OpenDSS/EPC CHIL (Controller Hardware in the Loop) Interface

Abstract: This document describes the main aspects of modeling and simulation of Controller Hardware-in-the-Loop (C-HIL) approach using Typhoon OpenDSS library. An EPC HIL (Hardware in the Loop) Compatible inverter is used as the actual controller interfaced to the Typhoon HIL simulator.

CONTENTS

INTRODUCTION

The OpenDSS interface library is a specialized Typhoon Schematic Editor (tse) library that covers simulations in both phasor and time domains. That is possible because each component from the library has its representation in OpenDSS and in Typhoon HIL toolchains. Through an interface (importer/exporter functions) between the Schematic Editor and an OpenDSS solver, a power system model can be converted into those two representation domains and run the features available on that platform. One of the main purposes of Typhoon HIL toolchain is the Hardware-in-the-Loop (HIL) approach, in which an actual (physical) device is evaluated in a closed loop with a virtualized system inside a real-time simulator.

On this context, this document describes the use of OpenDSS interface library to provide power flow and HIL studies for an actual EPC Power inverter, as shown in Figure 1. Although an EPC controller is used in this example, it is worth mentioning that any OEM (Original Equipment Manufacturer) device could be used in this approach if its primary component has an equivalent representation in the current Typhoon OpenDSS library.

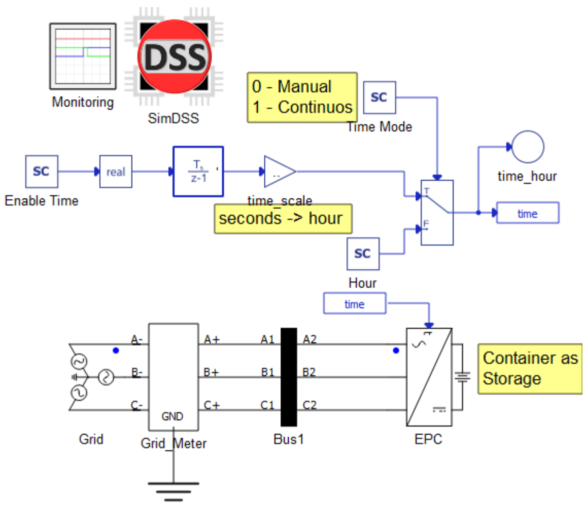
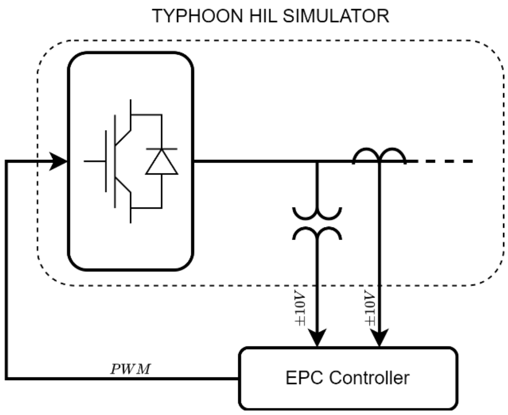


Figure 1 – EPC CHIL Example.

EPC HIL Compatible

Figure 2 illustrates the OEM interface used in this example. In summary, a switching inverter model (and the rest of the system) emulated by a real-time simulator is interfaced with an inverter controller through analog and digital signals: current and voltage measurements (analog signals) from the model are sent to the controller, which sends IGBT gate drive signals back to the simulation via the digital input interface to the HIL, according to its internal control loops.

The OEM controller in this example is an EPC Power inverter controller, part of a HIL Compatible product series from Typhoon HIL. This HIL compatible solution provides a hardware interface, library components, example models, and documentation supporting the interface between the HIL device and two EPC controllers. Each controller can work in multiple configurations: 2-level inverter CAB1000 (1MW), 3-level inverter CAB1000 (1MW), and 2-level inverter PD500 (500kW), in both BESS (Battery Energy Storage System) as PV (Photovoltaic) firmware.



