PowerFactory SMA EMT Model

Comparison and Benchmarking against PSCAD

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Executive summary

SMA Solar Technology AG (hereafter referred to as SMA) is a German based manufacturer of grid connected photovoltaic (PV) and battery inverter systems (BESS). SMA have developed Electromagnetic Transient (EMT) models of their inverter systems in both PSCAD and PowerFactory platforms. SMA had established their EMT model in the PSCAD platform for some years and have recently (since 2021) developed a PowerFactory version of this model.

In this report a comprehensive comparison of the SMA EMT PowerFactory and PSCAD models has been presented. The layout and structure of the two models was compared and it was shown that even though the two models are organised differently, their key features and functionality is essentially the same. One notable difference between the two models is the implementation of aggregation, which utilises a scaling component in PSCAD and a parallel controlled voltage source in PowerFactory. A further difference between the two models is the approach required for setting up the model from scratch, where templates and helper scripts in PowerFactory can be used to complete this task.

The performance comparison that was undertaken used a SMIB model and included a wide variety of disturbances such as faults of varying depth, grid voltage magnitude, phase angle and frequency disturbances and active and reactive power reference steps. A range of grid strengths were studied and the results demonstrated that the PowerFactory and PSCAD inverter models have dynamic responses which are practically identical, with discrepancies being very minor in nature. This included additional test cases involving extremely low SCR conditions exhibiting instability, the inclusion of the PV array model on the DC side and a test case representing a complex plant with multiple inverter aggregate units and a PPC.

With regard to simulation speed performance, the PowerFactory model response was observed to be largely comparable to that of the PSCAD model for the single inverter case as it is on average only 15% slower. However, the performance of the aggregate PowerFactory model observed to be slower than PSCAD (approximately 25% to 40%), whereas it is faster than PSCAD when the PV array model is included (approximately 20% to 40%).

In all, this assessment has shown that the PowerFactory SMA EMT model is fit for purpose for modelling and stability studies in the same manner as its PSCAD counterpart.

Contents

Figures

Tables

1 Introduction

SMA Solar Technology AG (hereafter referred to as SMA) is a German based manufacturer of grid connected photovoltaic (PV) and battery inverter systems (BESS). SMA have developed Electromagnetic Transient (EMT) models of their inverter systems in both PSCAD and PowerFactory platforms. SMA had established their EMT model in the PSCAD platform for some years and have recently (since 2021) developed a PowerFactory version of this model.

This report details a comprehensive comparison of the capabilities and performance of the PowerFactory and PSCAD EMT models as relevant to users who are interested in setting up the models, debugging their performance and carrying out time-domain stability studies. Specifically, the following aspects of the models are compared between the two platforms:

- The model structure and features.
- The approaches required for configuring the models by users.
- The model response under identical input conditions.
- The model simulation time required for identical input conditions.

2 Structure and features

2.1 Model structure

Both the PSCAD and PowerFactory SMA EMT models are made up of the following fundamental modelling components:

- A single inverter system comprising the inverter DC side circuitry and sources, the Insulated Gate Bipolar Transistor (IGBT) or average switch model making up the AC / DC interface, filter components, a step-up transformer and an inverter controller.
- A mechanism to aggregate the response of multiple inverters using this single inverter, to represent a multi-inverter plant.
- Other balance of plant electrical network elements which may reside outside of the single inverter system (cables, transformers, filters etc...).
- A Hybrid Controller, which is SMA's terminology for a Power Plant Controller (PPC), which may exist to control plant level voltage and power by sending commands to the inverter controller.

To see more clearly how the above components are implemented in the PSCAD model, a diagrammatic representation and an annotated PSCAD model screen shot are shown in Figure 2.1 and Figure 2.2 respectively.[1] Salient aspects of the model to point out are:

- The inverter system, excluding the step-up transformer and DC side source, is implemented within an inverter mask[2].
- A master library built-in PV array model is used to represent the PV panels and a fixed DC voltage source is used to represent the batteries.
- The inverter controller and PPC are black-boxed models using a pre-compiled lib files. Most of their parameters are defined in text files located within the PSCAD project folder (named "CfgFile[x].txt" for the inverter controller and "HyCtl_Cfg[x].txt" for the PPC, where [x] is a user defined configuration file number). A small number of parameters (e.g. the inverter type and the configuration file number) are set directly within the inverter mask itself.
- Both inverter and PPC masks output a set of debugging signals which are passed to a separate debug mask for viewing the internal signals of each controller. These signals can be used for investigation and debugging.

[1] Refer to [1] and [2] for additional information on the SMA PSCAD model

[2] A mask is a definition for a component which may be used in several places in a model. The definition stores additional circuitry and control logic within it.

- Aggregation of multiple inverters for a plant is achieved through the use of a scaling component, which is described in greater detail in Section 2.1.2.

