Automatic model parameter determination to fit IBR behavior.

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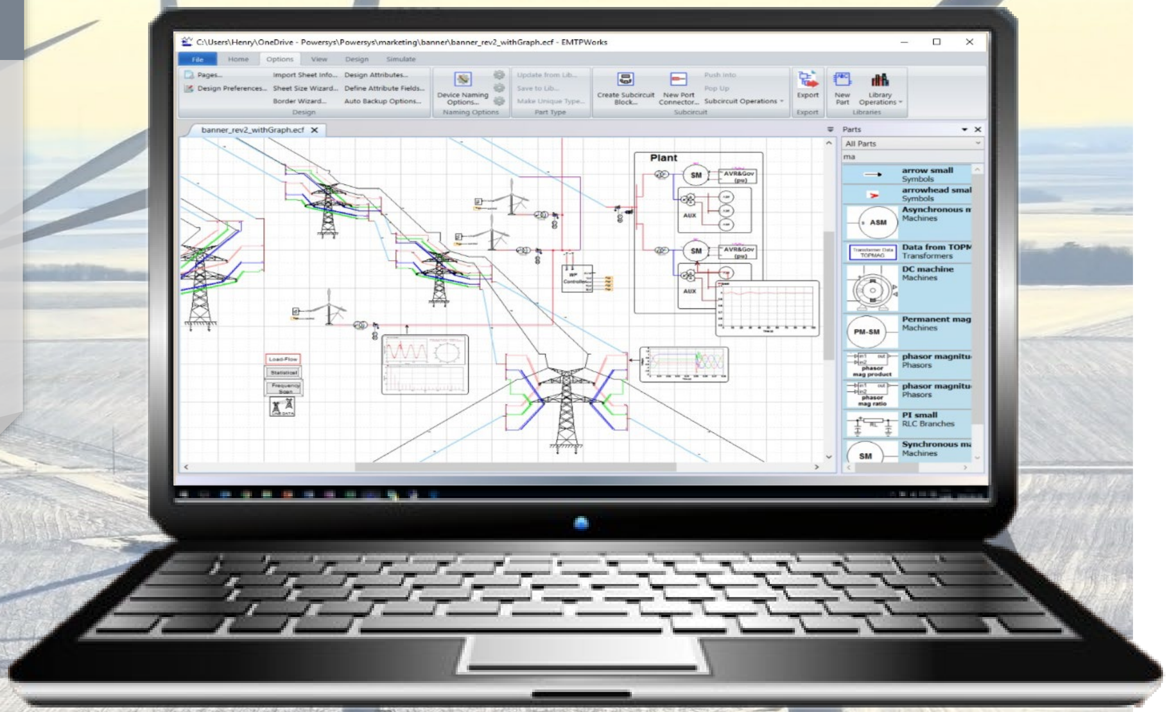

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Content

I. Tool development capability of EMTP

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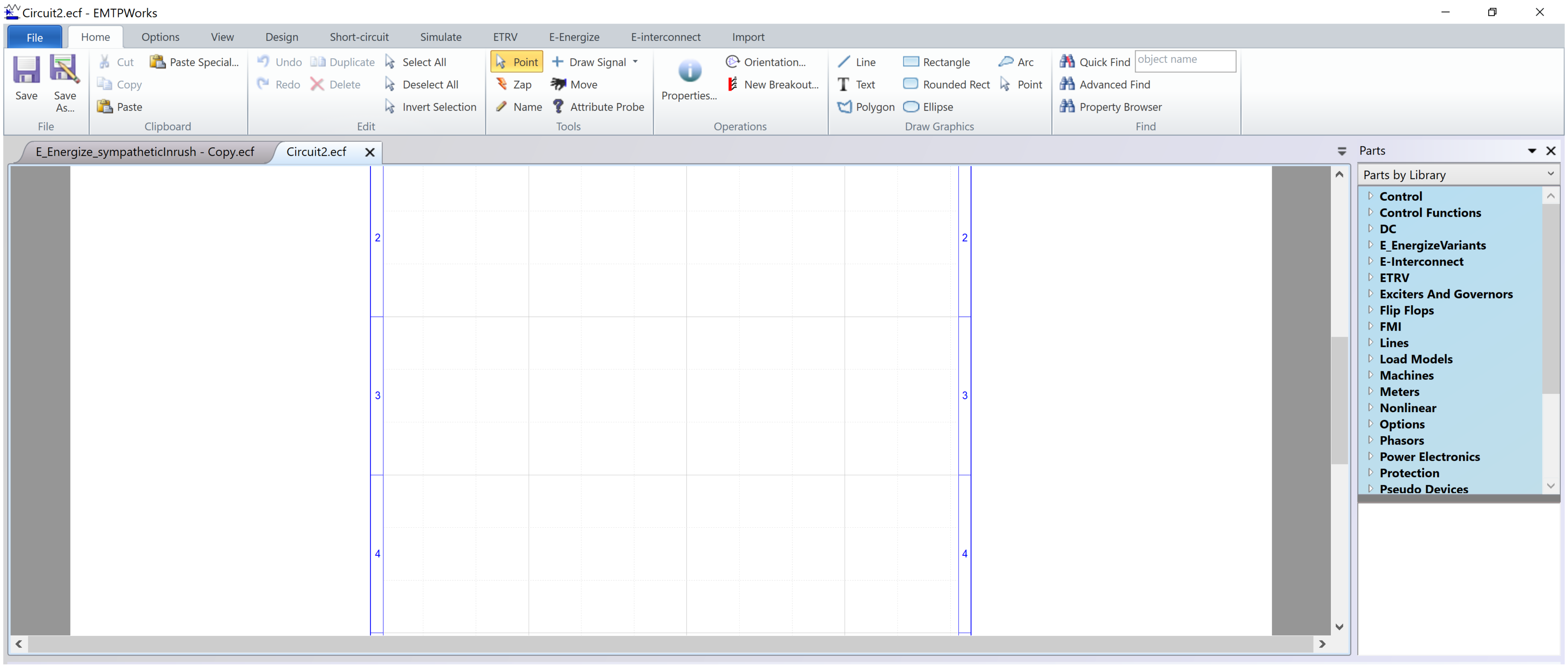
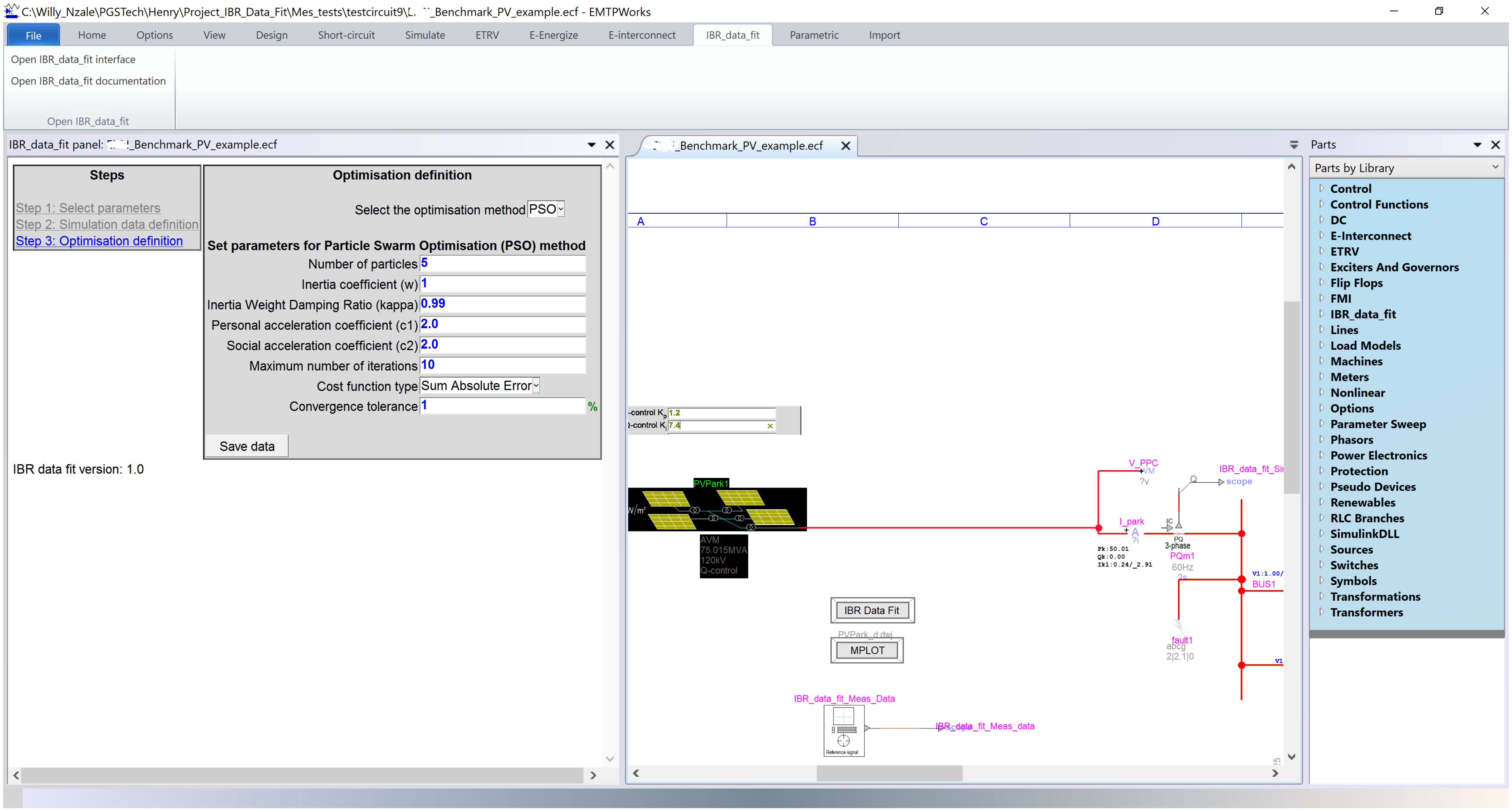


I. Tool development capability of EMTP

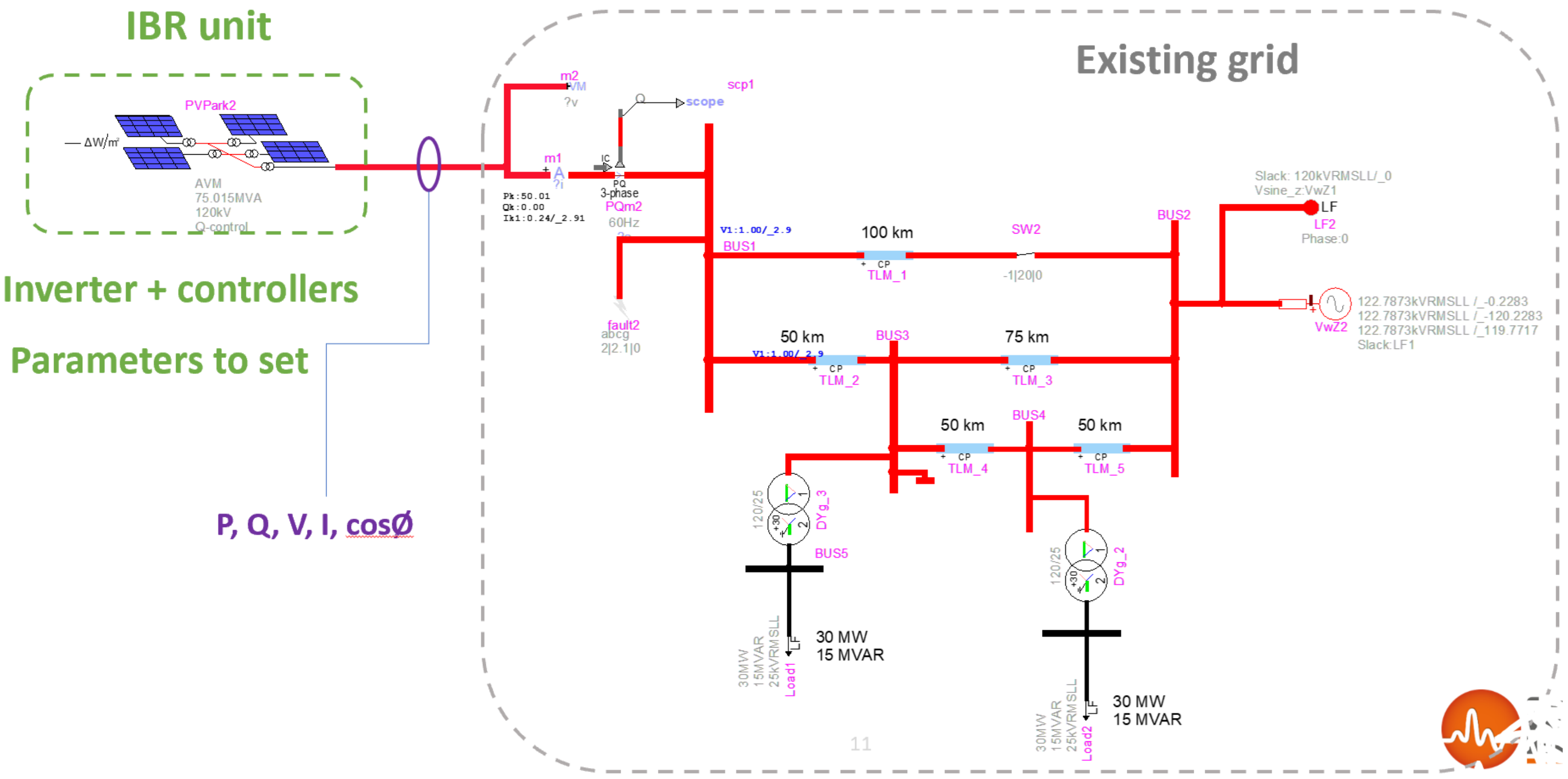


II. Automatic model parameter determination

II. Automatic model parameter determination

Context:

- Let’s consider an IBR plant connected to a grid. The plant and the grid are modeled in EMTP, but we do not know the settings of some parameters in the IBR model (controller gains, time constants, etc…).
- On-site measurements of the physical plant response in some operating conditions are available.
- A tool has been created in EMTP to automatically determine some unknown IBR plant parameters values by fitting the IBR model response to on-site measurements.

