Modeling and Simulation Testing of Photovoltaic Power Plants in EMTP® Software in Compliance with the Mexican Grid Code.

CONTENT

Modeling and Simulation Testing of Photovoltaic Power Plants

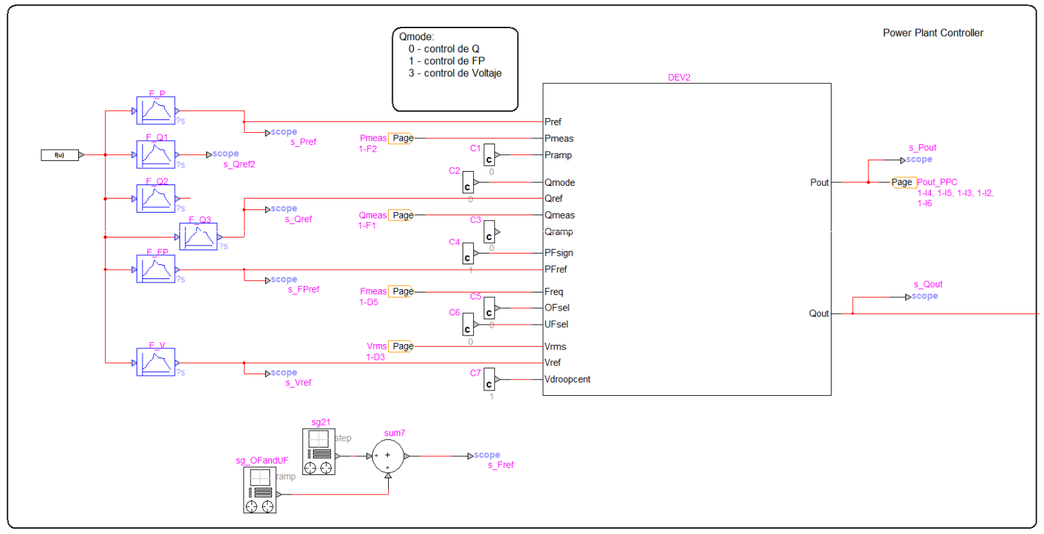
Ampere Consultoría Eléctrica Mexicana, S.A. de C.V. specializes in the development of mathematical models using EMTP® software, with the objective of evaluating the behavior and regulatory compliance of Photovoltaic Power Plants.