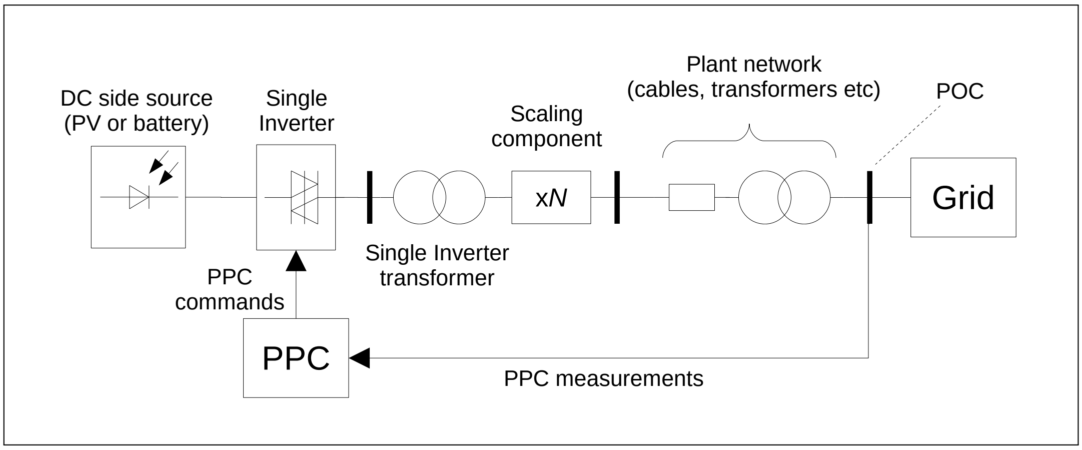

Figure 2.1: Overview of PSCAD model

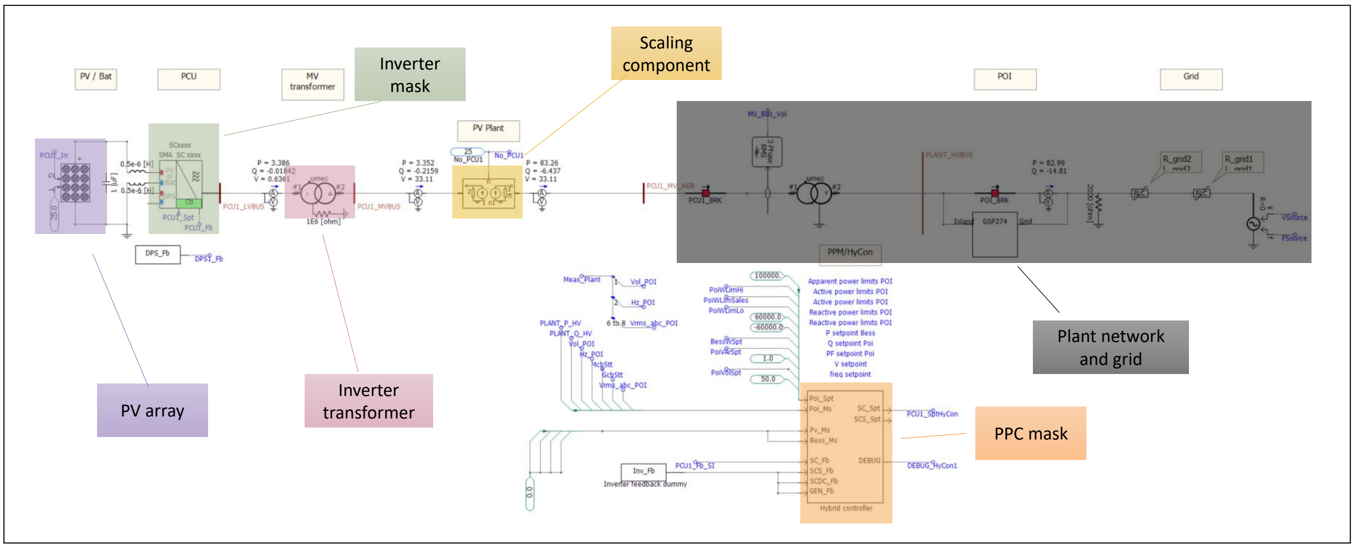

Figure 2.2: PSCAD plant model details

In contrast, a diagrammatic representation of the PowerFactory model and an annotated screen shot are shown in Figure 2.3 and Figure 2.3 respectively.[3] Salient points of comparison with the PSCAD model are:

- A PWM converter element (ElmVsc) is used to represent the IGBTs. The PWM converter element is configured with a "submodel"[4] which implements the average switch circuit model.
- A controlled DC current source (driven by a model emulating the PV array) is used to represent the PV panel and a fixed DC voltage source is used for the battery, which is similar to PSCAD.

[3] Refer to [3] and [4] for additional information on the SMA PowerFactory model
[4] A "submodel" can be used to define detailed power electronic models specifically for EMT simulation [5].

- The inverter controller and PPC models are implemented using pre-compiled DLL files which are compliant with the IEC C-interface 5.[5] Text files are used to define the vast majority of parameters for the inverter and PPC models, the same as in PSCAD.
- There is no debug interface for the models, but rather signals are available within each of the electrical and control components which can be monitored and therefore displayed in simulation plots for investigation and debugging.
- Aggregation of multiple inverters for a plant is achieved through the use of a parallel controlled AC voltage source (see Section 2.1.2), which is different from PSCAD.