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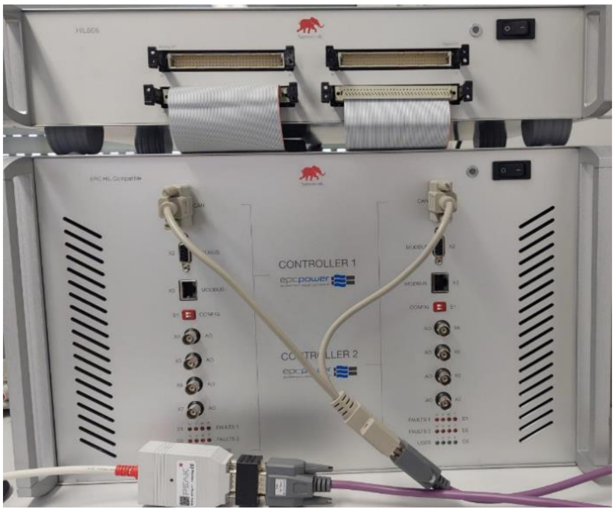

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Figure 2 – a) Interface approach and b) hardware connections of an EPC HIL Compatible.

MODELING AND PARAMETERIZATION

The current stage of the OpenDSS interface library supports only components from the default core library. Figure 3, for example, shows the internal modeling of the Storage component, which uses a Simple Battery Inverter (average) from Typhoon HIL microgrid library. Developers can use the "Container" component from the OpenDSS library to enable different internal representations. The Container component adopts the mask of any supported OpenDSS Object while having no time domain pre-defined under its subsystem.

Figure 4 shows the conversion of a Container into an OpenDSS Storage component. Only the power terminals (phases A, B, and C) and Signal Processing terminals (reference for time) remain on the component. After that, the user can normally use this component as a Storage object and connect to the power system model, as shown in Figure 1. In this example, a Grid Object is connected to the Storage object through the Bus1 Object. This scheme already enables the OpenDSS simulation using the SimDSS component.

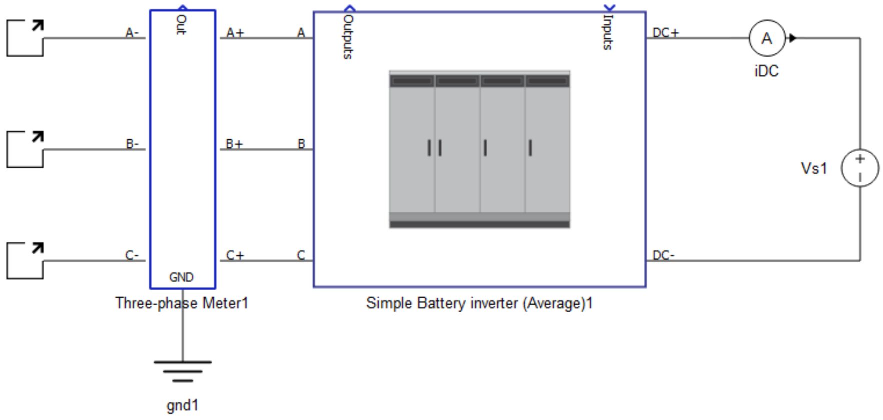

Figure 3 – Internal Storage component.

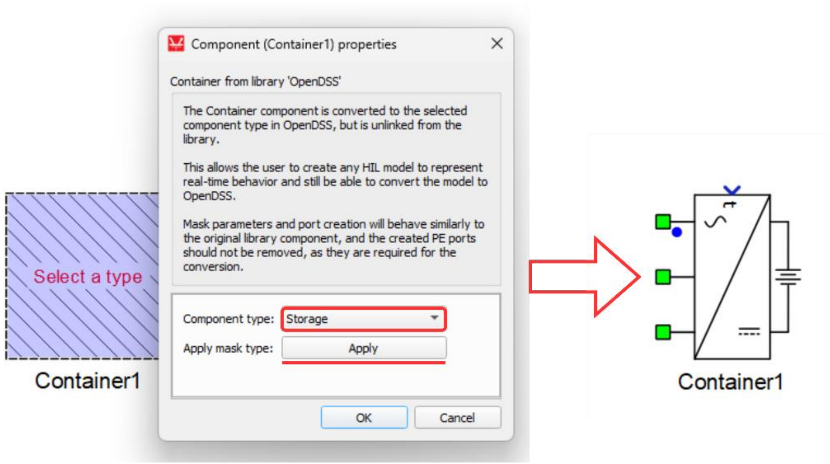

Figure 4 – Converting a Container component to a Storage component.