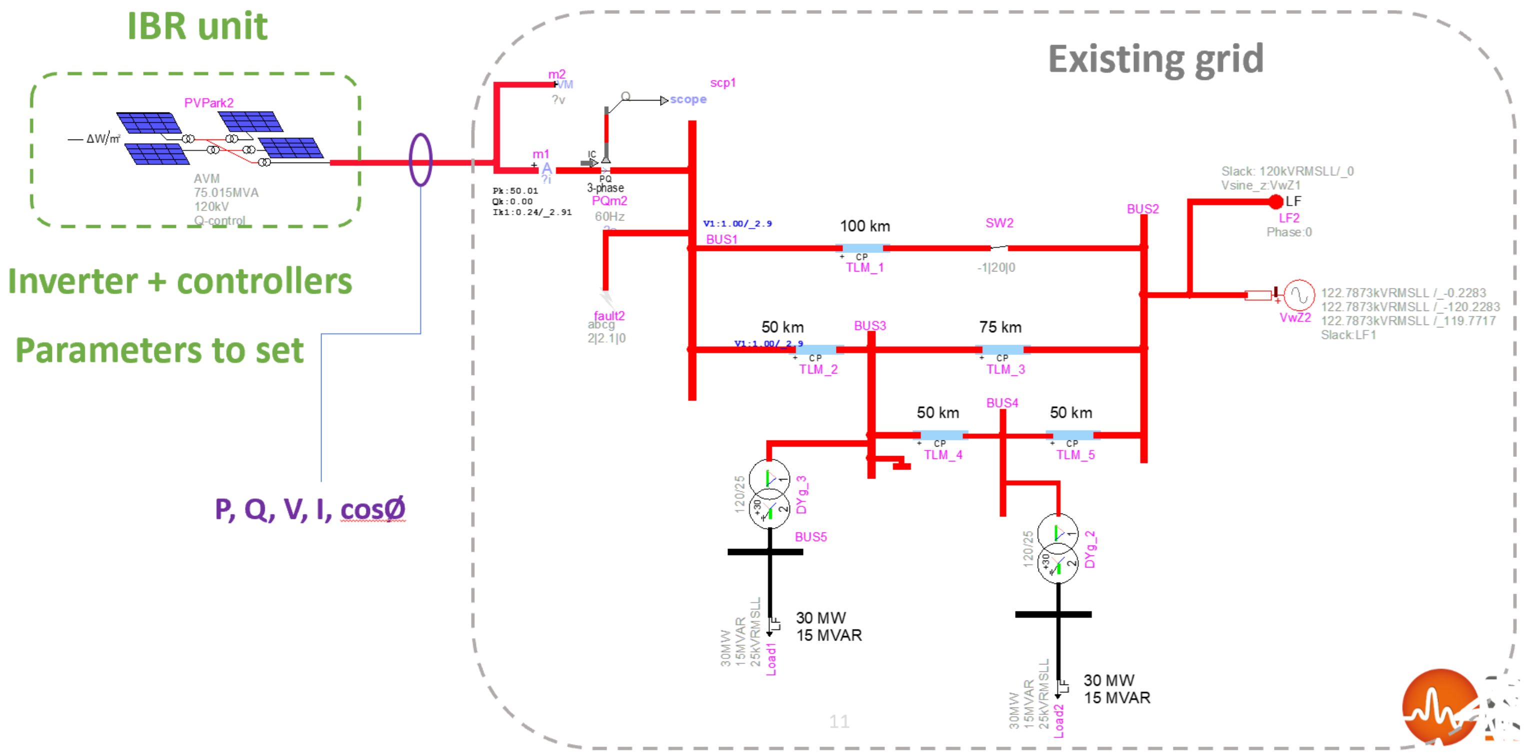


V-control K_v	1.75	
Q-control K_p	2.09	
Q-control K_i	18.56	
Maximum output Q command	1	pu
Minimum output Q command	-1	pu
Output Q command revise time	0.0001	s
FRT pickup voltage	0.175	pu
FRT reset voltage	0.125	pu

II. Automatic model parameter determination

Context:

- The tool performs the following tasks automatically:
  - Assign values to some parameters of the plant model,
  - simulate the model and get the plant response,
  - compare the simulation results with expected waveforms (experimental measurements),
  - update/modify parameters values and redo the process until the perfect match is found.
- Parameters update process is performed using an artificial intelligence method known as **the particle swarm optimization (PSO) algorithm**.



II. Automatic model parameter determination

An overview or the particle swarm optimization (PSO) algorithm:

- Several entities (particles) are searching for the best solution.
- It is an iterative process (instant1, instant2, instant3, etc…).
- At each iteration (instant), each particle has a **position**, a **velocity** and a **cost**.
- At each iteration (instant), each particle position is updated based on past knowledge.

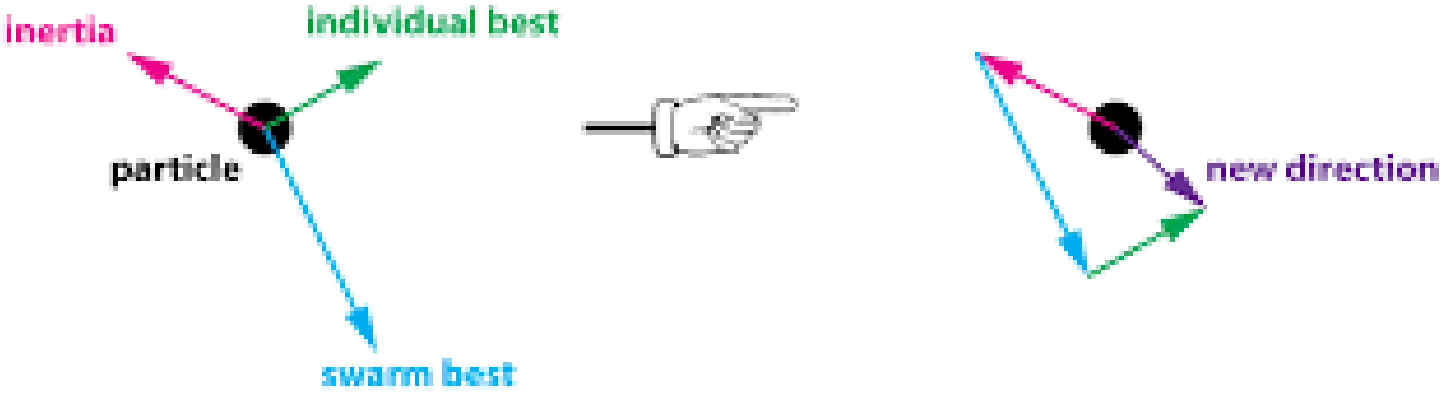
$$P_i^{t+1} = P_i^t + V_i^{t+1}$$ *Particle position update*

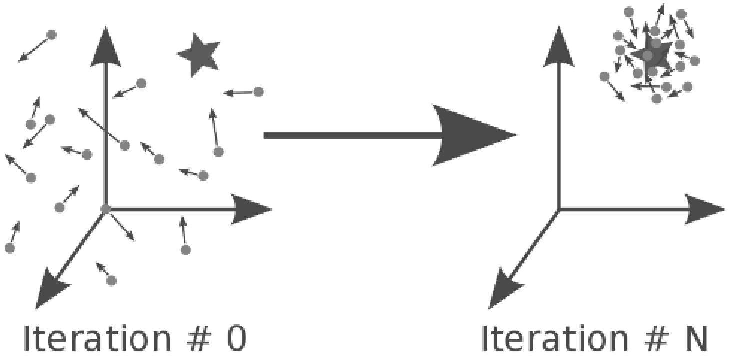
$$V_i^{t+1} = W.V_i^t + c_1 U_1^t (P_{b_1}^t - P_i^t) + c_2 U_2^t (g_b^t - P_i^t)$$ *Velocity update*

Inertia : Makes the particle move in the same direction and with the same velocity.

Personal Influence : Improves the individual. Makes the particle return to a previous position, better than the current.

Social Influence : Makes the particle follow the best neighbors direction.





II. Automatic model parameter determination

PSO applied to parameter determination **Ex: estimating the PI controller gains of the reactive power control**

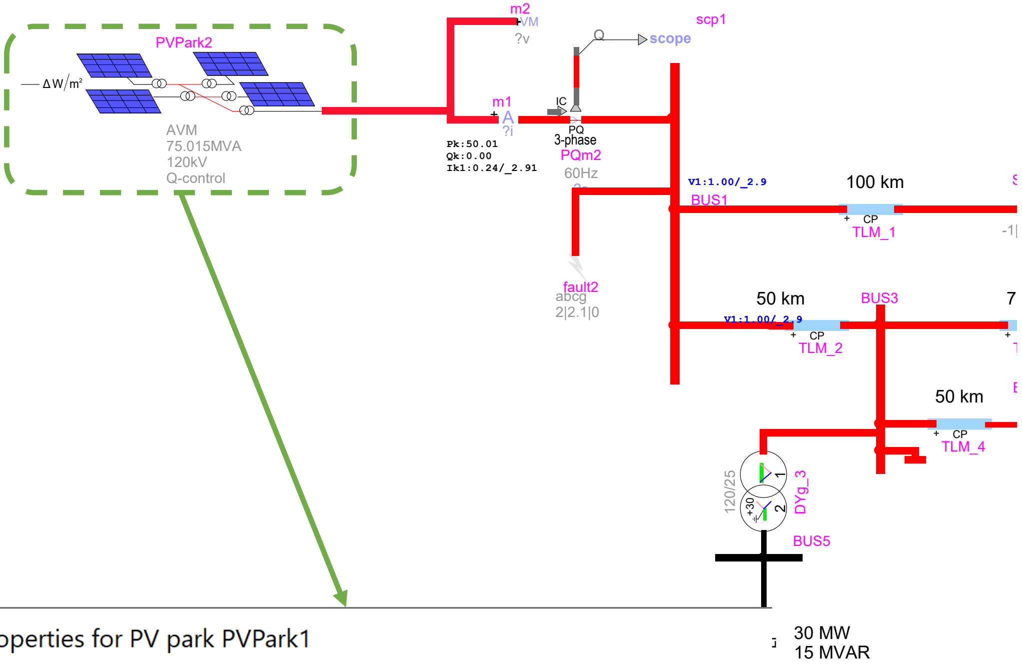
The blue line represents the on-site measurement of the plant response to a Q-step change

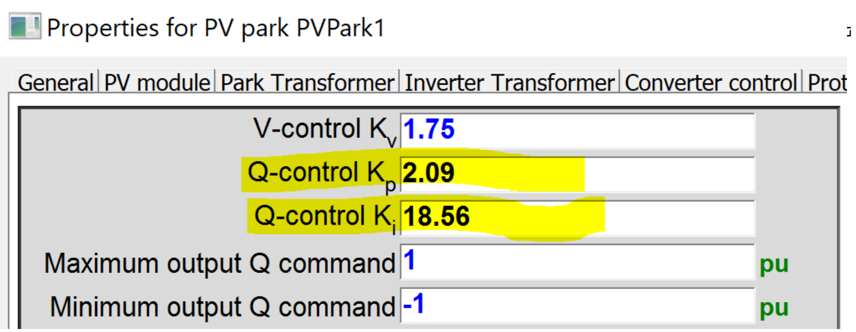
Each value of K_p and K_i (a particle position) yields a specific plant response (red line)