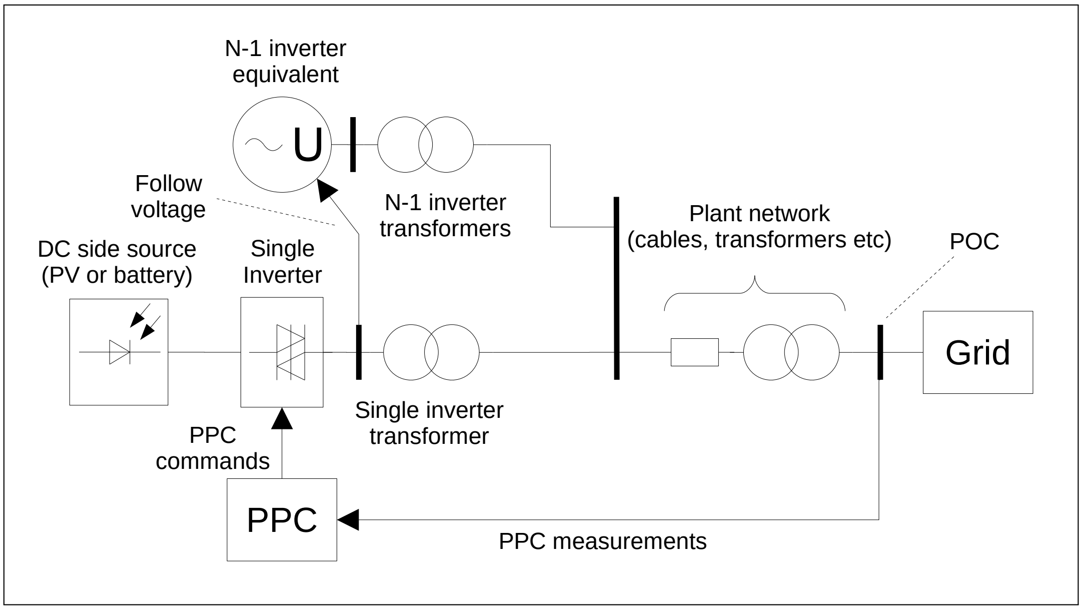

Figure 2.3: Overview of PowerFactory model

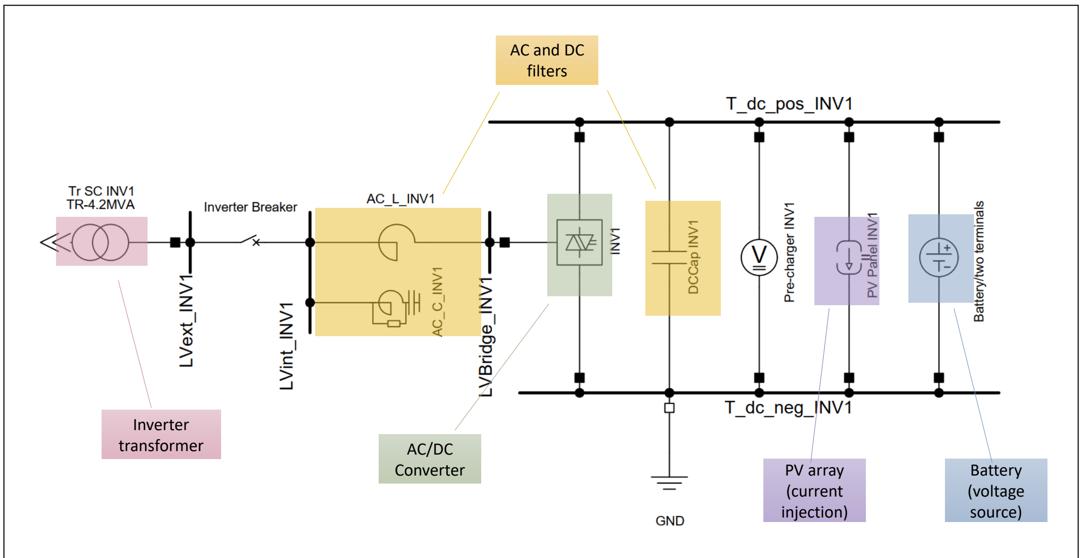

Figure 2.4: PowerFactory single inverter system model details

[5] The IEC C-interface is also referred to as the “External C Interface according to IEC 61400-27”

2.1.1 Control block structure and signal flow

The previous section compared the overall model electrical structure, however another important aspect is the structure of control blocks and the flow of signals between them. In PSCAD there are practically no structures or no constraints around signals being passed between different control blocks. Hence, in the case of the PSCAD model, key signal flows between major elements are implemented directly between components as shown in Figure 2.5 (see Figure 2.2 for where these various elements appear in the model). However, in PowerFactory signal interchange between control blocks can only be achieved via slots within a Composite Model (ElmComp). For this model, the nested structure shown in Figure 2.6 has been adopted. Please refer to Figure 2.7 for where these elements reside within the model. The point to note is that despite the differences in the organisation of the control blocks, the overall signal flow is essentially the same for both the PSCAD and PowerFactory models.

In the PowerFactory model, the control functions are separated into many control blocks. However, the most important blocks from a users perspective are detailed in Table 2.1.

Table 2.1: Key PowerFactory model blocks

Title	Block name	Parent composite model	Description / Use
Inverter control block	SMA_SCXXXX_Control	Model_SMA_SCXXXX_Control	Black-boxed inverter control model.
Inverter measurement block	Measurement Processing	Model_SMA_SCXXXX_Control	Access to key electrical measurement signals.
Inverter set-points block	Converter Setpoints	Model_SMA_SCXXXX_Control	Access to inverter set-points (when PPC not used).
Debug signals block	CM_RenameDebugSignals	Model_SMA_SCXXXX_Control	Access to inverter debugging signals.
PPC block	HyCon DLL	CompMod HyCon	Access to key PPC input and output signals
PPC set-points block	HyCon Setpoints	CompMod HyCon	Access to PPC set-points.
PPC block	HyCon DLL	CompMod HyCon	Access to key PPC input and output signals
PPC set-points block	HyCon Setpoints	CompMod HyCon	Access to PPC set-points.