Figure 5 shows the internal model of the Container component that supports the interface with an EPC Power HIL Compatible component. A CAB 1000 (battery firmware) is connected to the power terminals in the Power Layer. An ideal voltage source is used here as the inverter's DC (Direct Current) source. The load point is converted to the desired power reference through a look-up table with the Loadshape object that defines the power according to the hour of the day. The loadshape points and plot are shown in Table 1 and Figure 6, respectively. A time ratio conversion is implemented on the root of the model (Figure 1) applying a gain of 0.2, which means that 1 seconds of real-time simulation corresponds to 0.2 hours.

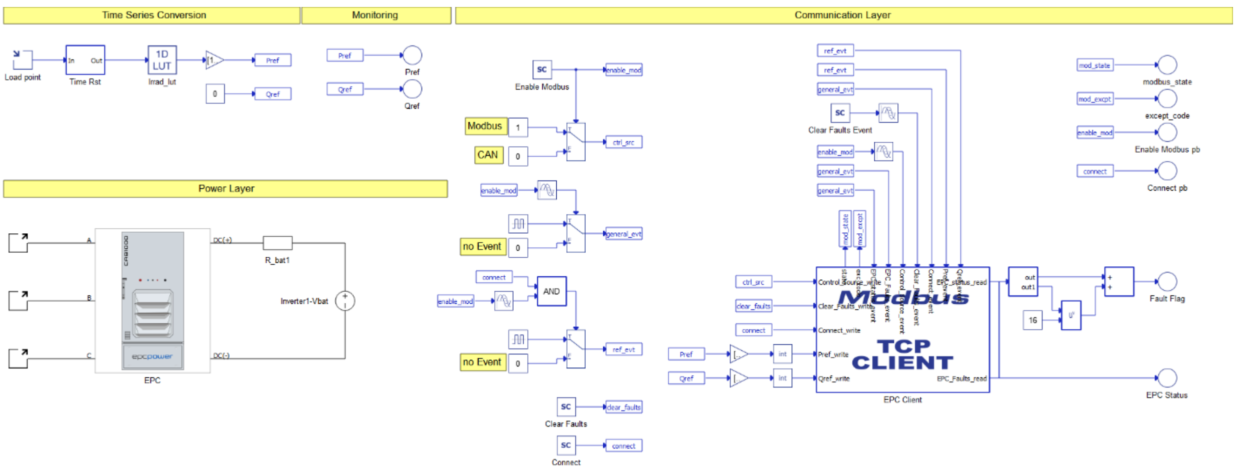

Figure 5 – Internal modeling of the Storage as an EPC Power HIL Compatible

Table 1 - Loadshape points defined for the Storage.

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Mult	0.4	0.3	0.2	0.2	0.2	0.1	0.1	-0.2	-0.3	-0.5	-0.5	-0.8
Hour	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Mult	-1.0	-1.0	-1.0	-1.0	-0.5	0.5	1.0	1.0	1.0	0.9	0.7	0.5