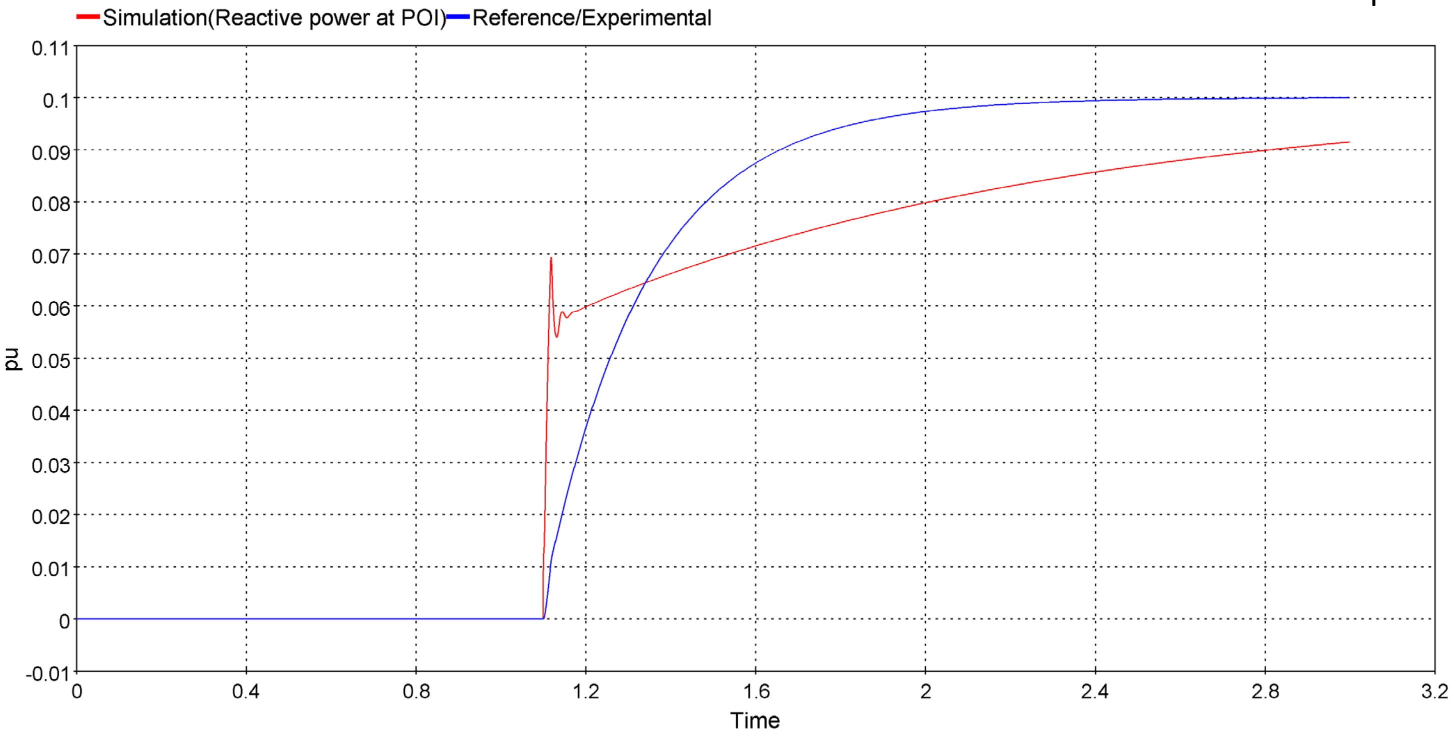
Cost function:

$$\sum_{i=0}^{i=N} |f_{Exp}(i) - f_{sim}(i)|$$

N: Number of Samples







The goal is to find K_p and K_i so that the red line (simulated) fits the blue one (measurement).

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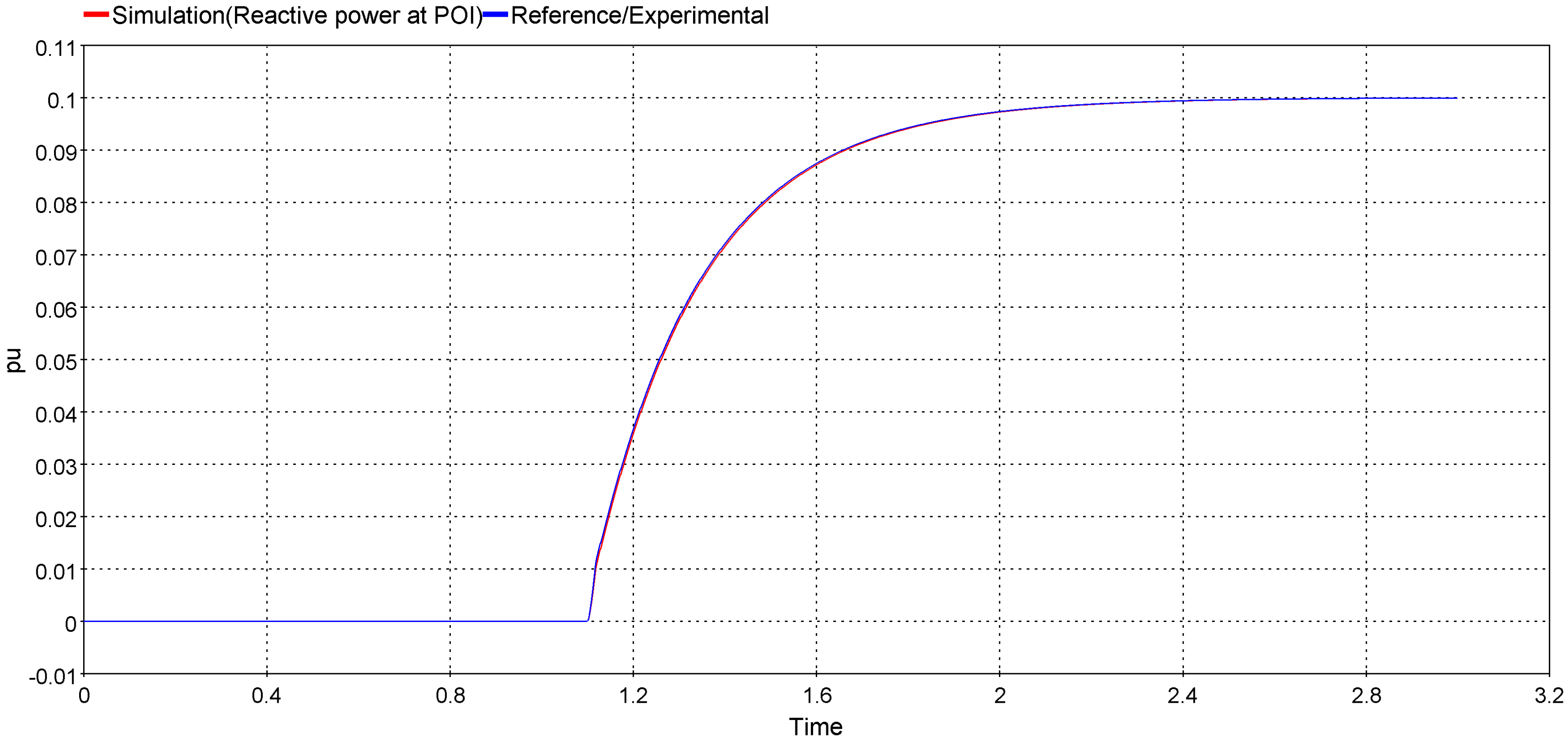
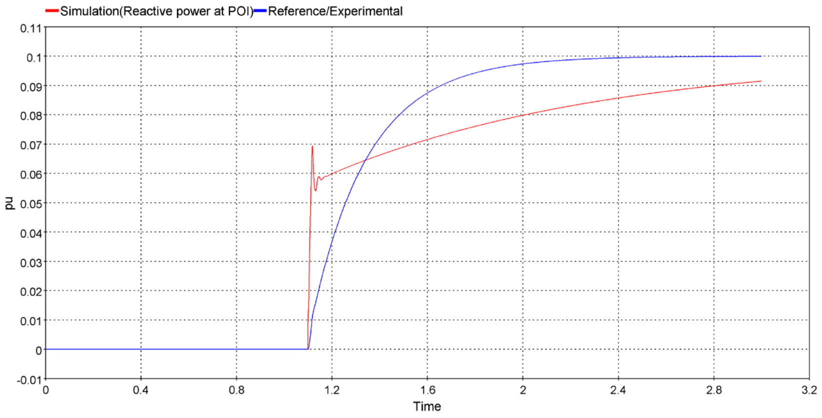
II. Automatic model parameter determination

PSO applied to parameter determination **Ex: estimating the PI controller gains of the reactive power control**

The PSO algorithm performs iterations and stops as soon as the cost associated to a particle gets lower than a predefined threshold. The corresponding particle value is taken as the final solution (K_p and K_i).





	Final solution	Expected value
K_P	0.08	0.1
K_I	5.4	5.5

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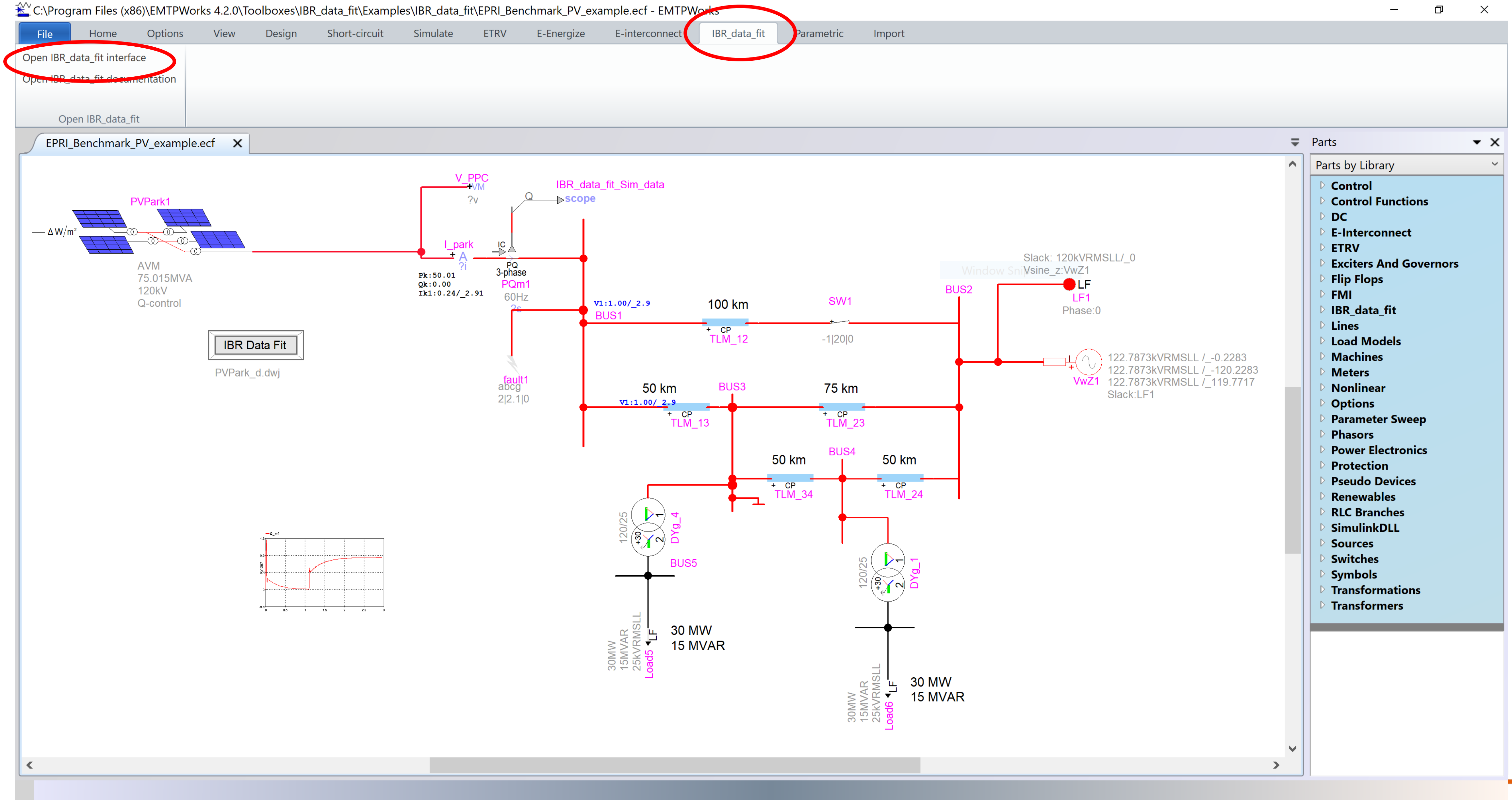
II. Automatic model parameter determination

The automatic model parameter determination has been implemented in EMTP using the tool development capability presented at the beginning. The next section presents the tool itself.