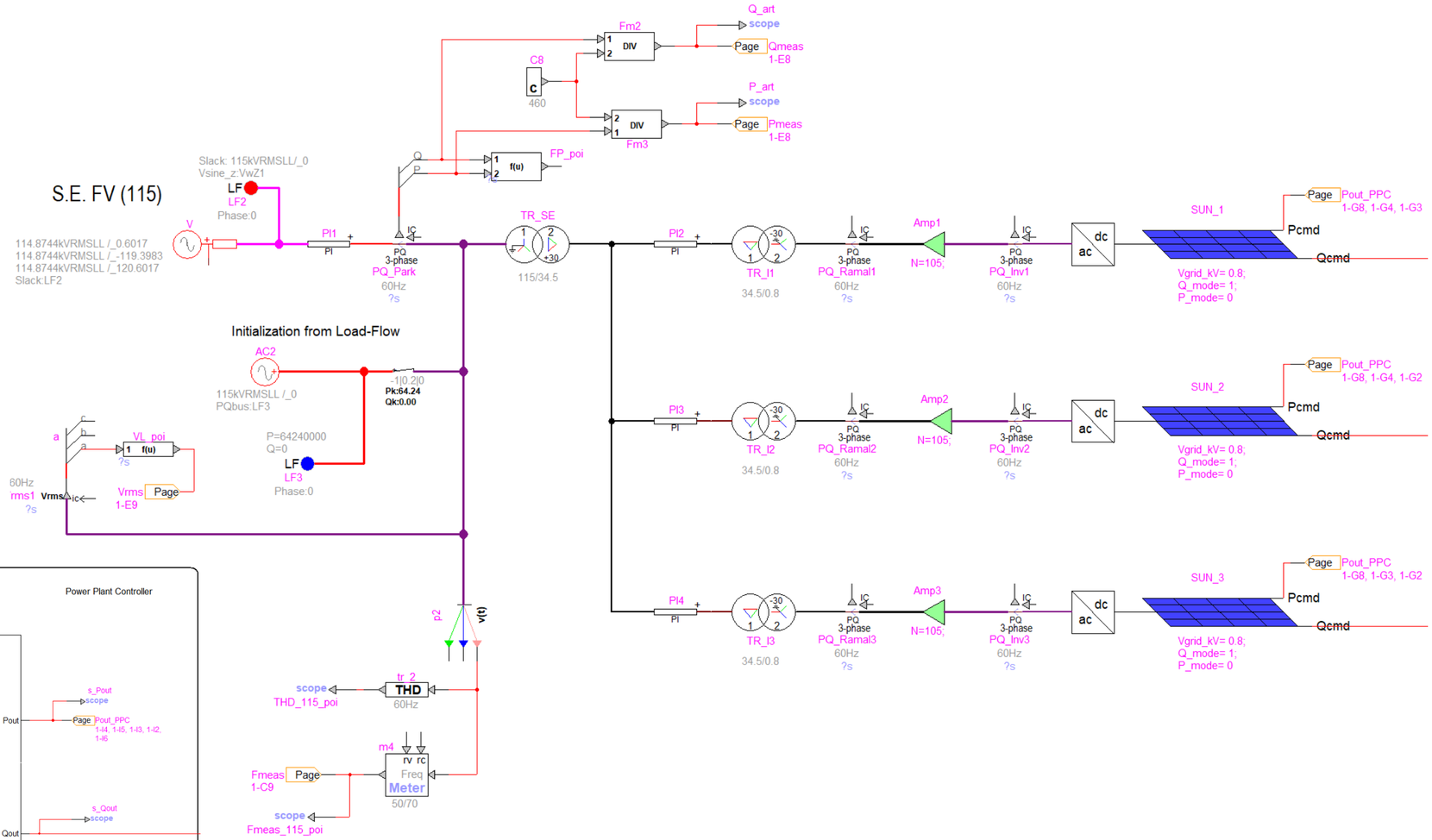
This work arises in response to the commissioning requirements for the interconnection of a project. As part of the process, a detailed report should be prepared with the relevant model.

A detailed model of the power plant is developed, enabling the analysis of its dynamic behavior under various operating conditions. In compliance with the Mexican Grid Code, various simulations are performed as evidence of regulatory compliance, including but not limited to the following:

- **Mathematical model initialization:** The proper functioning of the elements that make up the power plant model is verified, ensuring that no power or voltage disturbances occur during its operation.
- **Active power control test.**
- **Reactive power control test.**
- **Power factor test.**
- **Voltage control test.**
- **Analysis of the power plant's behavior under frequency deviations:** The primary regulation and response to high and low-frequency conditions are evaluated according to the requirements established in the Mexican Grid Code.