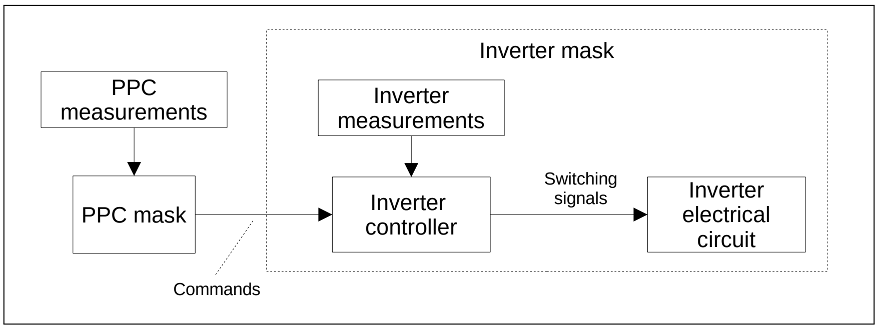

Figure 2.5: Diagram of PSCAD model control structure

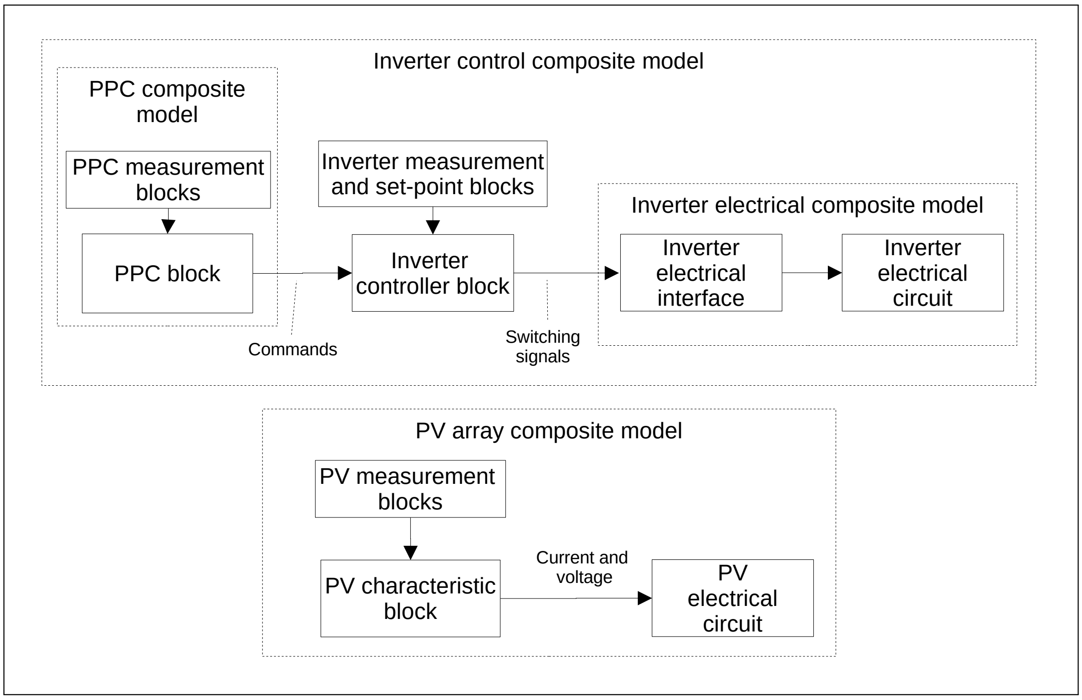

Figure 2.6: Diagram of PowerFactory model control structure

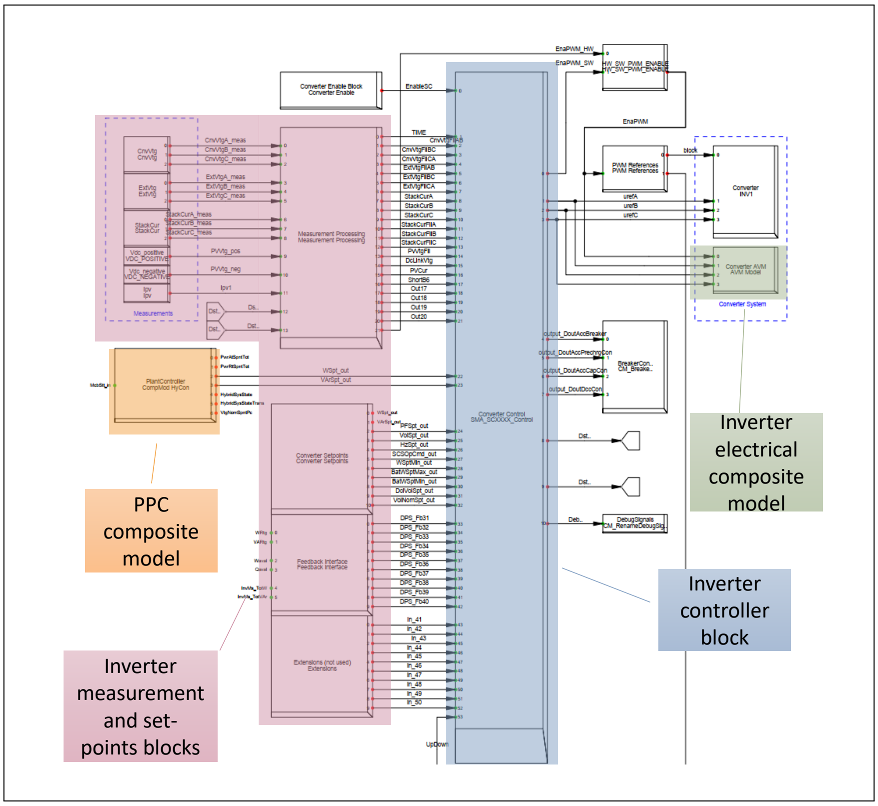

Figure 2.7: PowerFactory model inverter control composite model details

2.1.2 Aggregation implementation

Both the PSCAD and PowerFactory inverter controller models must interface to the measurement and control signals of a single inverter unit only. However for most applications of these EMT models, a single inverter unit is required to represent the aggregate behaviour of multiple units. Hence for both platforms, special techniques are required to make the single inverter model represent a plant consisting of multiple units.