III. The IBR data fit tool

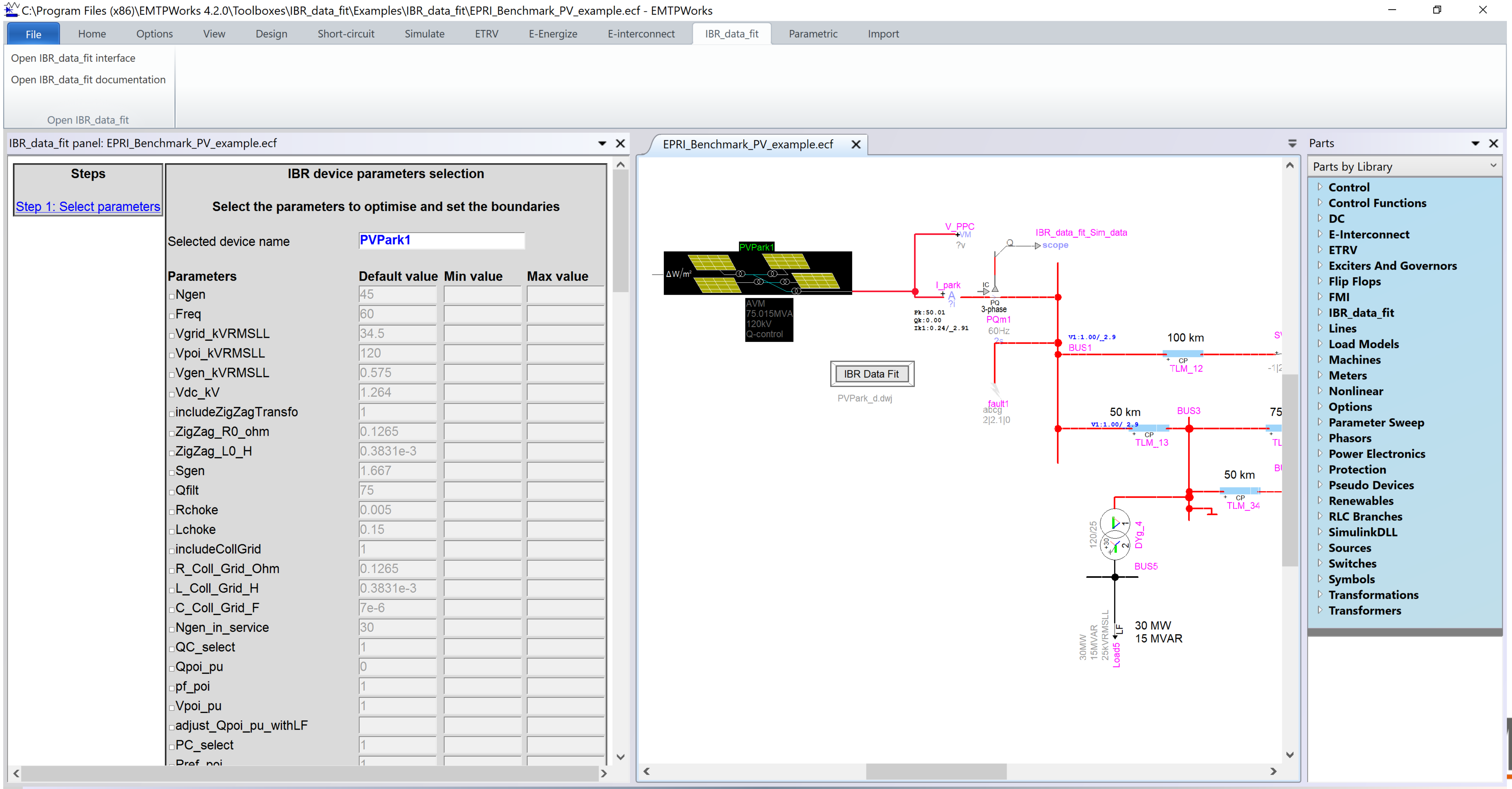
III. The IBR data fit tool

Launch the tool



III. The IBR data fit tool

Step 1 : Select parameters to vary



III. The IBR data fit tool

Step 2 : Simulation data definition

Steps

Step 1: Select parameters
Step 2: Simulation data definition

Simulation data definition

Reference and observed signals scopes names

Reference data signal scope: "IBR_data_fit_Meas_data"
Observed data signal scope: "IBR_data_fit_Sim_data"

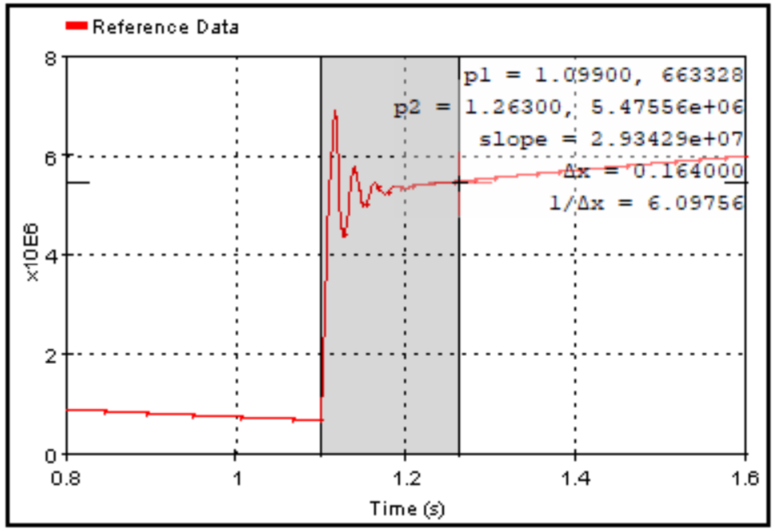
Define observation interval

Observation start time 1.0 s
Observation stop time 2.6 s

Save data

On-site measurements data (reference) are saved in a .dat file.

A scope is added to the EMTP circuit with the name IBR_data_fit_Sim_data at the same location where on-site measurement had been performed.



III. The IBR data fit tool

Step 3: Optimization definition

Steps

Step 1: Select parameters
Step 2: Simulation data definition
Step 3: Optimisation definition

Optimisation definition

Select the optimisation method: PSO

Set parameters for Particle Swarm Optimisation (PSO) method

Number of particles	5
Inertia coefficient (w)	1
Inertia Weight Damping Ratio (kappa)	0.99
Personal acceleration coefficient (c1)	2.0
Social acceleration coefficient (c2)	2.0
Maximum number of iterations	10
Cost function type	Sum Absolute Error
Convergence tolerance	1 %