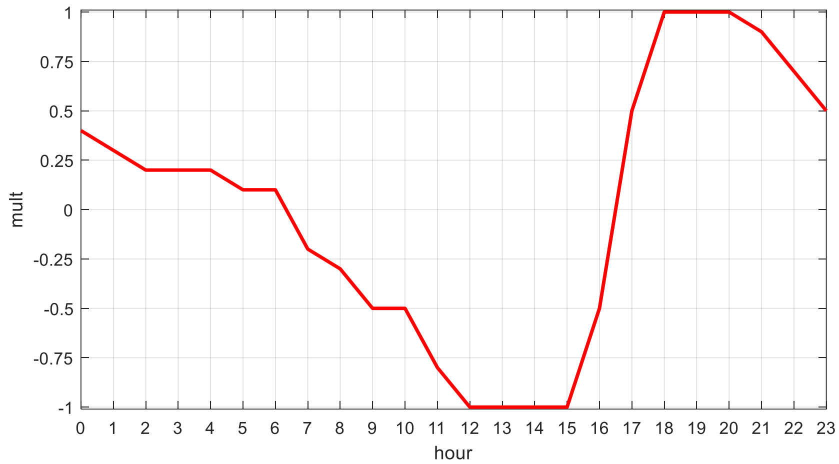

Figure 6 – Loadshape plot defined for the Storage.

Additionally, a communication layer involving a Modbus Client is implemented to send the power setpoints to the inverter controller and to read internal status flags. The registers used are shown in Table 2.

Table 2 – Modbus Registers Map.

Register	Name	Addr. (operation)	Scale	Unit	Type	Remark
Pref	CmdRealPwr	3215 (W)	10	kW	S16	Loadshape ref
Qref	CmdReactivePwr	3216 (W)	10	kvar	S16	Zero (PF=1)
Clear Faults	CmdBits	3214 (W)	--	--	U16	b0 - fault b1 - wng
Connect	Conn	246 (W)	--	--	Enum16	1 – connect 0 - disconnect Also works as a heartbeat
Status	StVnd	123 (R)	--	--	Enum16	--
Fault Flags	FltFlgs	3153 (R)	--	--	Bitfield32	--
Master Control Source	CtlSrc	3230 (W)	--	--	Enum16	0 – CAN 1 – Modbus

The component's parameterization is described in Table 3. Some property values are chosen to guarantee the compatibility between the OpenDSS and the Typhoon Model. In the Follow operation mode, the Storage component follows the active power dispatch according to the loadshape points and the battery's State of Charge (SOC). As the battery is represented as an ideal source in the Typhoon model, depending on the Initial SOC and kWh properties values, the OpenDSS results can curtail the power dispatch of the battery. In contrast, this curtailment will not affect the behavior of the EPC Power inverer time-domain model.

Table 3 – Component's properties.

Property	Value	Description
General.Dispatch P	Follow	Equivalent to DispMode property. "Follow" enables the Storage to follow the active loadshape points
General.Dispatch Q	Unit PF	Forces kVA=kwrated and kVAr=0
General.Initial SOC	50%	Has not impact in Typhoon time-domain model, just on OpenDSS
Ratings.Nominal voltage	0.480 kV	--
Ratings.Rated kW	1000 kW	EPC Nominal Power
Ratings.Rated kWh	100000 kWh	Has not impact in Typhoon time-domain model since the battery is represented by an ideal voltage source
Ratings.Charge efficiency	100%	--
Ratings.Discharge efficiency	100%	--
Ratings.Idling losses	0%	--
Ratings.Reserve mode SOC	2%	--

SIMULATION

Once the component is parameterized correctly (mask properties) and internally represented (Typhoon time-domain model), the user can run both power flow and real-time simulations. The model implemented in this example enables the system performance evaluation in time-series (daily mode) or for a specific time of the day (snapshot mode). In the OpenDSS, the user can select the Simulation Mode using the SimDSS Component. Figure 7 shows the grid power variables for a daily operation mode of 24 hours using 24 steps of 1 hour. To evaluate the system at a specific hour of the day, the user can append a DSS command after the solution with the following expression:

```
Solve mode=daily number=1 stepsize=1h hour=17
```

In this case, one snapshot result will be evaluated for hour=17. Table 4 shows the report for a "Show Powers kVA Elements" command.

Compiling and loading the model to an actual HIL device allows the user to evaluate this same system using the HIL approach. Figure 9 shows a SCADA panel with the simulations in the same scenarios evaluated using the OpenDSS. Figure 9.a shows 24 hours of the loadshape using 120 seconds of real-time simulation, and Figure 9.b shows the specific point of operation for hour=17.