In the case of the PSCAD model this is achieved through the use of a current scaling component, which interfaces a single inverter system to the grid at the inverter step-up transformer HV side (see Figure 2.1). This technique allows the inverter controller to interact with a single inverter element on the inverter side of the scaling component. However, on the grid side of the scaling component, the output current of this single inverter is scaled up by the total number of inverters to represent a full size multi-inverter plant. However, the scaling process in PSCAD introduces an inherent (and fictitious) single time step delay into the simulation, an effect which is similar to a very short transmission line [6]. Furthermore, the scaling component introduces a fictitious series reactance, which is inversely proportional to the fictitious shunt susceptance it introduces, and which therefore cannot be non-zero. The relationship between the scaling component's shunt susceptance, series reactance and other parameters is given by the following [6]:

$$B_{pu} = \frac{(2\pi f_0 \Delta t)}{X_{pu}} \tag{1}$$

Where B_{pu} is the pu susceptance introduced by the scaling component at fundamental frequency, f_0 is the fundamental frequency, Δt is the simulation time step and X_{pu} is the configured pu reactance value of the scaling component. It is necessary to account for the introduced series reactance by adjusting any real inverter step-up transformer reactance so that the sum of the two add up to the true transformer reactance.

In PowerFactory, a single detailed inverter unit (consisting of inverter transformer, filters, converter circuit and DC side components) is also utilised for interfacing to the inverter controller. The difference with PSCAD is that a parallel branch with a controlled AC voltage source is used instead for the aggregation (see Figure 2.3). This parallel branch models the response of all the other inverter units within a plant (representing the response of $N-1$ inverters for a plant consisting of N inverters in total). This branch consists of the following:

- An aggregate inverter transformer representing $N-1$ units
- Aggregate series and shunt filters components to the converter terminals, representing $N-1$ units
- A controlled AC voltage source connected at the converter terminals (in place of the $N-1$ converters)

The output voltage of the controlled voltage source is configured to replicate the single inverter unit's converter terminal voltage (the node behind the AC filter). Taking the impedance and admittance values of the single inverter unit's components as the base, parameters are adjusted so that all impedance values within the parallel branch are scaled down by a factor of $N-1$ (i.e. divided) and all admittance values are scaled up by a factor of $N-1$ (i.e. multiplied). PowerFactory's solution engine ensures that the output voltage of the controlled AC voltage source is identical to that of the single inverter within a simulation time step and hence does not introduce the fictitious time delay observed in PSCAD.

2.2 Model setup

The SMA EMT model setup procedures for PSCAD and PowerFactory are rather different, largely owing to the level of structure that exists within each software platform. The set-up procedure in PSCAD involves the following steps (see [1] and [2] for further details):

1. Start with the example Single Machine Infinite Bus (SMIB) project.
2. Select the inverter type from the inverter mask.
3. Setup the parameters for the inverter and hybrid controller in the appropriate external text files as required.
4. Customise the electrical part of the balance of plant network (e.g. cables, transformers etc).

In comparison, the PowerFactory model setup procedure primarily involves the use of the provided templates and scripts, which are explained in detail in [3] and [4]. In summary, setting up the PowerFactory model involves the following steps:

1. Start with a network (or bus) to which a single or aggregate inverter model is to be connected.
2. Select the appropriate template for the project from those that are available such as:
   - Aggregate (referred to as “scaled”) or single inverter representation.
   - Solar PV or battery inverter system.
   - With or without PPC (Hybrid Controller).
3. Setup the inverter type and components using the script “Select_Inverter_Type”.
4. If using an aggregate model, use the script “Scale_Inverter2Plant” to appropriately scale the parallel aggregate voltage source elements.
5. Setup the parameters for the inverter and hybrid controller in the appropriate external text files, the same as in PSCAD.
6. Customise the electrical part of the balance of plant network (e.g. cables, transformers etc), the same as in PSCAD.
7. Setup any output channels required for monitoring.

To copy the AC and DC electrical components and dynamic models over, it is possible to duplicate existing model elements within PowerFactory via a copy and paste operation. However, care must be taken to ensure that the links within the dynamic model setup are not broken. Examples of this includes the assignment of elements within slots of the composite models and links between measurement devices and electrical locations being monitored.

2.3 Model start-up

Both the PSCAD and PowerFactory EMT models start up from a disconnected state with zero current output. The models take several seconds to close their connection circuit breakers and reach initialised steady state conditions. The current version of the PSCAD model supports the use of snapshots, which allow a user to start a simulation from a point in time when a snapshot was taken. Using this feature, the time taken for model initialisation can be avoided for repeat simulations for the same operating point. However, the current version of the PowerFactory model (see Section 3.1.1) does not implement this feature, although it is planned for future model versions.[6]

[6] Please see Section 3.1.1 for specific model versions referred to in this section.

3 Performance benchmarking

This section details the tests carried out to benchmark the performance of the PSCAD and PowerFactory EMT models. The model versions, model characteristics and the results of the benchmarking process are detailed below.

3.1 Test model

The test model used for benchmarking consists of a SMIB system and is shown in Figure 3.1. It is comprised of:

- 0.63 kV, 4.2 MVA (SC4200-UP) inverter with a voltage source connected at the DC side
- 33 kV / 0.63 kV step up transformer
- Thevenin equivalent voltage source connected at the 33 kV Point of Connection (POC)

A single inverter and an aggregate inverter SMIB models are developed for the tests. The single inverter model consists of one inverter unit connected to the POC via a single step up transformer with the grid Short Circuit Ratio (SCR) defined on a base of 4.2 MVA. The aggregate model on the other hand represents 100 parallel inverters and step transformer units connected directly to the POC. The grid SCR for the aggregate model is defined on a base of 420 MVA (which is the single inverter rating scaled by the total number of inverters).