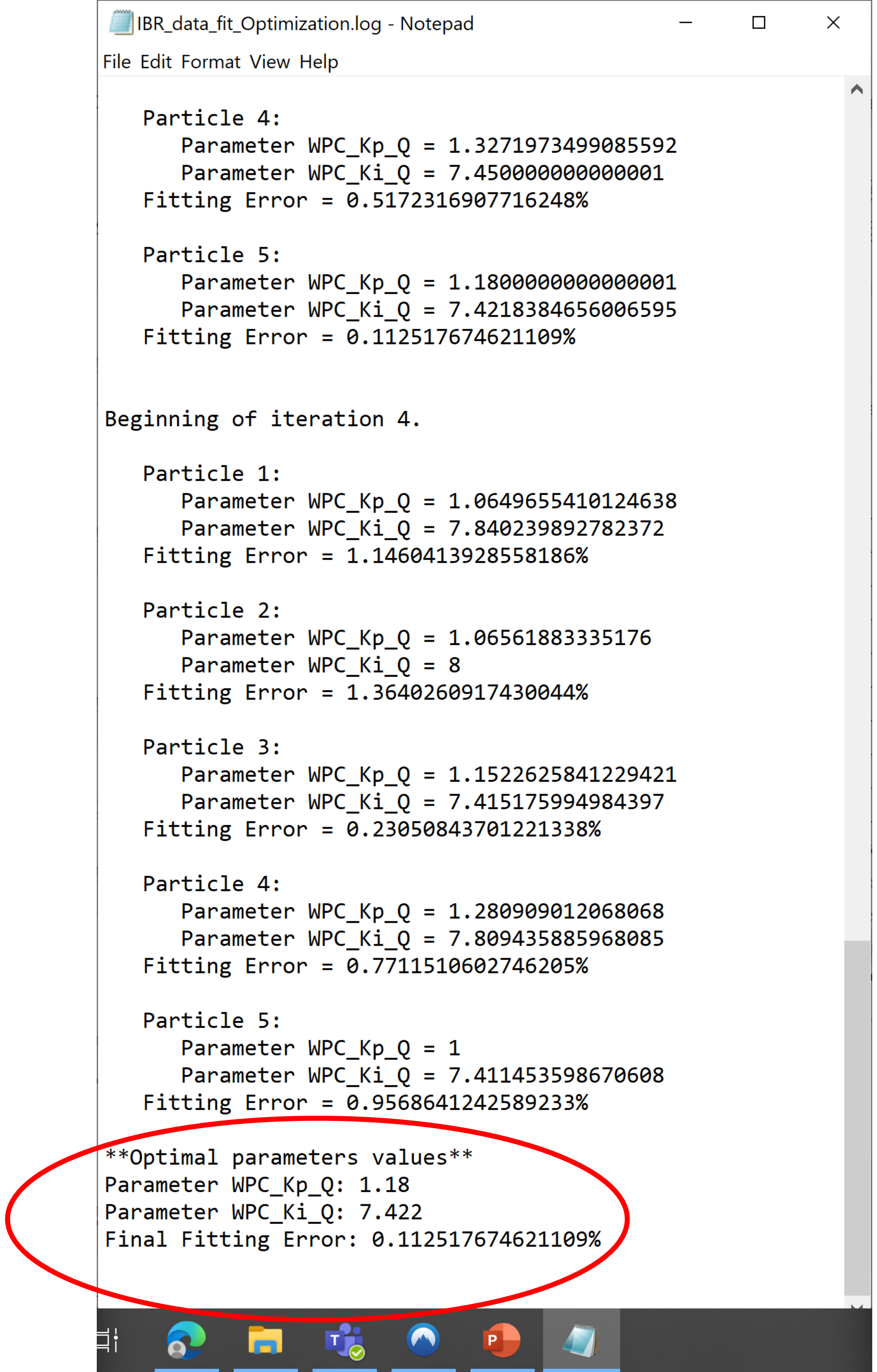
Save data

IBR data fit version: 1.0

III. The IBR data fit tool

Final step: get optimization results

Optimization results are available in a text file located inside the _pj folder with the name IBR_data_fit_Optimization.log


```
IBR_data_fit_Optimization.log - Notepad
File Edit Format View Help

   Particle 4:
      Parameter WPC_Kp_Q = 1.327197349085592
      Parameter WPC_Ki_Q = 7.450000000000001
   Fitting Error = 0.5172316907716248%

   Particle 5:
      Parameter WPC_Kp_Q = 1.1800000000000001
      Parameter WPC_Ki_Q = 7.4218384656006595
   Fitting Error = 0.112517674621109%


Beginning of iteration 4.

   Particle 1:
      Parameter WPC_Kp_Q = 1.0649655410124638
      Parameter WPC_Ki_Q = 7.840239892782372
   Fitting Error = 1.1460413928558186%

   Particle 2:
      Parameter WPC_Kp_Q = 1.06561883335176
      Parameter WPC_Ki_Q = 8
   Fitting Error = 1.3640260917430044%

   Particle 3:
      Parameter WPC_Kp_Q = 1.1522625841229421
      Parameter WPC_Ki_Q = 7.415175994984397
   Fitting Error = 0.23050843701221338%

   Particle 4:
      Parameter WPC_Kp_Q = 1.280909012068068
      Parameter WPC_Ki_Q = 7.809435885968085
   Fitting Error = 0.7711510602746205%

   Particle 5:
      Parameter WPC_Kp_Q = 1
      Parameter WPC_Ki_Q = 7.411453598670608
   Fitting Error = 0.9568641242589233%

**Optimal parameters values**
Parameter WPC_Kp_Q: 1.18
Parameter WPC_Ki_Q: 7.422
Final Fitting Error: 0.112517674621109%
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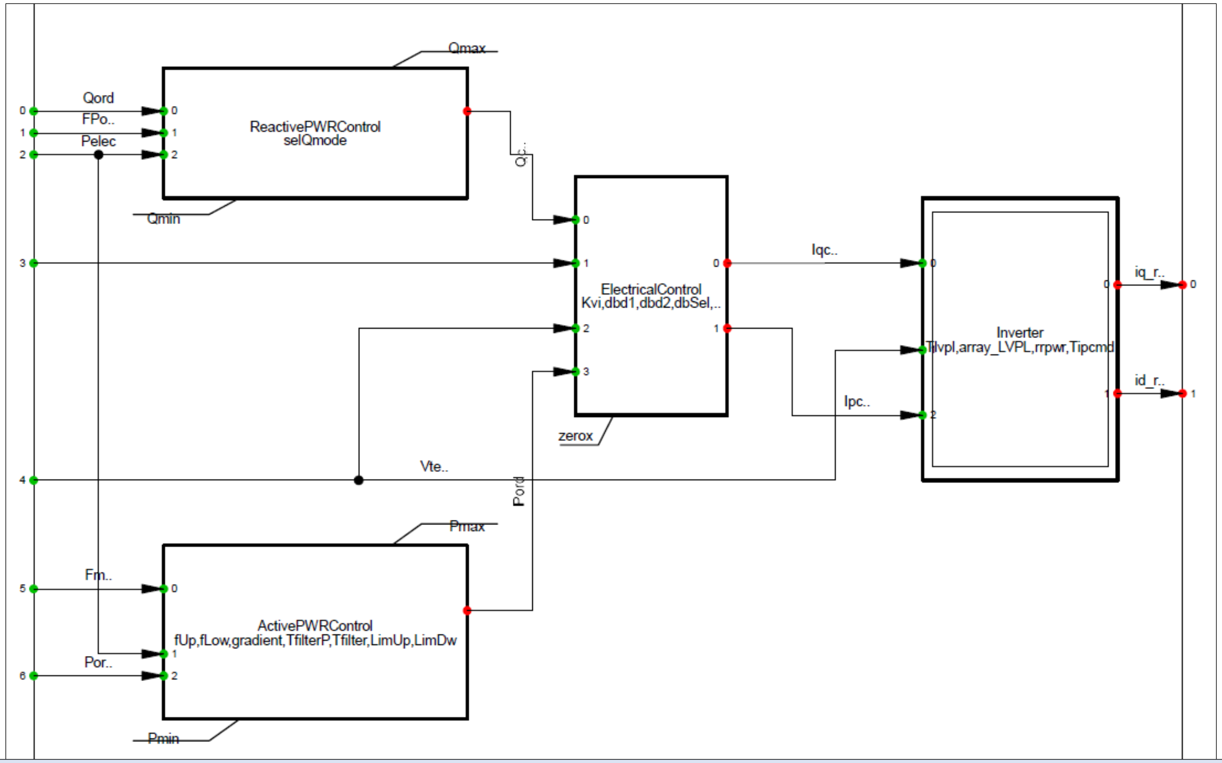
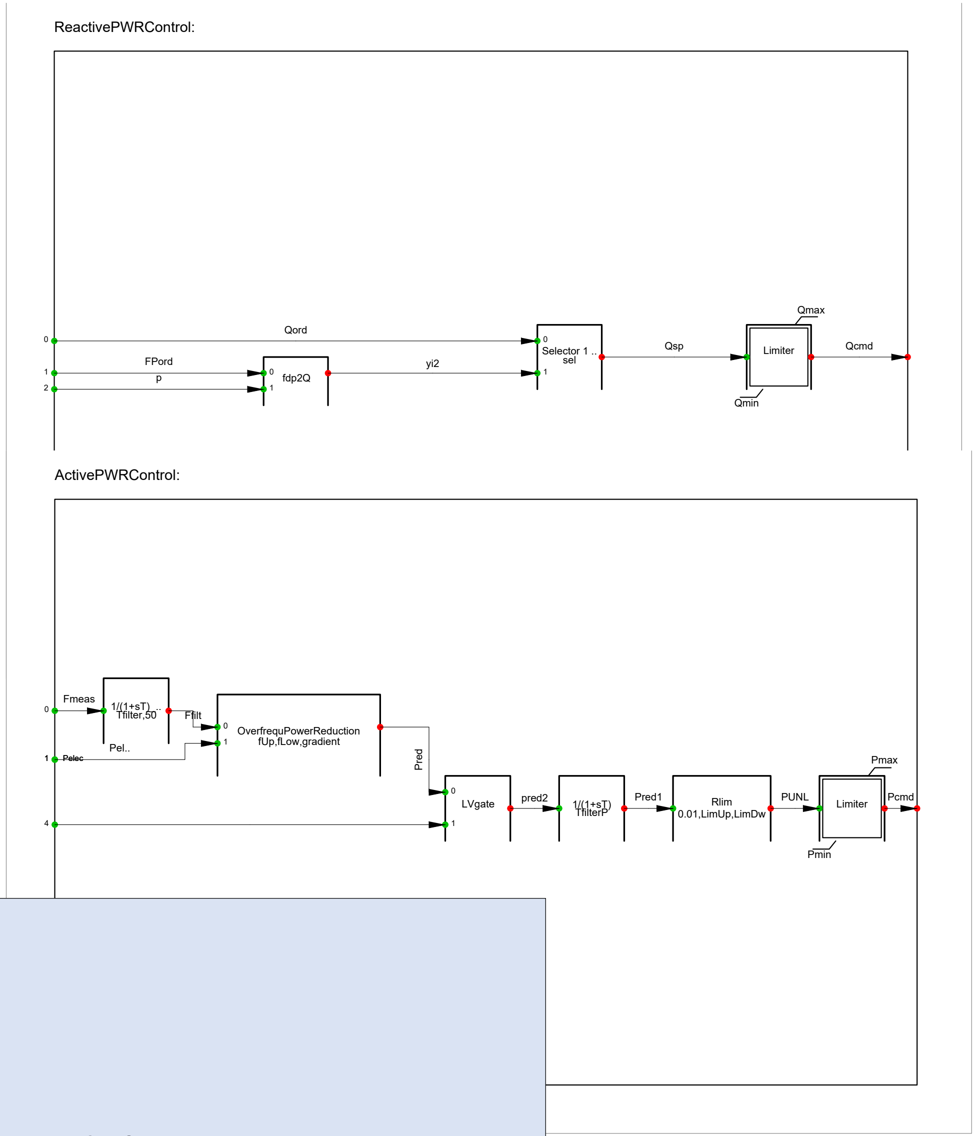
IV. Case study

IV. Case study

Calibration of a NON-WECC Model (extremely simplified)





- RMS Model validated on site (Step changes, not faults)
- NON-WECC model → More challenging fitting
- Simple control blocks → difficult to translate to a more complex model
- NON WECC model → Almost equivalent to a Black Box model for practical effects