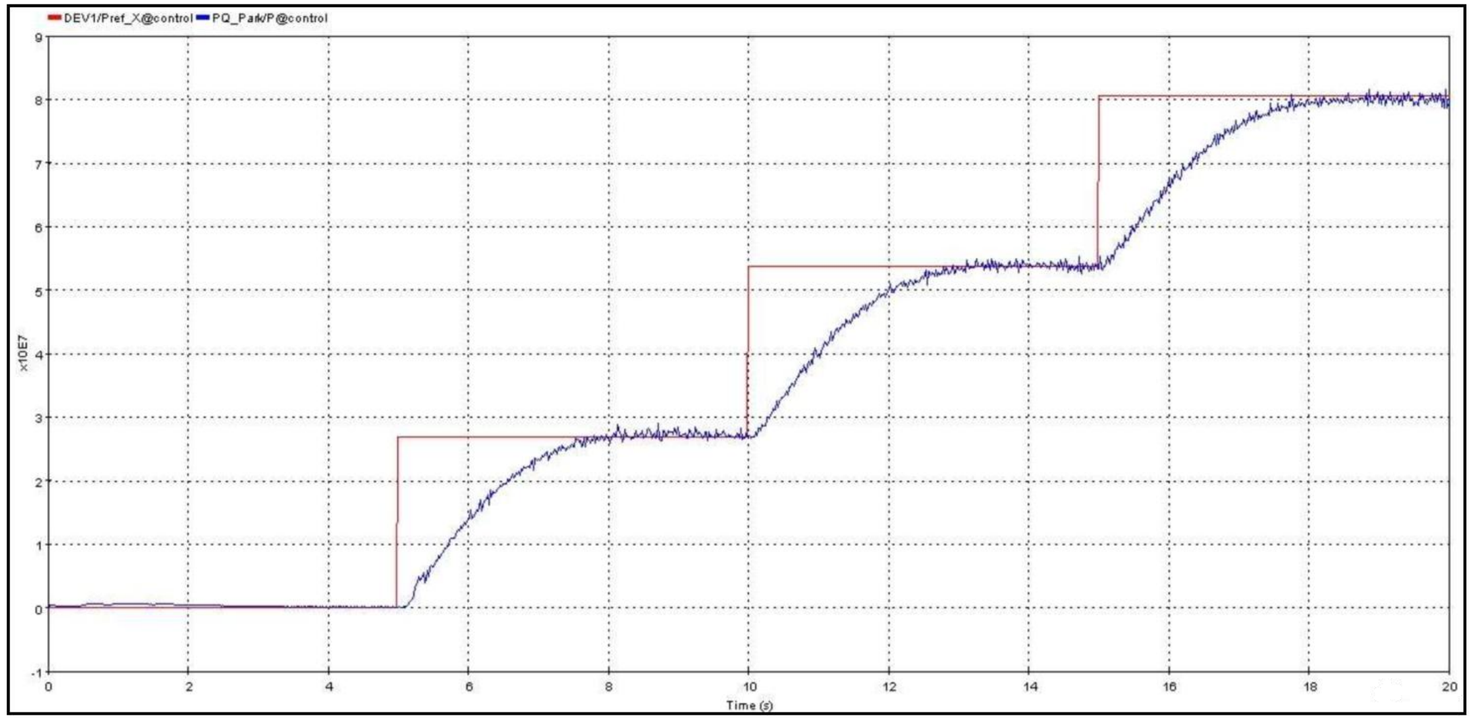
Modeling


Qmode:
0 - control de Q
1 - control de FP
3 - control de Voltaje
Power Plant Controller
DEV2
Pref
Pmeas
Pramp
Qmode
Qref
Qmeas
Qramp
PFsign
PFref
Freq
OFsel
UFsel
Vrms
Vref
Vdroopcent
Pout
Qout
F_P
F_Q1
F_Q2
F_Q3
F_FP
F_V
s_Pref
s_Qref2
s_Qref
s_FPref
s_Vref
s_Pout
s_Qout
s_Fref
sg21
sg_OFandUF
sum7