The electrical and control system parameters of this model were configured to be identical between PowerFactory and PSCAD, and they are detailed in Appendix A.

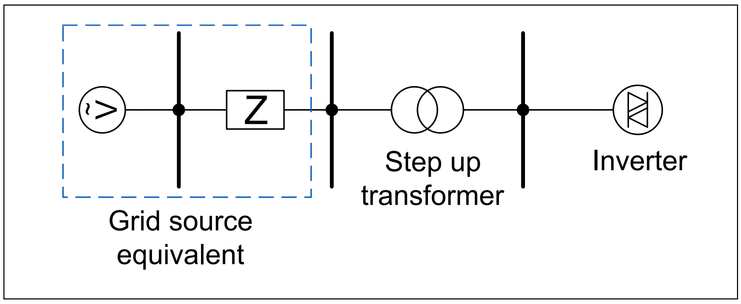

Figure 3.1: Simplified single line diagram showing the test model arrangement

3.1.1 Software and model versions

In PowerFactory, the tests were conducted using:

- PowerFactory 2023 SP5 (x64)
- Model version: “SMA_SC(S)_EMT_R09003703_HyCon_021716A00_agg_packed”

In PSCAD the tests were conducted using:

- PSCAD 5.0.2 (64-bit) with Intel® Fortran Compiler Classic 2021.6.0
- Model version: “SMASC_K_090033R02” and “SMAHYC_021616R02”

3.1.2 Derived metering quantities

EMT simulations inherently simulate per phase instantaneous current and voltage waveforms at the modelled electrical nodes and branches. However, for simulations involving inverter-based resource plant stability, we are normally interested in derived phasor quantities such as voltage magnitude, active power and reactive power. Derivation of these quantities involves signal processing of the per phase instantaneous current and voltage waveforms. In PSCAD a combination of the ETRAN run-time library [7] and the in-built PSCAD Fast Fourier Transform (FFT) meter are used to derive these phasor quantities. In

PowerFactory, a DIgSILENT Simulation Language (DSL) model is used which carries out the required conversions and is available from the DIgSILENT website [8].[7] Since the implementation of these metering algorithms are not identical between PSCAD and PowerFactory, different dynamics are to be expected when they are presented with the same input measurements.

3.2 Response comparison test cases

3.2.1 Scope and methodology

The model was tested under a range of grid strength conditions to ensure robust performance. These included weak and strong system conditions, corresponding to a POC SCR of 2.3 (resulting inverter terminal SCR of 2.0) and POC SCR of 7.5 (resulting inverter terminal SCR of 5.0), respectively. The tests were conducted with maximum active power and zero reactive power output at the inverter terminals with the grid source voltage magnitude adjusted to achieve 1.0 pu voltage at the POC. The following types of tests were then conducted on the SMIB model:

- Flat run tests.
- Fault tests comprising three phase (3L), two phase to earth (2LG) and single phase ot earth (LG) faults of varying depths applied at the POC bus.
- External grid disturbance tests comprising voltage magnitude jump, phase angle jump and frequency ramp disturbances applied to the voltage source.
- Active and reactive power reference steps applied to the inverter controller.

A full set of tests was conducted on the single inverter version of the model and a limited number of repeat tests were undertaken for the aggregate version. In addition, several special tests were conducted to examine the model behaviour under very low SCR conditions, with the detailed PV array module included and when representing a complex system with multiple inverter aggregate units and a PPC.

3.2.2 Quantities shown

To compare the responses between the two models, the quantities shown in Table 3.1 were plotted.

[7] Since PowerFactory 2023, built-in phasor measurement functionality is also available via measurement device elements and is generally recommended over the use of the aforementioned DSL model. However, these built-in phasor measurements were not used in the benchmarking model detailed in this report.

Table 3.1: Signals used for the performance comparison

Name	Description	Units	PSCAD source	PF source
POC V1	POC positive sequence voltage magnitude	pu	ETRAN meter	Phasor meter
POC P1	POC positive sequence active power	pu	ETRAN meter	Phasor meter
POC Q1	POC positive sequence reactive power	pu	ETRAN meter	Phasor meter
POC frequency	POC frequency	Hz	ETRAN meter	Stand alone PLL model
Inverter V1	Inverter positive sequence voltage magnitude	pu	Calculated from Vd and Vq signals reported by the inverter controller model	
Inverter ID1	Inverter positive sequence direct axis measured current	pu	Inverter controller model	
Inverter IQ1	Inverter positive sequence quadrature axis measured current	pu	Inverter controller model	
Inverter ID1 reference	Inverter positive sequence direct axis reference current	pu	Inverter controller model	
Inverter IQ1 reference	Inverter positive sequence quadrature axis reference current	pu	Inverter controller model	
Inverter PLL VQ	Inverter positive sequence quadrature axis measured voltage	pu	Inverter controller model	
Inverter PLL frequency	Inverter PLL measured frequency	Hz	Inverter controller model	
Inverter FRT state	Flag indicating Fault Ride Through (FRT) state, 99 = FRT mode, 97 = normal mode	-	Inverter controller model	

3.2.3 General observations

Some differences in the signals for phasor and frequency metering which are external to the inverter controller are observed, which are due to the differences in the metering models between the two platforms as described in Section 3.1.2. These meters are used to monitor voltage magnitude, active power, reactive power and frequency. Whilst the steady state measurements are normally very well aligned, the different algorithms within these meters can result in different transient responses in the measurement when the system is subjected to a disturbance. Figure 3.2 shows this phenomenon very clearly for a frequency disturbance event where there is a noticeable difference in the metered POC frequency where different meter implementations are used in each platform, but no difference for the inverter PLL frequency since the same algorithm is used.