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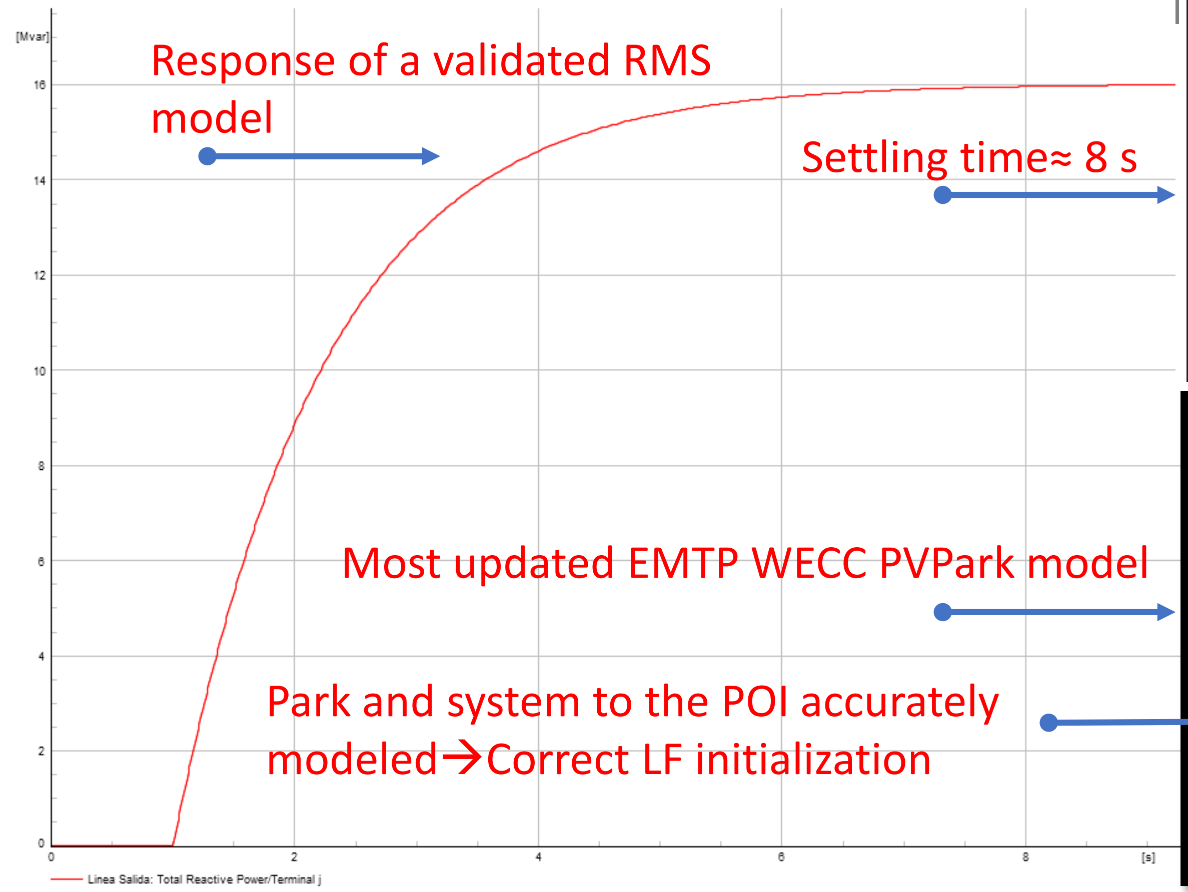
IV. Case study

PPC Parameter Calibration with a Q Step Change of 20% of the Nominal Power of the PV Park

Default values

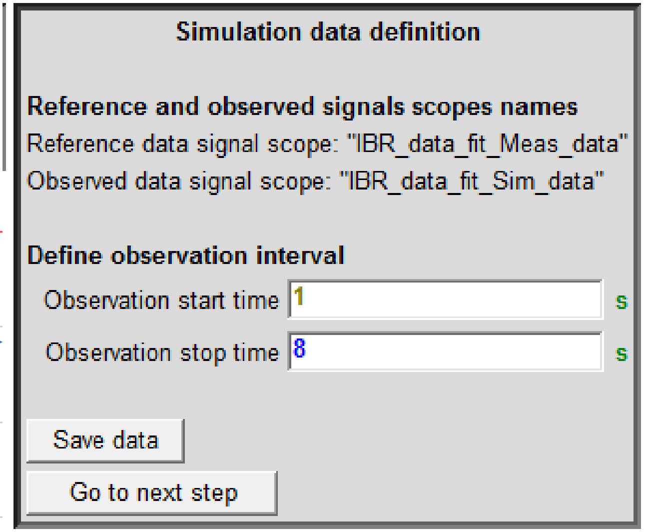


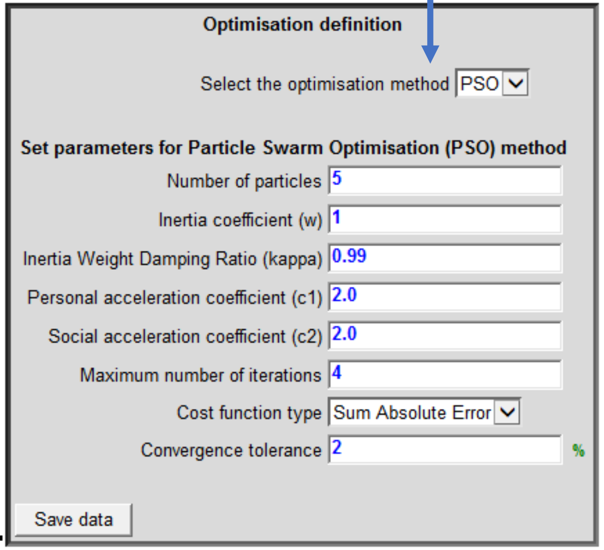
Response of a validated RMS model

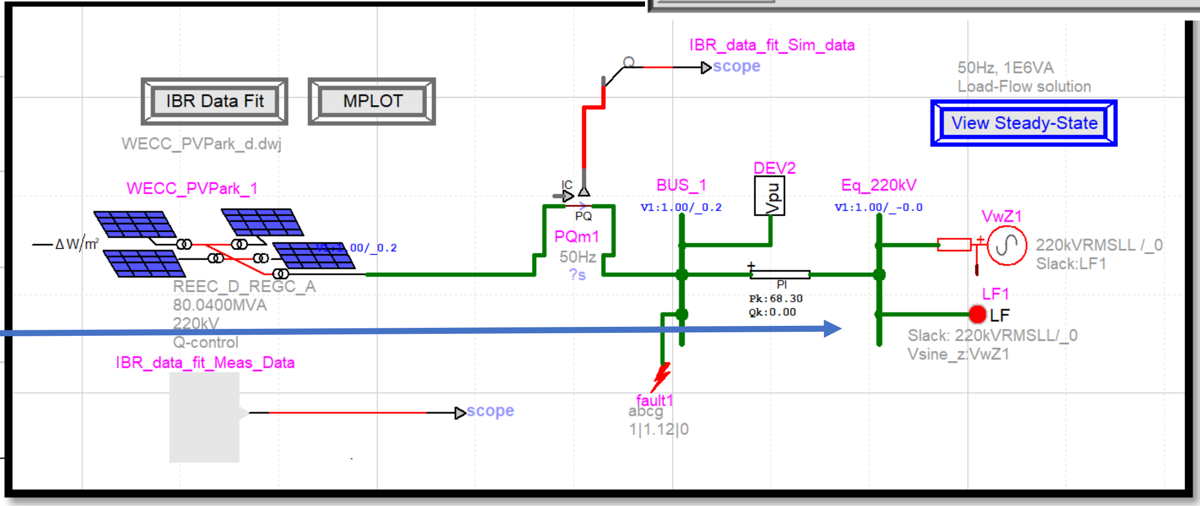
Settling time≈ 8 s

Most updated EMTP WECC PVPark model

Park and system to the POI accurately modeled→Correct LF initialization

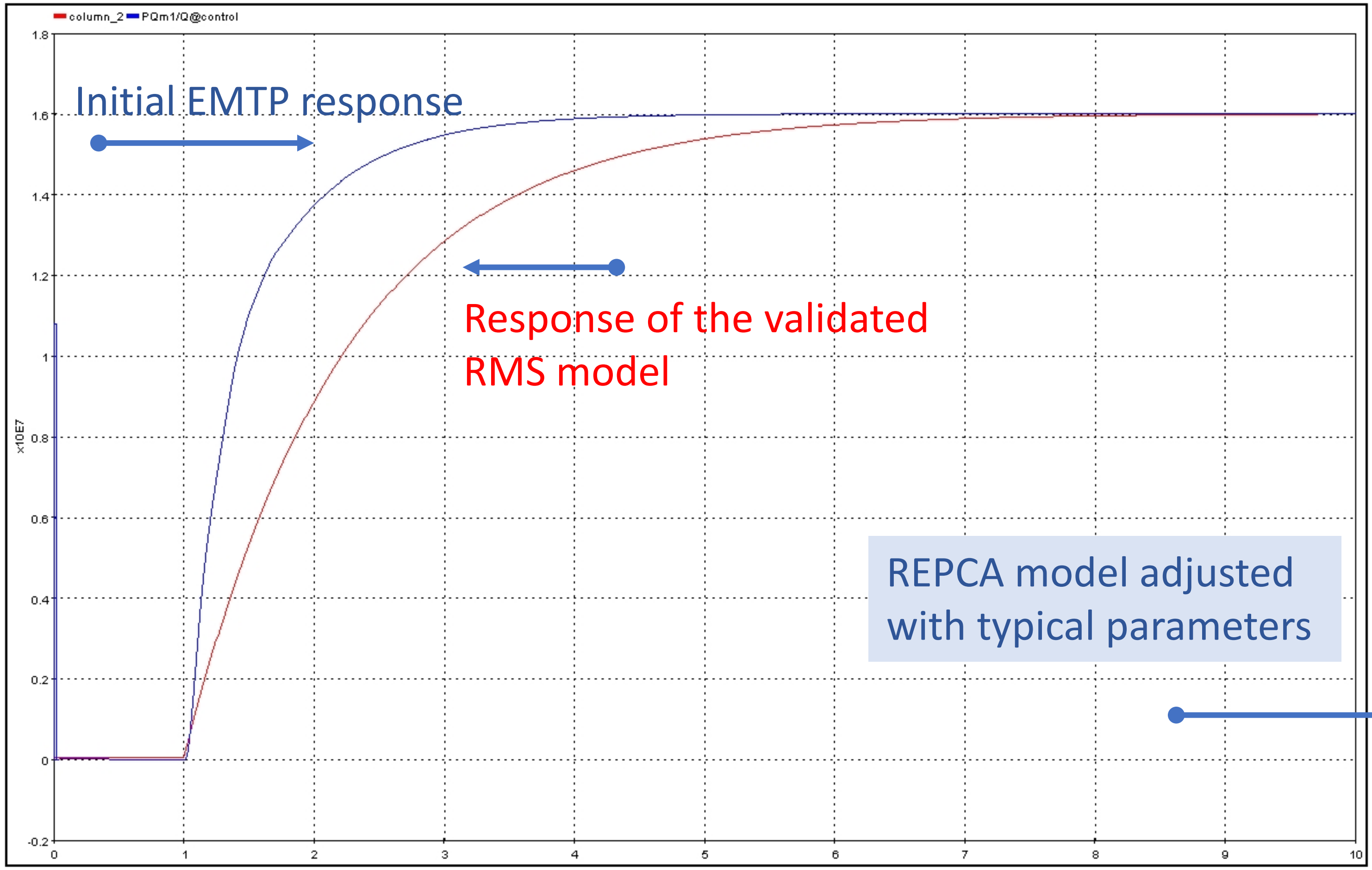






IV. Case study

CASE 1: Default values for the REPC WECC_PV_Park Model



Q/V control - REPCA model

Voltage droop control	droop control	
Time constant Tfltr	0.02	s
Proportional gain Kp	0.5	pu
Integral gain Ki	2.5	pu
Lead time constant Tft	0	s
Lag time constant Tfv	0.05	s
Voltage Vfrz	0.7	pu
Compensation resistance Rc	0	pu
Compensation reactance Xc	0	pu
Compensation gain Kc	0.02	pu
Upper limit on deadband emax	0.1	pu
Lower limit on deadband emin	-0.1	pu
Lower threshold for deadband dbd1	0	pu
Upper threshold for deadband dbd2	0	pu
Upper limit Qmax	0.436	pu
Lower limit Qmax	-0.436	pu
Output P and Q command revise time	0.001	s

Parameter Kp_REPC = 0.5
Parameter Ki_REPC = 2.5
Fitting Error = 10.75%

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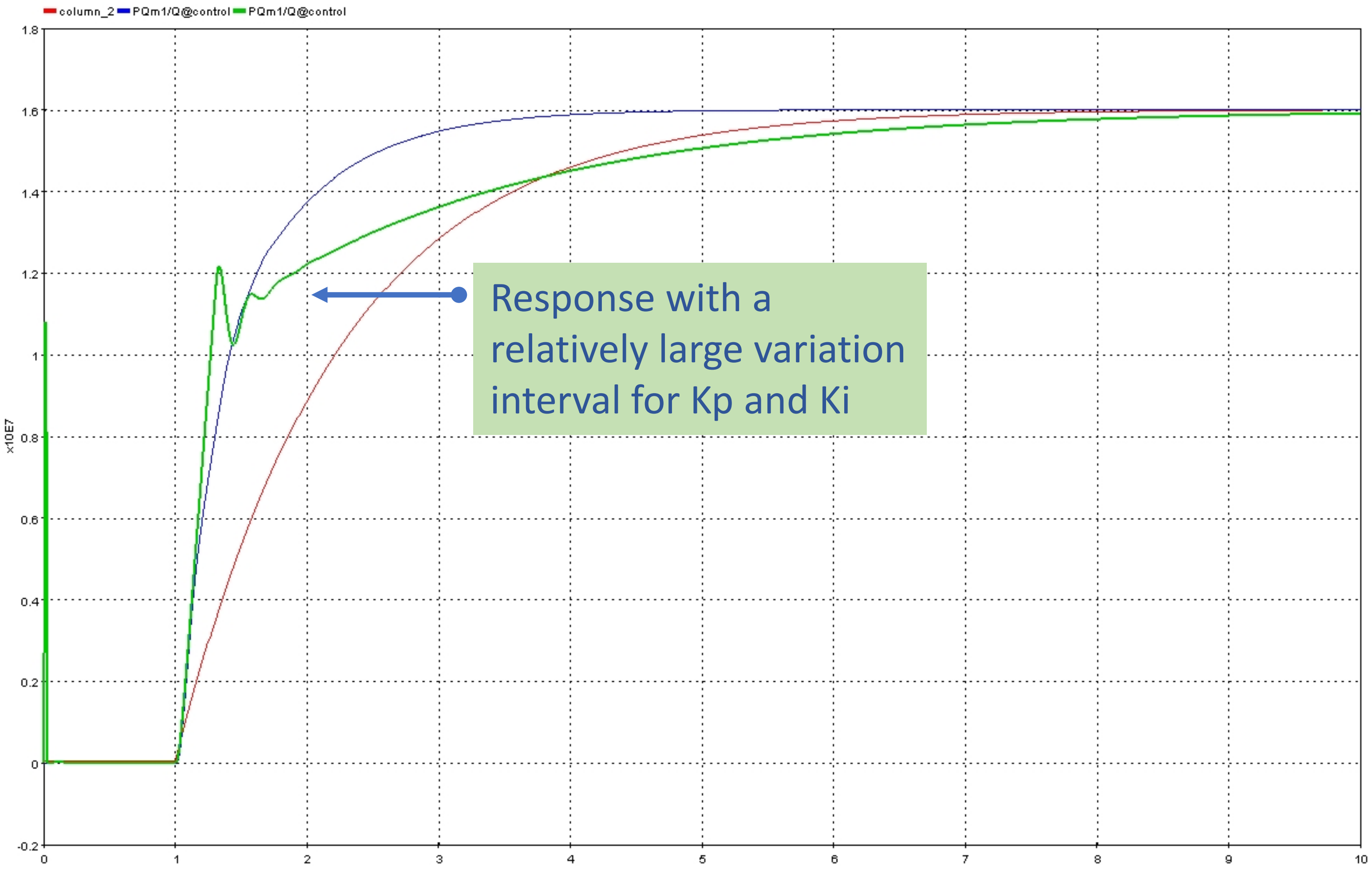
CASE 2: PSO Optimisation of Parameter Kp_REPC and Ki_REPC with variation intervals set to [0-20]



Q/V control - REPCA model		
Voltage droop control	droop control	
Time constant Tfltr	0.02	s
Proportional gain Kp	1.40945	pu
Integral gain Ki	1.2812	pu
Lead time constant Tft	0	s
Lag time constant Tfv	0.05	s
Voltage Vfrz	0.7	pu
Compensation resistance Rc	0	pu
Compensation reactance Xc	0	pu
Compensation gain Kc	0.02	pu
Upper limit on deadband emax	0.1	pu
Lower limit on deadband emin	-0.1	pu
Lower threshold for deadband dbd1	0	pu
Upper threshold for deadband dbd2	0	pu
Upper limit Qmax	0.436	pu
Lower limit Qmax	-0.436	pu