S.E. FV (115)
Slack: 115kVRMSLL/_0
Vsine_z:VwZ1
LF2
Phase:0
114.8744kVRMSLL /_0.6017
114.8744kVRMSLL /_-119.3983
114.8744kVRMSLL /_120.6017
Slack:LF2
PI1
PQ_Park
60Hz
TR_SE
115/34.5
Fm2
Fm3
C8
460
Q_art
P_art
Qmeas 1-E8
Pmeas 1-E8
FP_poi
Initialization from Load-Flow
AC2
115kVRMSLL /_0
PQbus:LF3
P=64240000
Q=0
LF3
Phase:0
Pk:64.24
Qk:0.00
VL_poi
Vrms 1-E9
60Hz
rms1
PI2
PI3
PI4
TR_I1
TR_I2
TR_I3
34.5/0.8
PQ_Ramal1
PQ_Ramal2
PQ_Ramal3
Amp1
Amp2
Amp3
N=105;
PQ_Inv1
PQ_Inv2
PQ_Inv3
SUN_1
SUN_2
SUN_3
Pout_PPC 1-G8, 1-G4, 1-G3
Pout_PPC 1-G8, 1-G4, 1-G2
Pout_PPC 1-G8, 1-G3, 1-G2
Pcmd
Qcmd
Vgrid_kV= 0.8;
Q_mode= 1;
P_mode= 0
tr_2
THD
60Hz
THD_115_poi
m4
Meter
50/70
Freq
Fmeas 1-C9
Fmeas_115_poi

Active power control test

The Photovoltaic Power Plant must be equipped with a logic interface (input port) that allows receiving instructions to stop the total or partial active power contribution in less than 5 seconds. Reactive Power Control Disabled (Q, PF, and V).



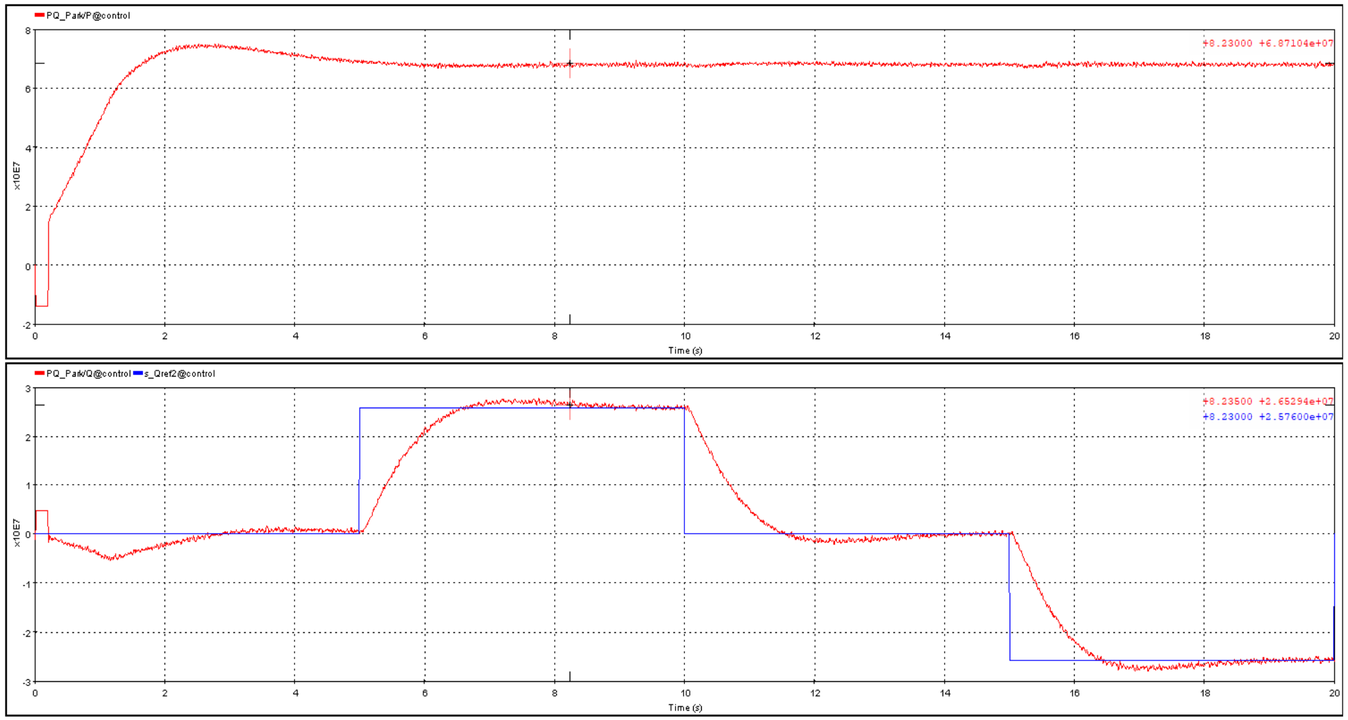
Time (s)	Pref (MW)
0-5	0
5-10	26
10-15	53
15-20	80.2