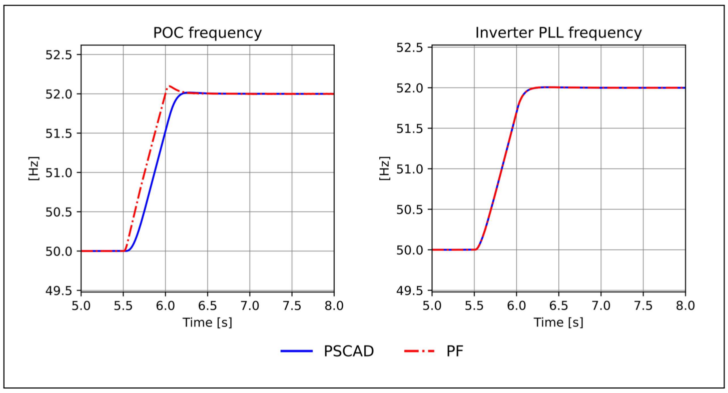

Figure 3.2: Possible discrepancy in monitored quantity due to metering differences. The left plot is measured using different metering techniques whereas the right plot is identical between the two platforms

3.2.4 Flat run tests

For the flat run tests, the alignment between the two models is excellent with errors being less than 0.1% of rated values. In the aggregate model, approximately 0.5 Mvar difference is observed at the POC, which is created by the PSCAD scaling component because it acts like a small segment of transmission line as described in Section 2.1.2. As shown in Figure 3.3, the plant reactive power error significantly reduces when the PSCAD model is run with a much lower simulation time step, which also reduces the effect of this fictitious transmission line.

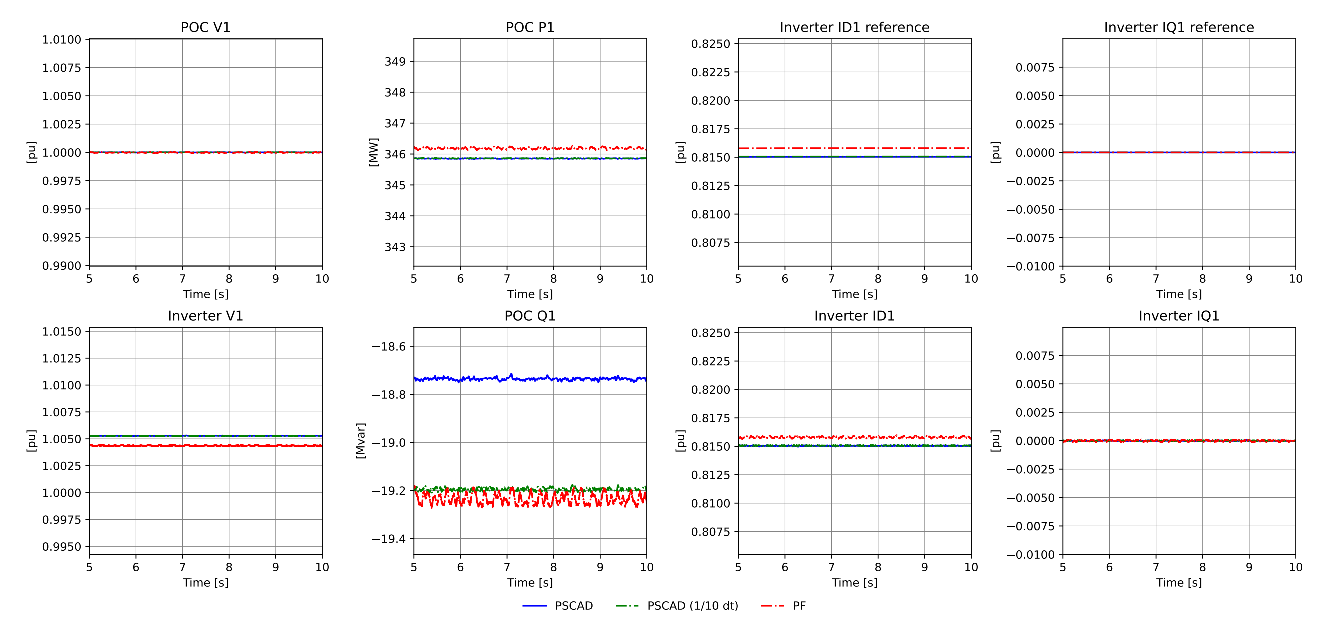

Figure 3.3: Example of flat run overlay comparison for aggregate models

3.2.5 Fault tests

The response of both models to fault events is generally very well aligned, as can be seen from examples of a deep and shallow fault shown in Figure 3.4 and Figure 3.5.

However, slight differences in the aggregate inverter response are observed for shallow faults which cause continuous re-triggering of FRT. For these cases, small differences in retriggering timings build up over time resulting in relatively large differences in observed dynamics at fault clearance (see Figure 3.6). For cases where the FRT retriggering does not occur, such a large discrepancy is not observed.