Table 4 – Power kVA from Grid for a daily mode simulation in the hour=17.

```
CIRCUIT ELEMENT POWER FLOW

(Power Flow into element from indicated Bus)

Power Delivery Elements

  Bus Phase     kW     +j   kVAr        kVA        PF

ELEMENT = "Vsource.grid"
BUS1    1       166.7 +j      0.0       166.7      -1.0000
BUS1    2       166.7 +j      0.0       166.7      -1.0000
BUS1    3       166.7 +j      0.0       166.7      -1.0000
   TERMINAL TOTAL    500.0 +j     0.0      500.0     -1.0000
BUS1    0         0.0 +j      0.0         0.0       1.0000
BUS1    0         0.0 +j      0.0         0.0       1.0000
BUS1    0         0.0 +j      0.0         0.0       1.0000
   TERMINAL TOTAL      0.0 +j     0.0        0.0       1.0000
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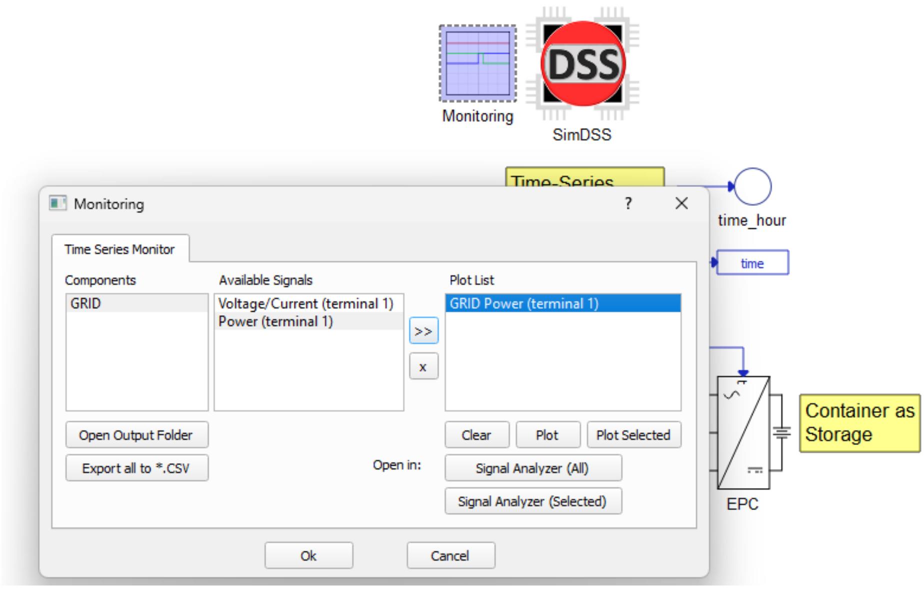

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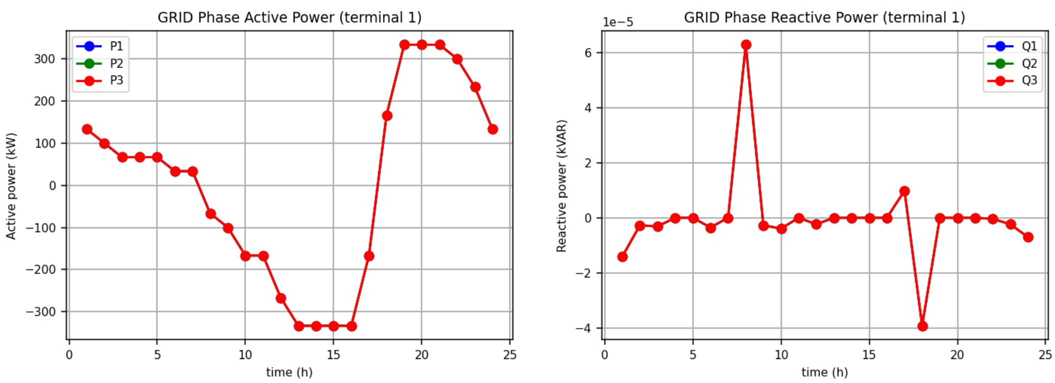

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Figure 7 – Time series simulation using the OpenDSS library interface. a) selecting and b) plotting Grid Power variables.

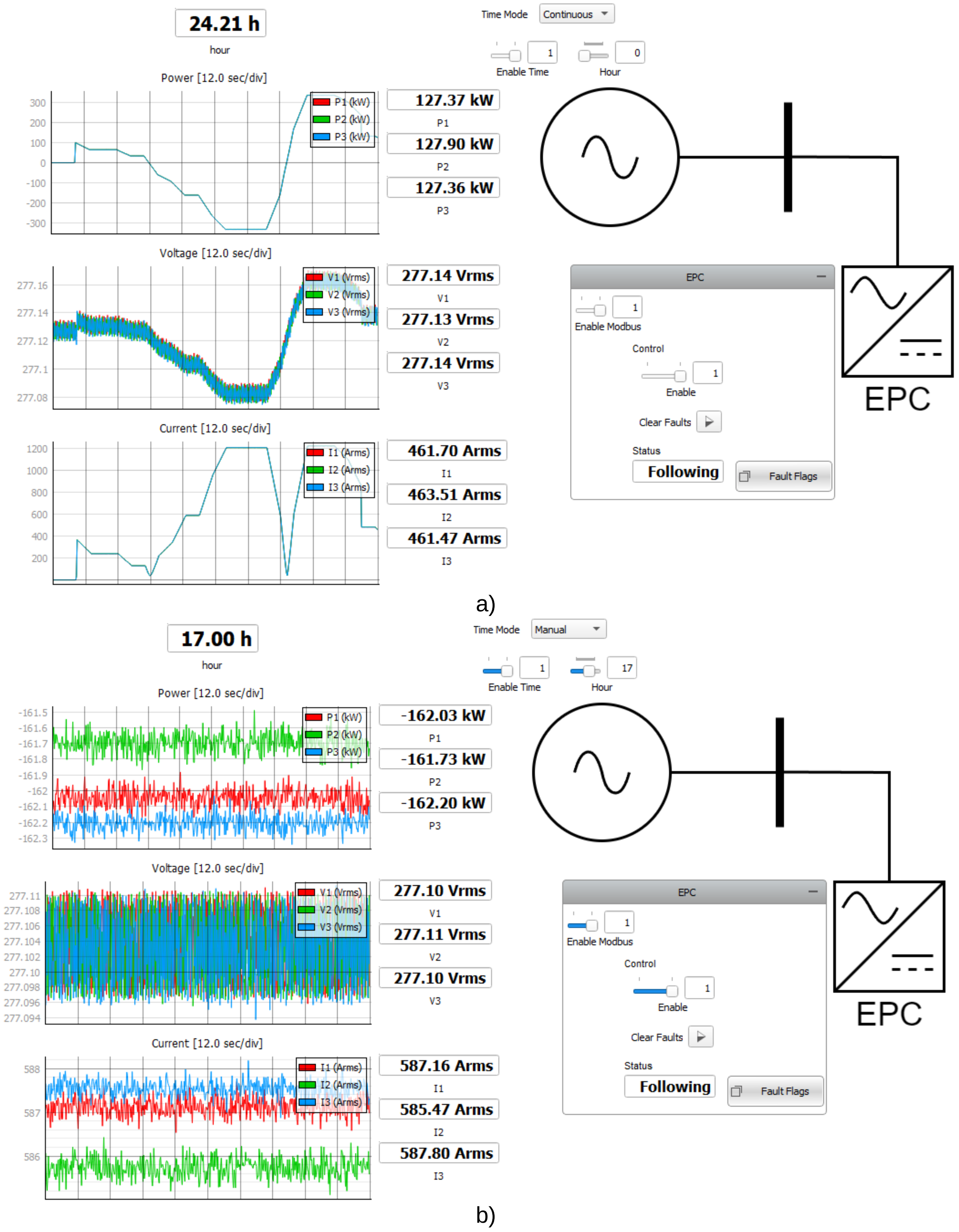

Figure 8 – SCADA panel for a) time-series and b) specific hour simulation mode for the EPC Power Interface