Output P and Q command revise time	0.001	s

Optimal parameters values
Parameter Kp_REPC: 1.40945
Parameter Ki_REPC: 1.2812
Final Fitting Error: 7.27%

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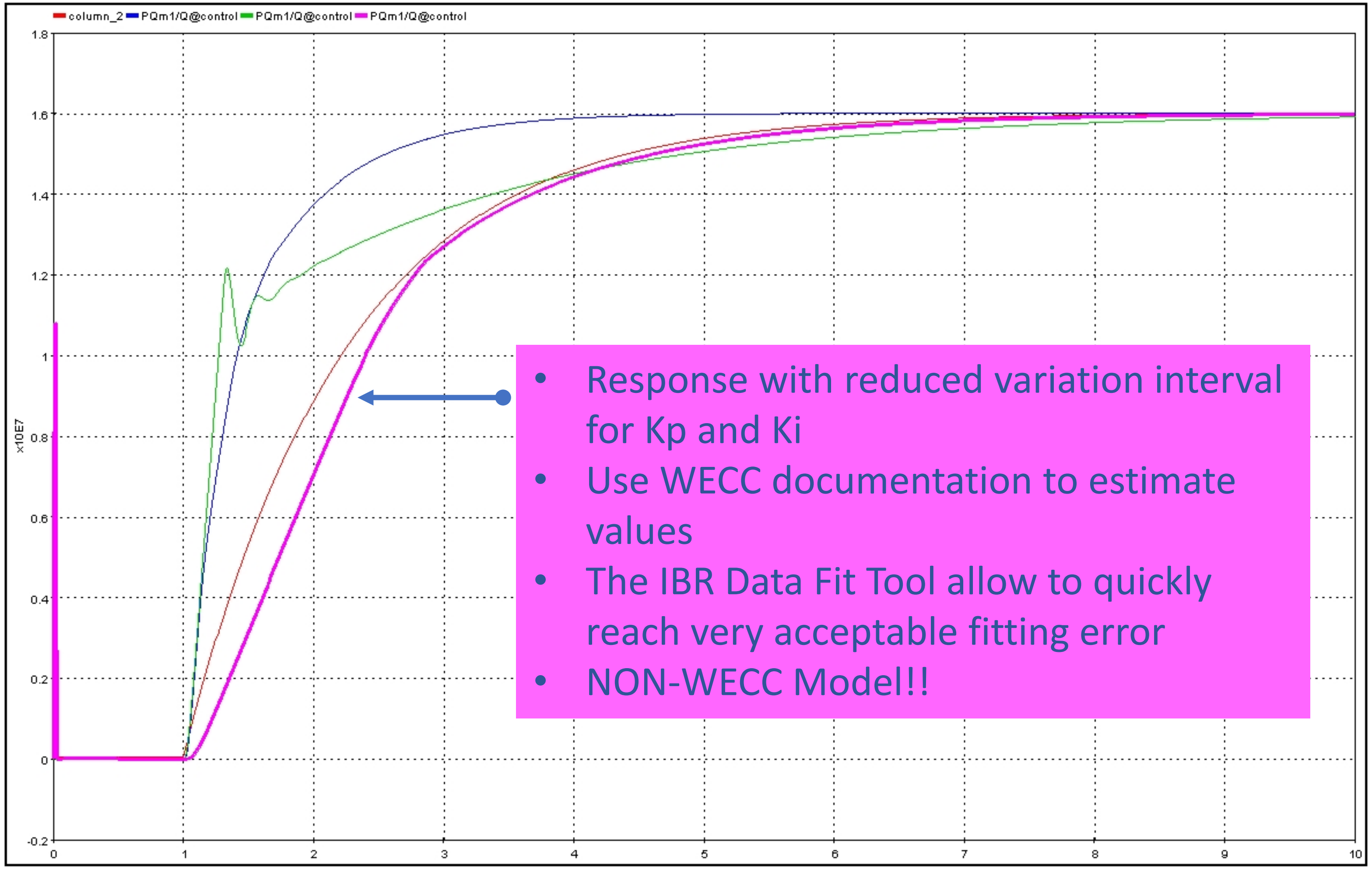
IV. Case study

CASE 3: PSO Optimisation of Parameter Kp_REPC and Ki_REPC with variation intervals set to [0-5]



- Response with reduced variation interval for Kp and Ki
- Use WECC documentation to estimate values
- The IBR Data Fit Tool allow to quickly reach very acceptable fitting error
- NON-WECC Model!!

Q/V control - REPCA model

Voltage droop control	droop control	
Time constant Tfltr	0.02	s
Proportional gain Kp	0	pu
Integral gain Ki	0.9699999999999997	pu
Lead time constant Tft	0	s
Lag time constant Tfv	0.05	s
Voltage Vfrz	0.7	pu
Compensation resistance Rc	0	pu
Compensation reactance Xc	0	pu
Compensation gain Kc	0.02	pu
Upper limit on deadband emax	0.1	pu
Lower limit on deadband emin	-0.1	pu
Lower threshold for deadband dbd1	0	pu
Upper threshold for deadband dbd2	0	pu
Upper limit Qmax	0.436	pu
Lower limit Qmax	-0.436	pu
Output P and Q command revise time	0.001	s

Optimal parameters values
Parameter Kp_REPC: 0
Parameter Ki_REPC: 0.969
Final Fitting Error: 1.5%

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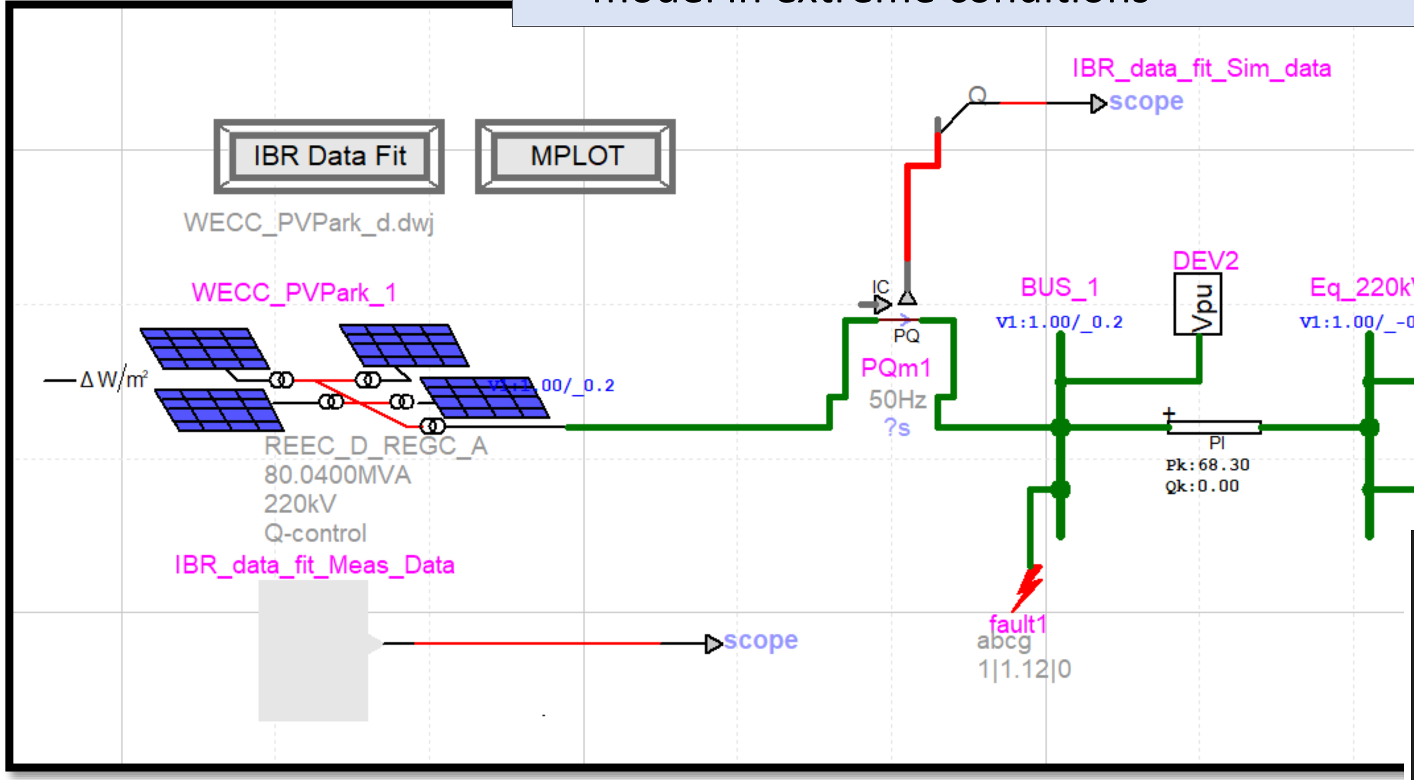
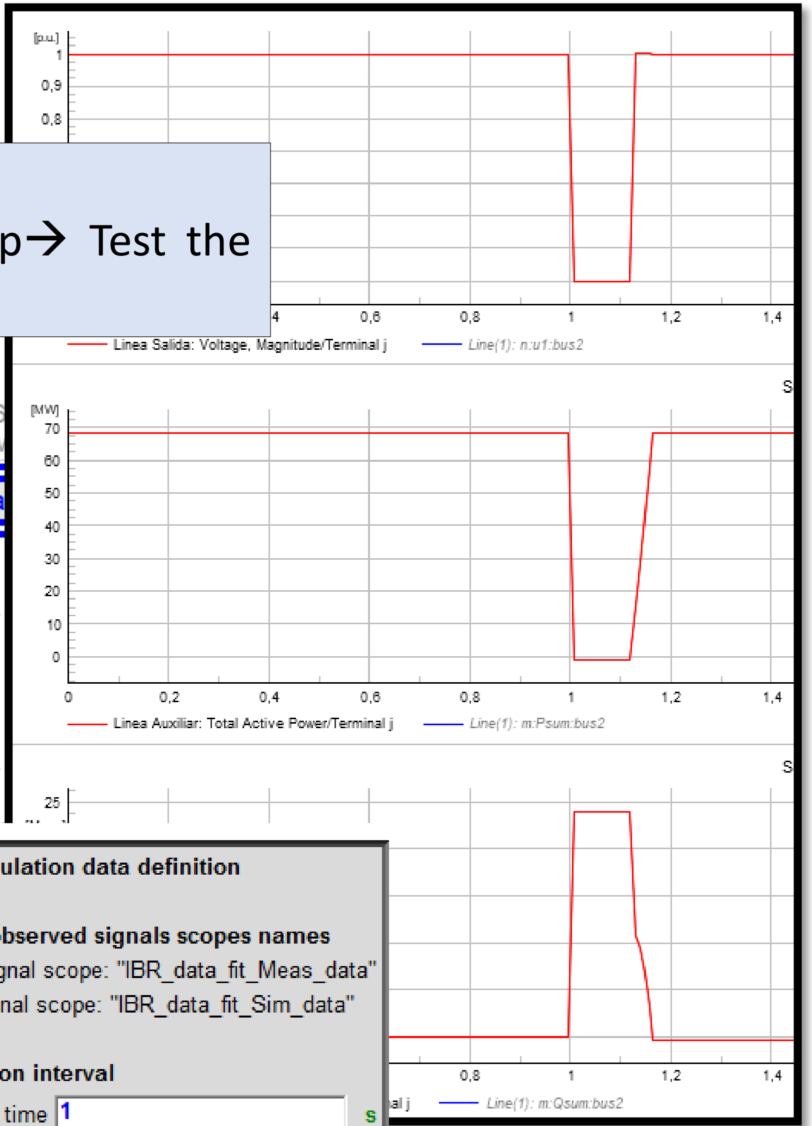
IV. Case study

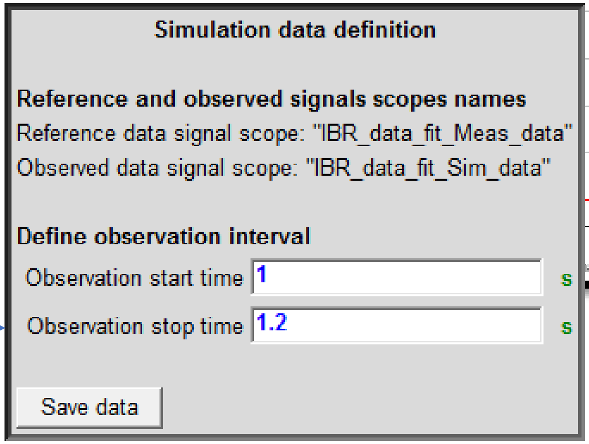
Inverter and Electrical Control parameter calibration with a 3ph-g fault

- 3Ph-g fault in the validated model at POI
- Fault impedance such to reach a deep voltage dip→ Test the model in extreme conditions





- Transient phenomenon last about 200 ms



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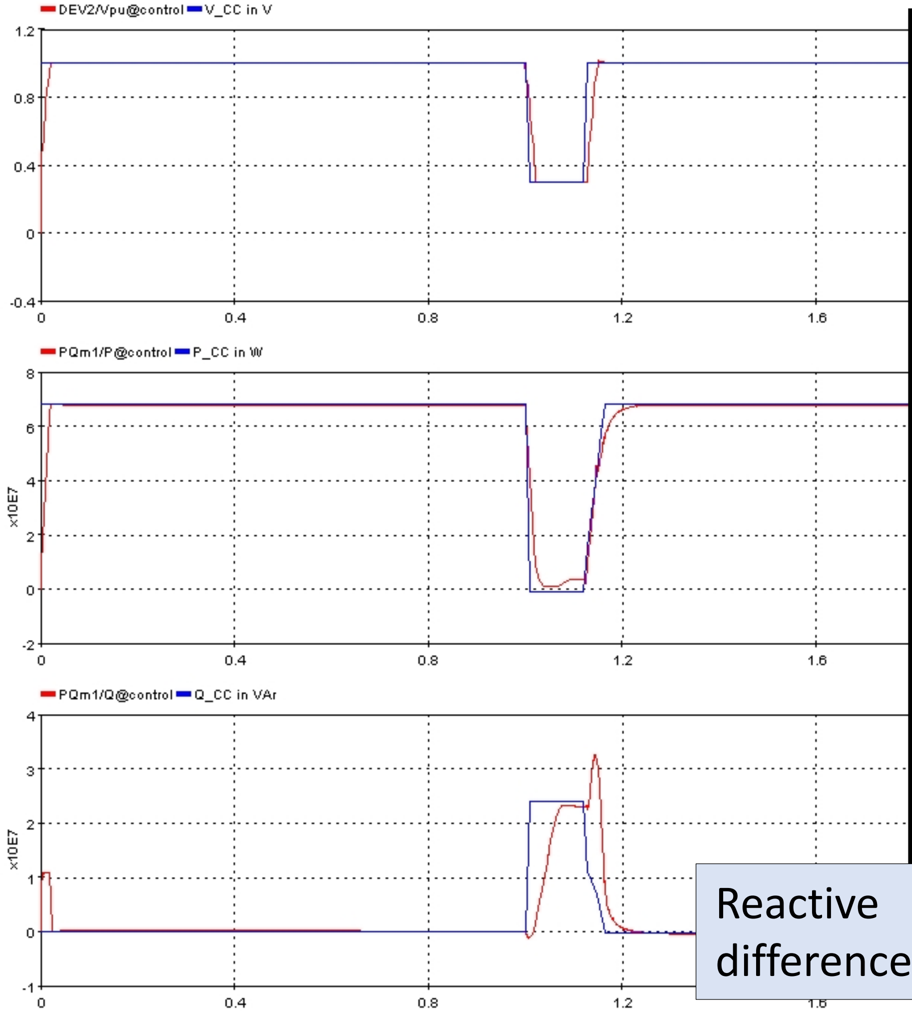
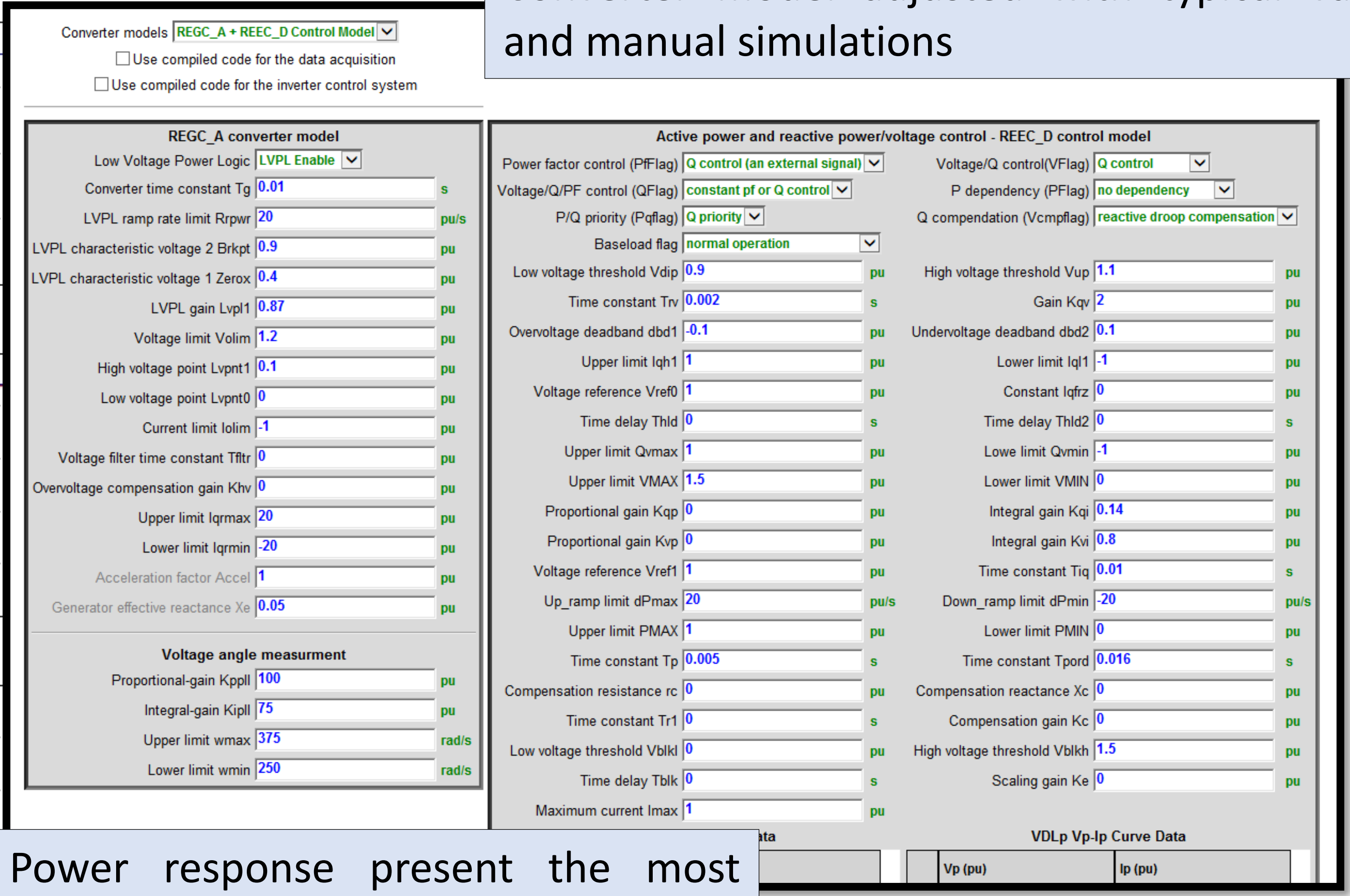
IV. Case study

CASE 1: Manually adjusted parameters of the WECC REGC_A+REEC_D Control Model



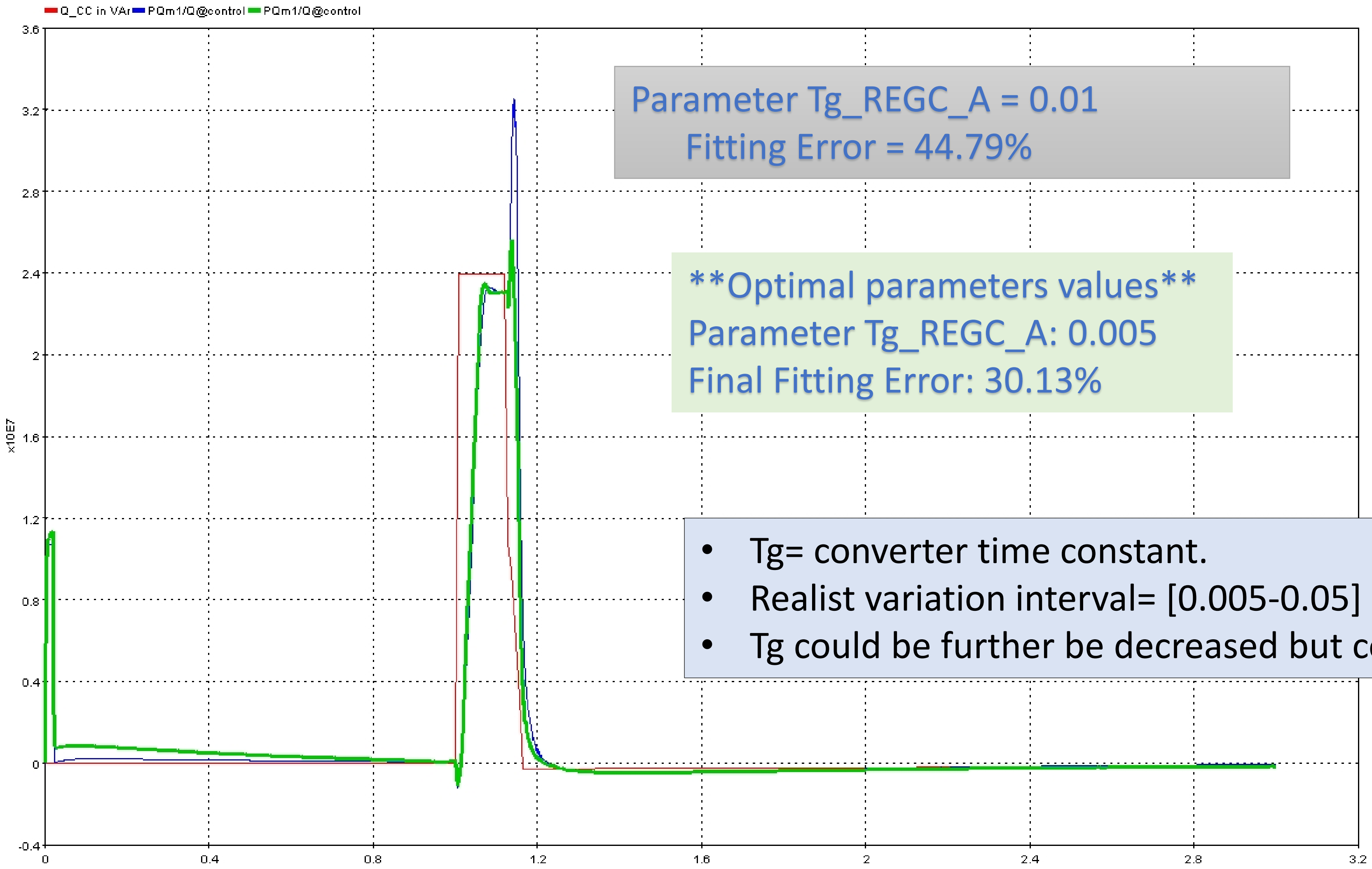