During the commissioning tests, an Active Power setpoint is applied from 100% to 0% with a 100% Pn (Nominal Power) ramp.

Reactive power control test

Time (s)	Qref (MVAr)
0-5	0
5-10	26
10-15	0
15-20	-26

The Photovoltaic Power Plant must adjust its operation to reach the setpoint requested by CENACE. In a steady-state condition, the tolerance relative to the setpoint must not exceed 2%.



In response to a setpoint change, the Photovoltaic Power Plant must meet the following criteria:

- Reach at least 90% of the new setpoint within a maximum time ($\mathbf{t_1}$) of 3 seconds.
- Adjust to the specified value within a maximum time ($\mathbf{t_2}$) of 5 seconds.

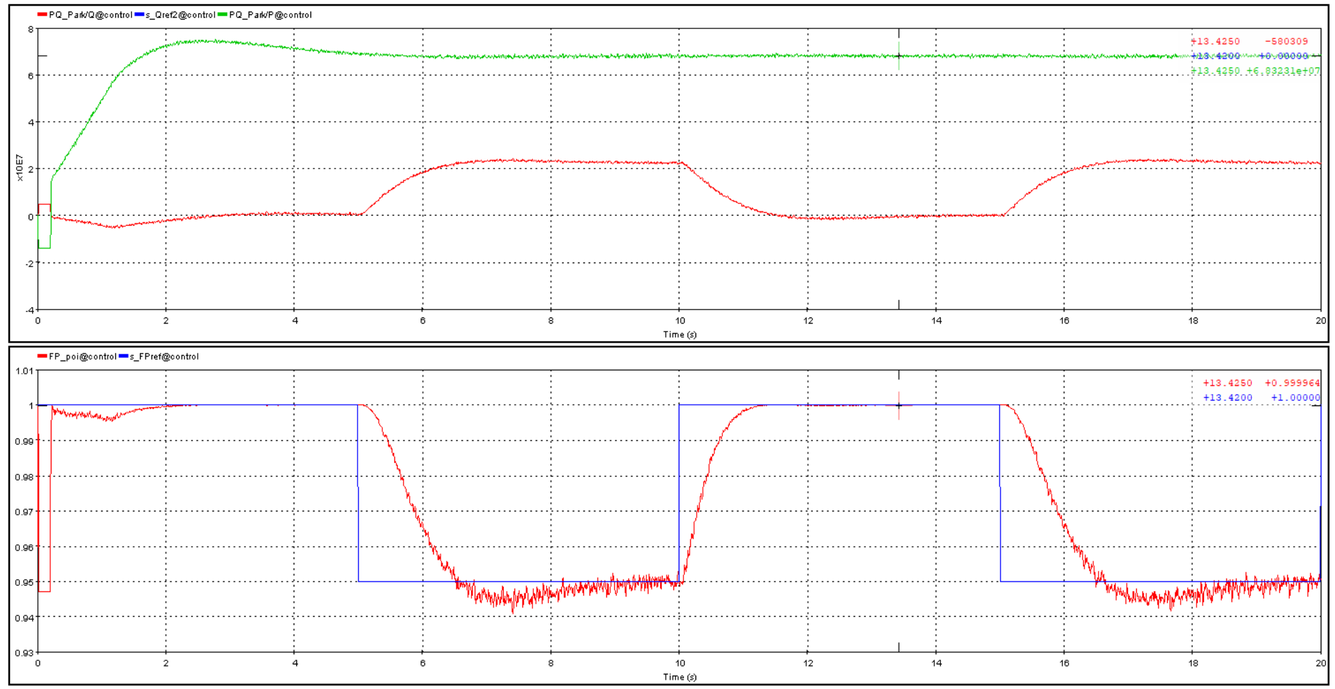
Power factor test

The Photovoltaic Power Plant must automatically regulate the power factor within the reactive power range required and specified by CENACE. In a steady-state condition, the tolerance relative to the setpoint must not exceed 0.1%.

Time (s)	PFref (p.u.)
0-5	1
5-10	0.95
10-15	1
15-20	0.95

In response to a setpoint change, the Photovoltaic Power Plant must meet the following criteria:

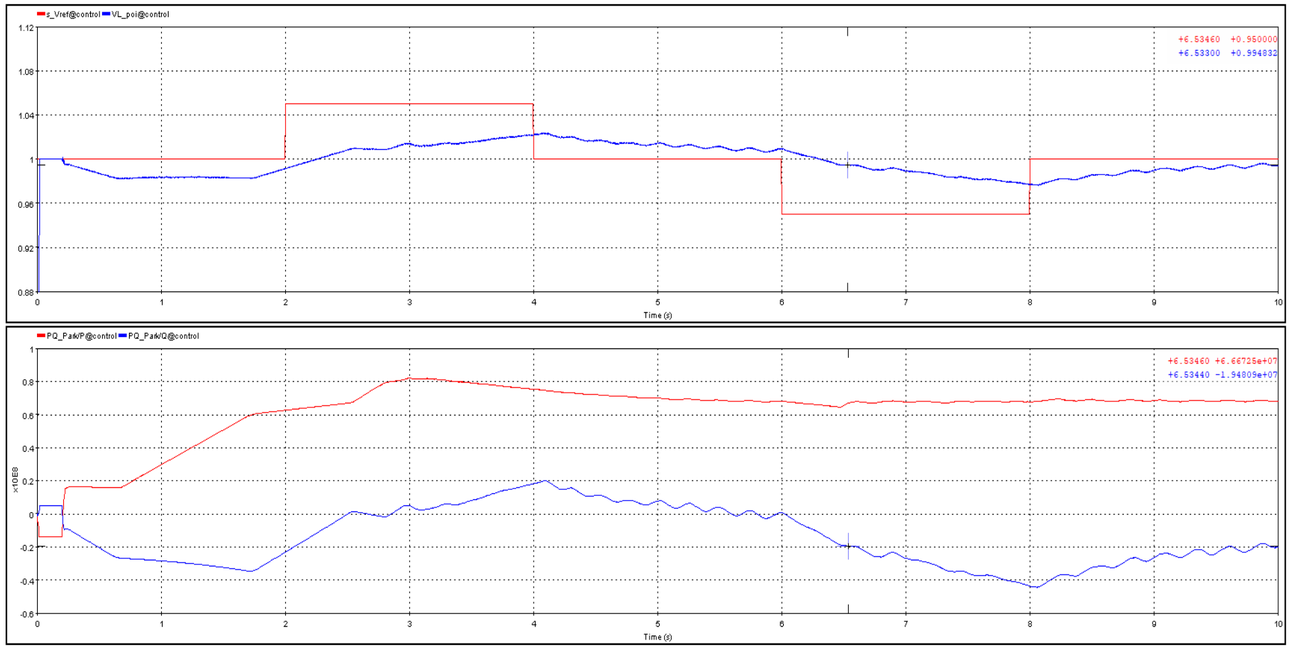
- Reach at least 90% of the new setpoint within a maximum time ($\mathbf{t_1}$) of 3 s.
- Adjust to the specified value within a max. time ($\mathbf{t_2}$) of 5 s.



