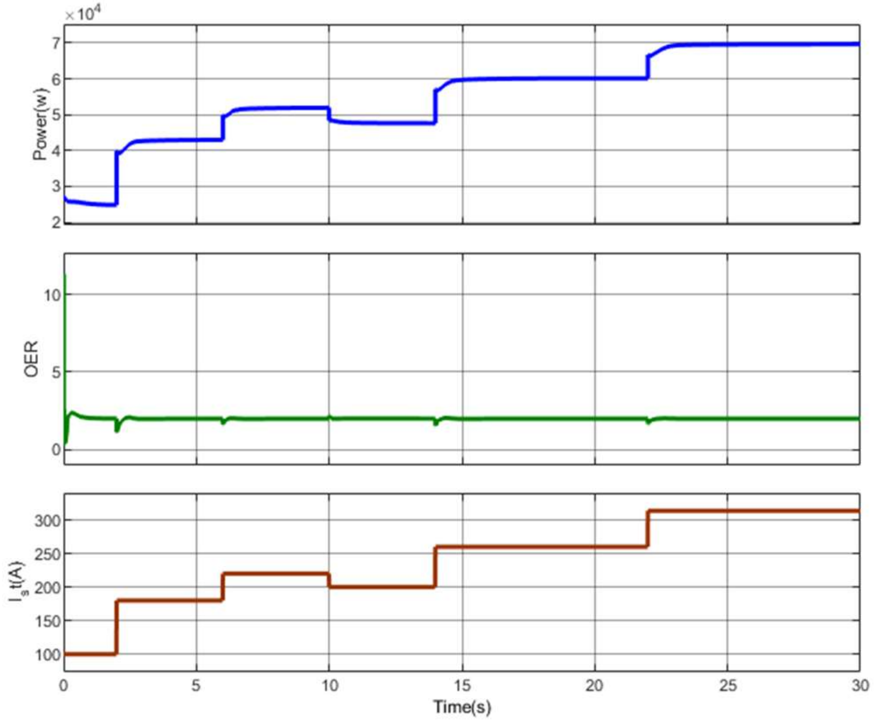

Fig. 17 OER control of electrolyser under varying current

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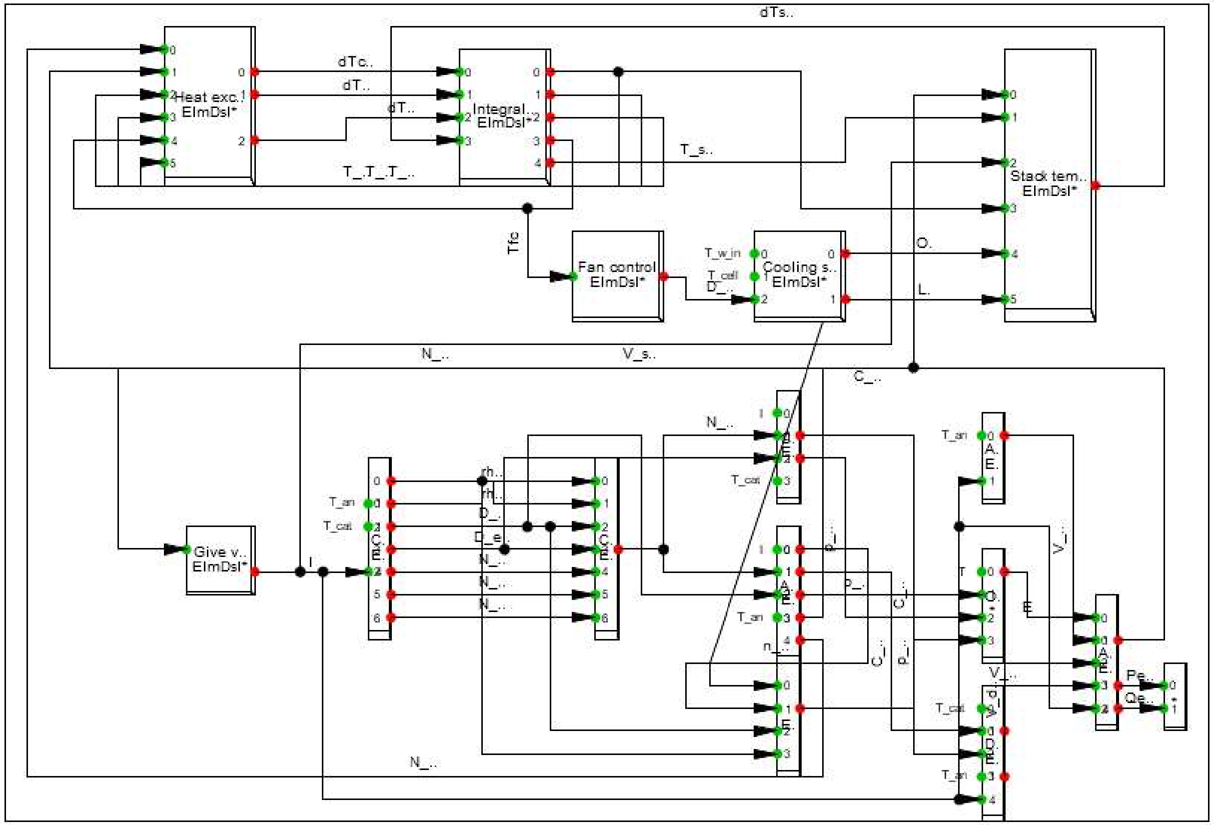
DIgSILENT/Power factory model

Electrolyzer:



Fi. 18 Dynamic composite model of eletrolyser of Power Factory

	Name	Type
	Electrolyzer	Electrolyzer
dsl	Activation vol	Activation overvoltage
dsl	Add voltage	Add_vol
dsl	Anode mass flow	Anode mass flow
dsl	Cal_N_H2O	Calculate N_H2O_m
dsl	Cal_p_H2O	Calculate_p_H2O_me
dsl	Cathod mass flow	Cathod mass flow
dsl	Cathode coeff	Cathode coefficient
dsl	Cooling system	Cooling system
dsl	DSL Model	Calculate_p_H2O_me
dsl	Diffusion vol	Diffusion_ohmic_Volt...
dsl	Fan control	Fan_control
dsl	Give value to stack	Give_value_tostack
dsl	Heat exchanger	Heat exchanger
dsl	Integral Temp	Integral Temp
dsl	Open circuit vol	Open_circuit_voltage
dsl	stack temperature	Stack temperature
	General Load	General Load Type
	Terminal_H	
	Terminal_L	
	2-Winding Transformer	2 MVA 20/0.4 kV Yyn6 ...
	External Grid	

DIgSILENT/Power factory model

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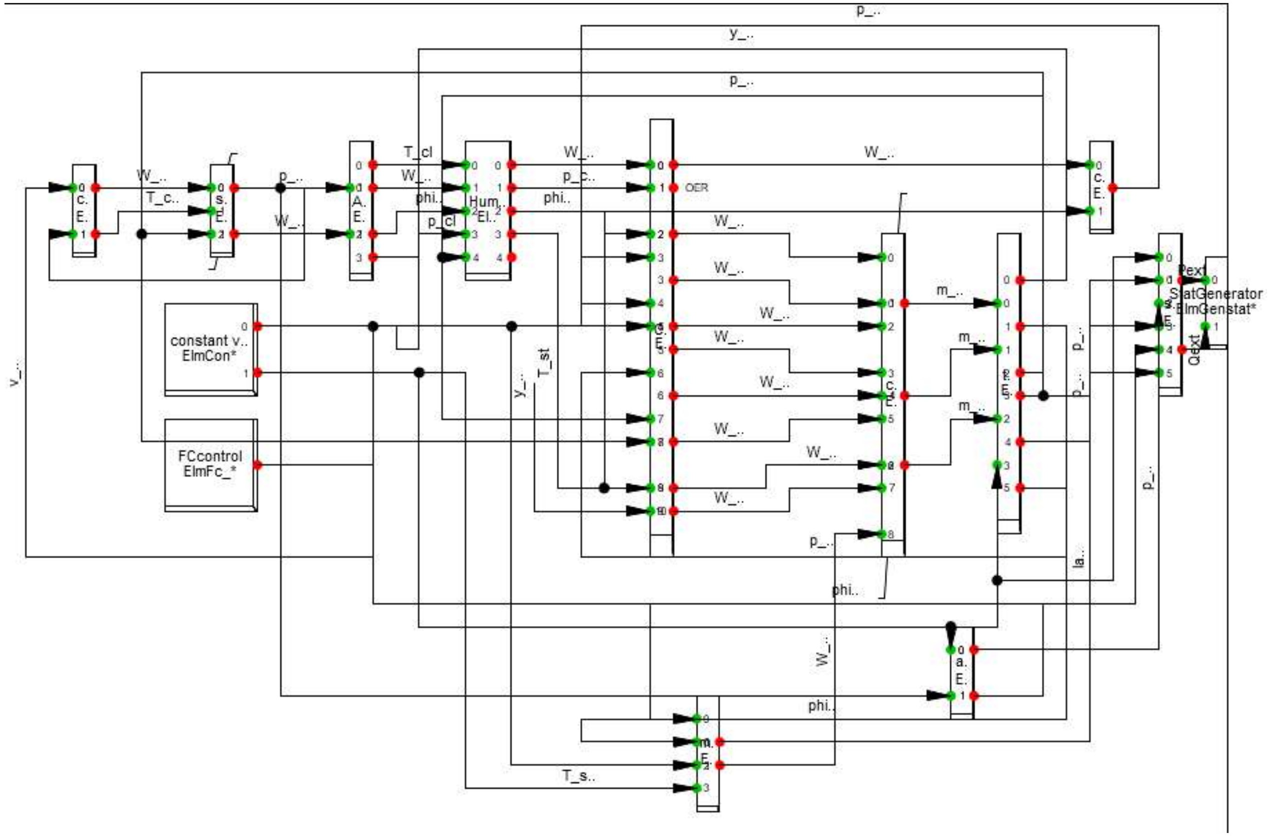

Fig. 19 Dynamic model of fuel cell of Power Factory

	FC_modelCtrl	FC model and ctrl
dsl	Anode Mass flow	Anode mass flow
dsl	Cathod mass integr	Cathod flow_integ
dsl	Cathode mass flow	Cathode Mass Flow
dsl	Cathode return manifold	Cathod return manifold
dsl	Constant_value	Constant_Value
dsl	FC_control	FC_control
dsl	FC_stack voltage	FCstack_voltage
dsl	Membrane hydration	Membrane hydration
dsl	O2 supply manifold block	O2_supply manifold_...
dsl	O2_compressor	O2_Compressor
dsl	O2_cooler	O2_air cooler
dsl	O2_humidifier	O2_humidifier
dsl	O2_supply manifold	O2_Supply manifold
dsl	thermo dynamic calculation	thermo dynamic calc...
	Static Generator	
	General Load	Lod-1
	Terminal H	
	Terminal L	
	2-Winding Transformer	2 MVA 20/0.4 kV 3 GE...
	External Grid	

Thanks for listening!