Converter model adjusted with typical values and manual simulations

Reactive Power response present the most difference respect to the validated model

IV. Case study

CASE 2: PSO Optimisation of Parameter Tg_REGC_A with variation interval set to [0.005-0.05]



Parameter Tg_REGC_A = 0.01
Fitting Error = 44.79%

Optimal parameters values
Parameter Tg_REGC_A: 0.005
Final Fitting Error: 30.13%

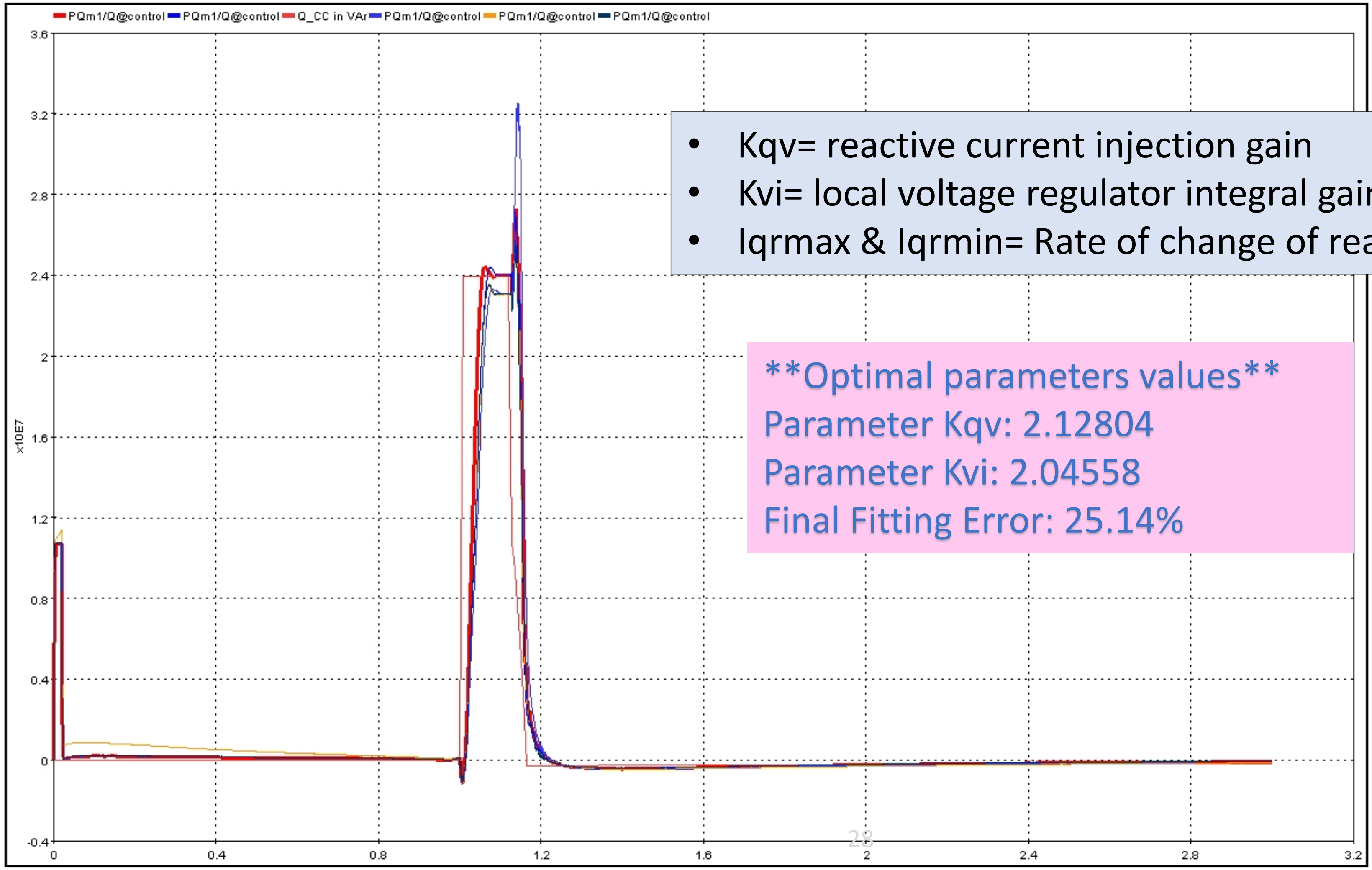
- Tg= converter time constant.
- Realist variation interval= [0.005-0.05]
- Tg could be further be decreased but could be unrealistic.

IV. Case study

CASE 3: PSO Optimisation of Parameters of the REEC_D

Kqv_REEC_D [0-5] (2); Kvi_REEC_D [0-5] (0.8)

(with Iqrmax and Iqrmin at maximum)

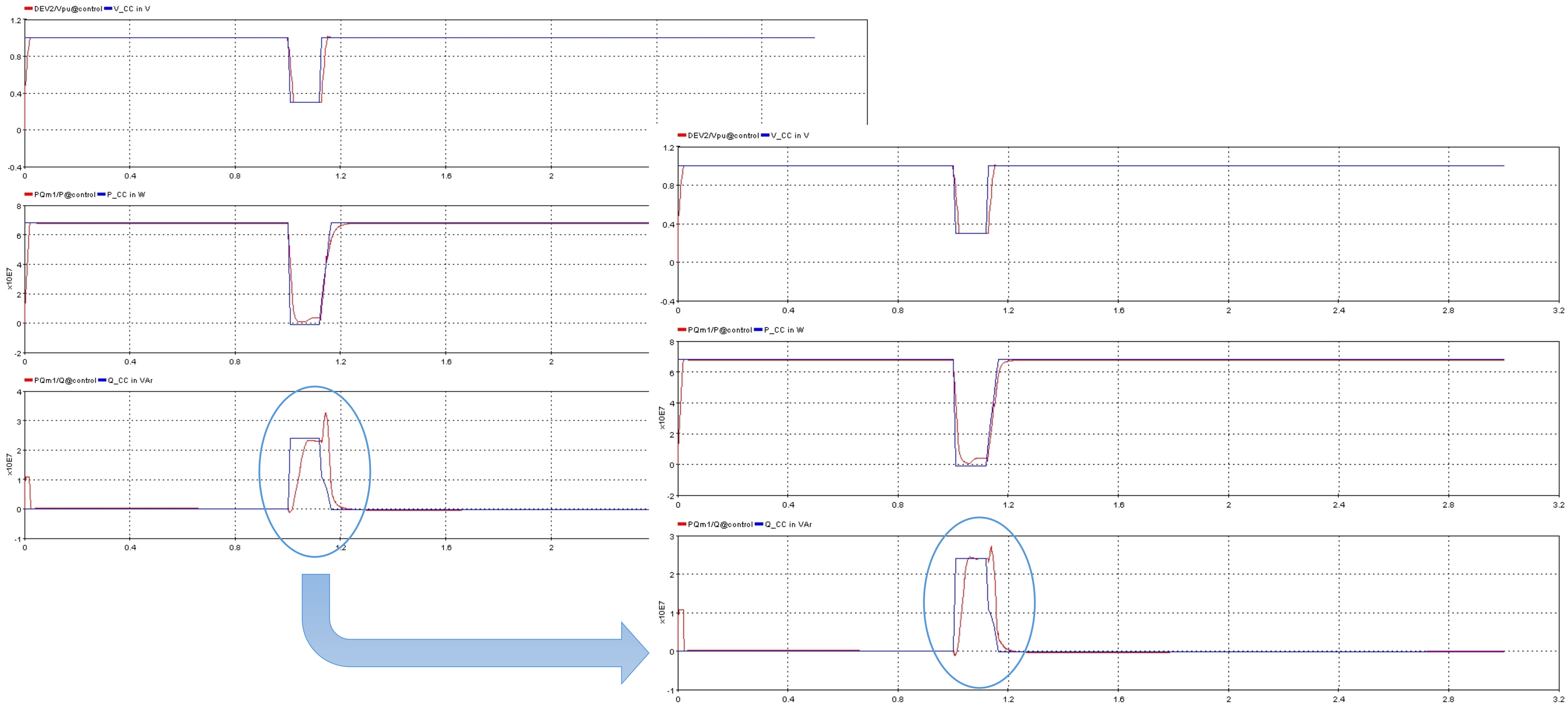


- Kqv= reactive current injection gain
- Kvi= local voltage regulator integral gain
- Iqrmax & Iqrmin= Rate of change of reactive current.

Optimal parameters values
Parameter Kqv: 2.12804
Parameter Kvi: 2.04558
Final Fitting Error: 25.14%

IV. Case study

Final Fitting for a 3ph-g fault



- IBR Data Fit Tool useful fir the finer adjustment.

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V. Conclusions

V. Conclusions

- The initial adjustment of the model parameters is extremely important.
- The IBR Data Fit Tool proved to be particularly effective when the ranges of variation of the parameters to be calibrated were shortened.
- The IBR Data Fit Tool is very effective for finer adjustments.
- The adjustment of non-WECC models (simplified) was more difficult and the IBR Data Fit Tool was particularly useful in this case.

References

B. Poudel, B. Bhandari, E. Amiri, P. Rastgoufard, T. E. Field and R. A. McCanne, "*Interconnection Study and Optimization of Grid Connected Photovoltaic System Using Electromagnetic Transient Program*," 2021 IEEE Kansas Power and Energy Conference (KPEC), 2021, pp. 1-6, doi: 10.1109/KPEC51835.2021.9446233.

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