Voltage control test

Time (s)	Vref (p.u.)
0-2	1
2-4	1.05
4-6	1
6-8	0.95

The Photovoltaic Power Plant must contribute to the automatic voltage control by delivering reactive power to the grid, with a voltage setpoint range of at least 0.95 to 1.05 pu. In a steady-state condition, the tolerance relative to the setpoint must not exceed 0.5%.



In response to a setpoint change, the Photovoltaic Power Plant must meet the following criteria:

- Reach at least 90% of the new setpoint within a maximum time ($\mathbf{t_1}$) of 3 seconds.
- Adjust to the specified value within a maximum time ($\mathbf{t_2}$) of 5 s.

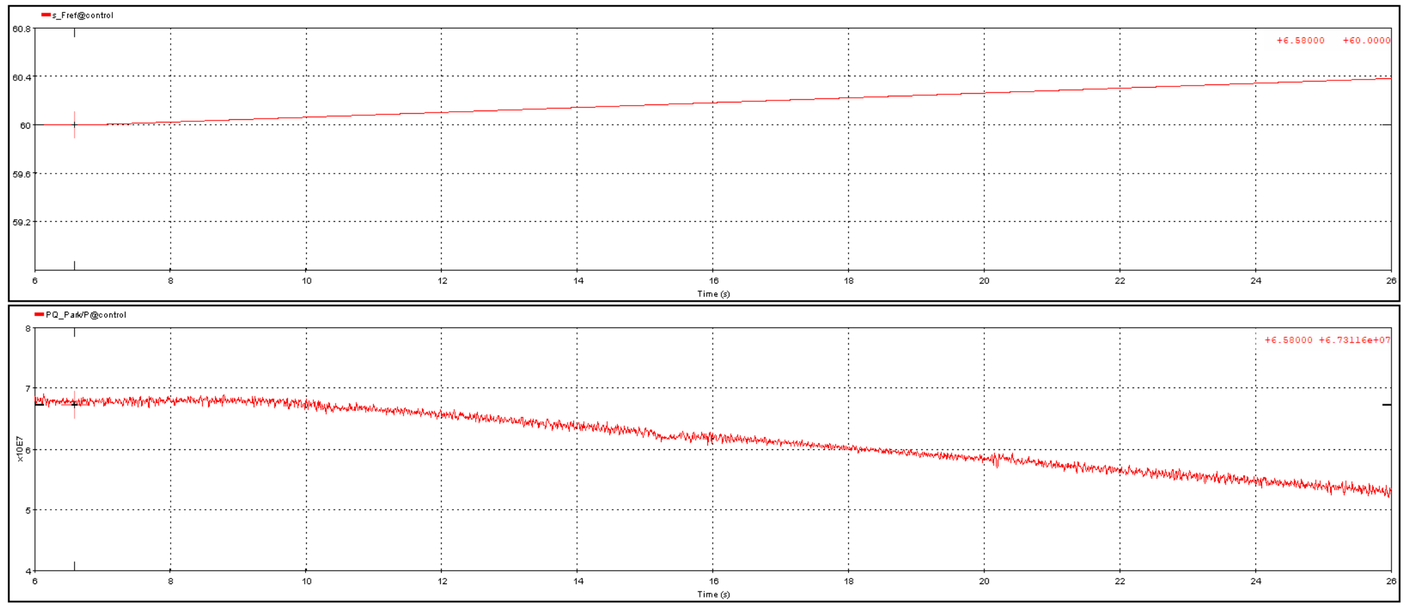
Note: during the voltage control test, the Photovoltaic Power Plant does not achieve the established setpoint values

Frequency deviations

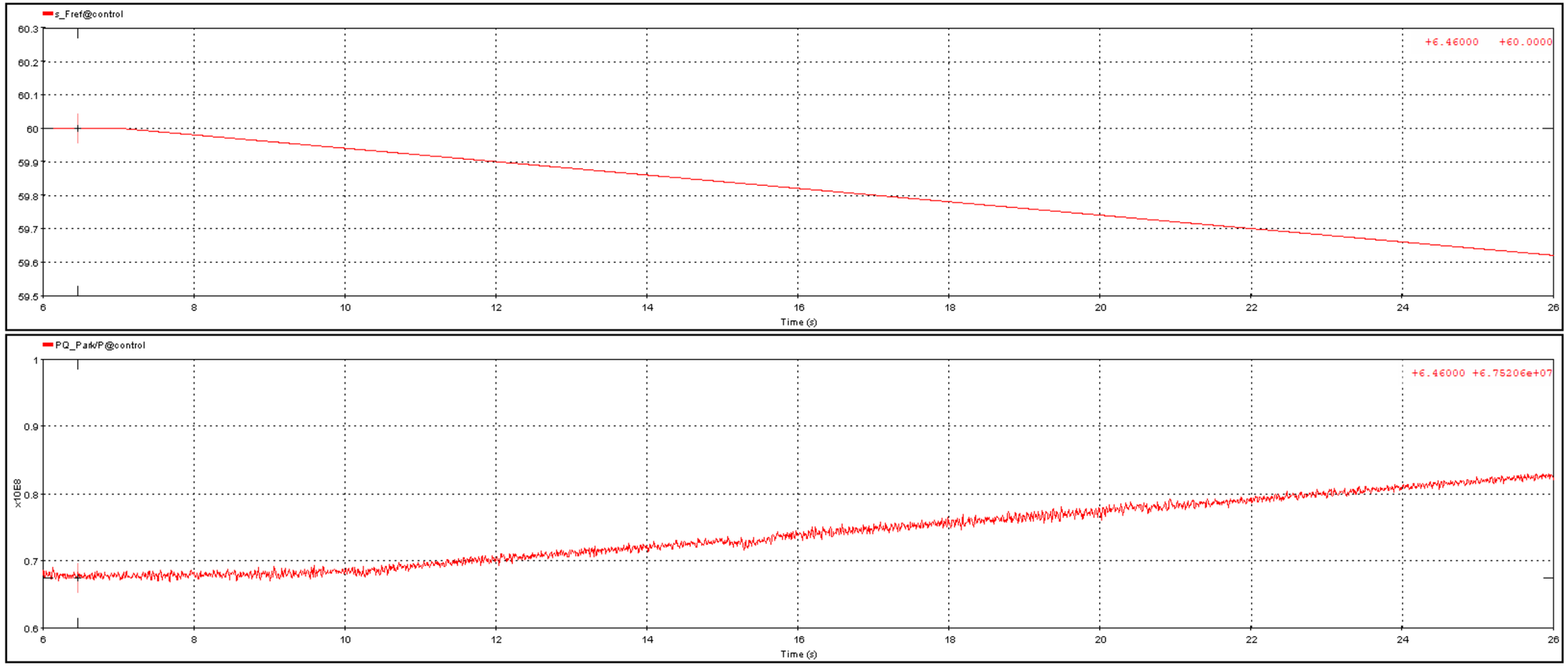
During the execution of this test, the Photovoltaic Power Plant must take an active power of P = 0.8 p.u. (64.16 MW). In order to enable Frequency Response control at the Point of Interconnection (POI), one of the 4 available modes must be selected from the over-frequency (**OF**) or under-frequency (**UF**) inputs of the PPC model of the Photovoltaic Power Plant.

Similarly, the deadband values and the regulation characteristic must also be selected.

The **over-frequency** mode type 3 (see PPC documentation) is enabled, a deadband of ±30mHz is selected, and a slope of 3% is set.



The **under-frequency** mode type 3 (see PPC documentation) is enabled, a deadband of ±30mHz is selected, and a slope of 3% is set.



THANK YOU FOR YOUR ATTENTION