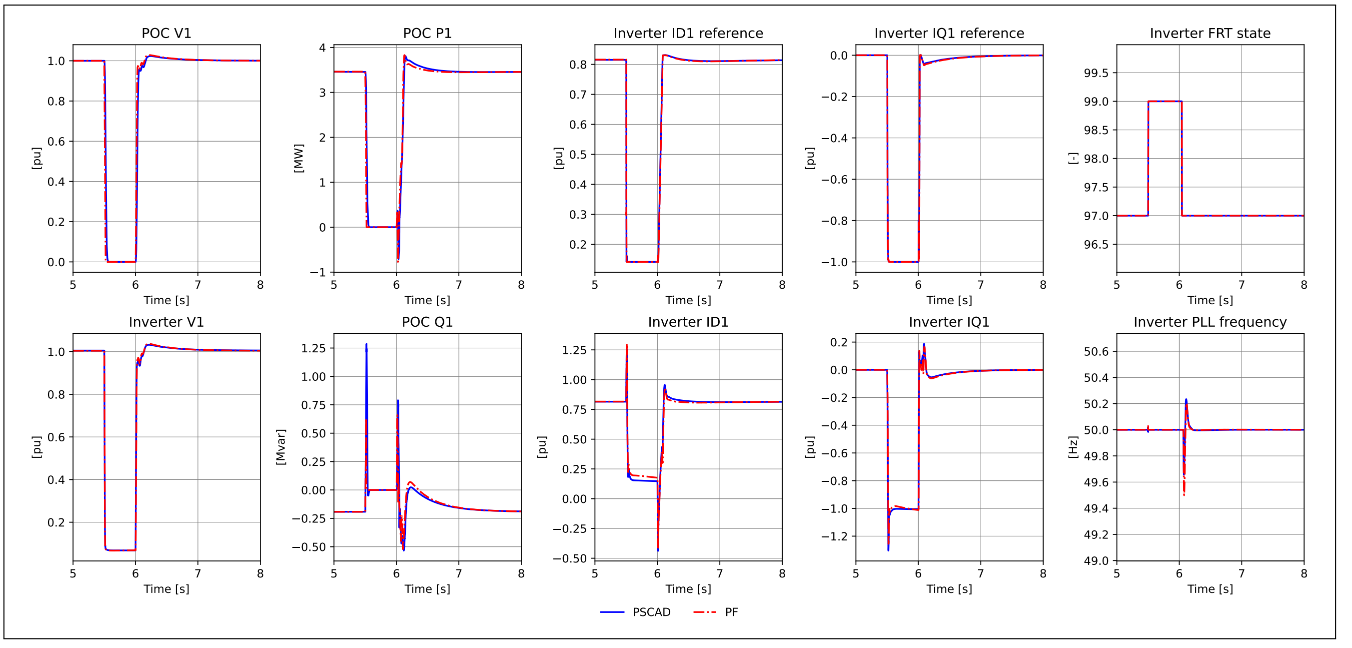

Figure 3.4: Example of a single inverter response to a deep fault

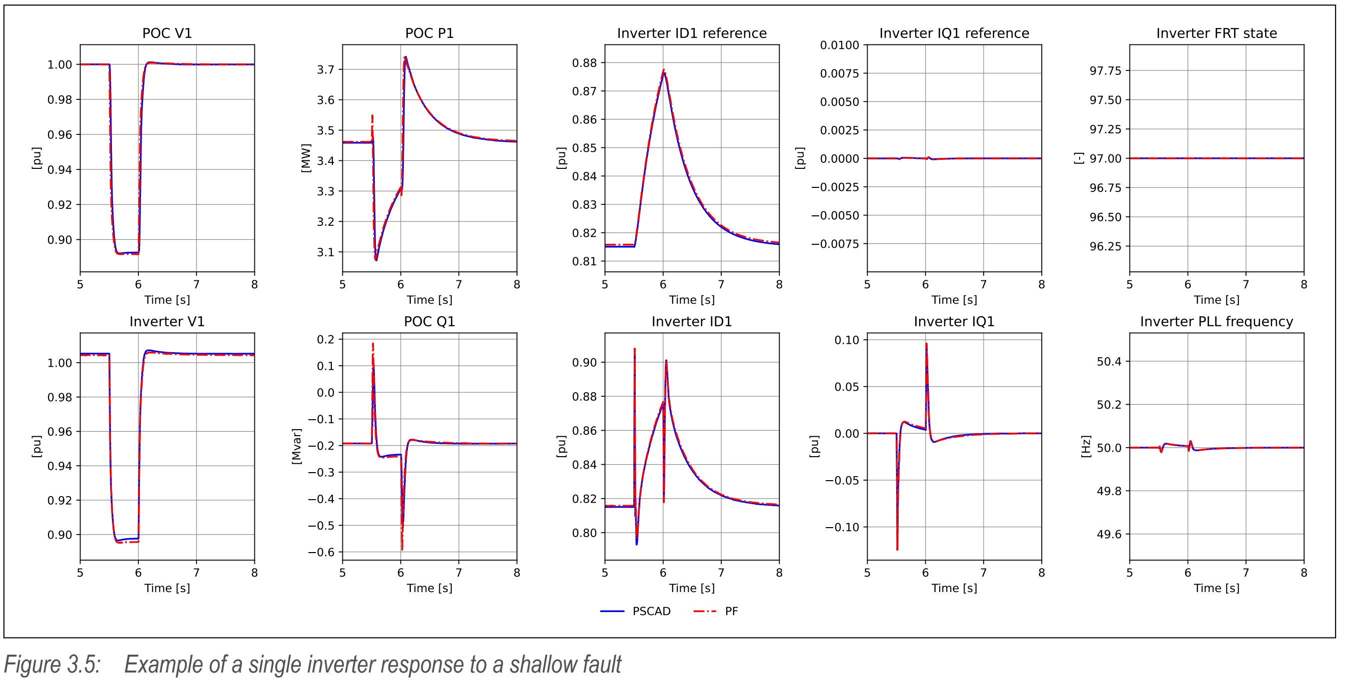

Figure 3.5: Example of a single inverter response to a shallow fault

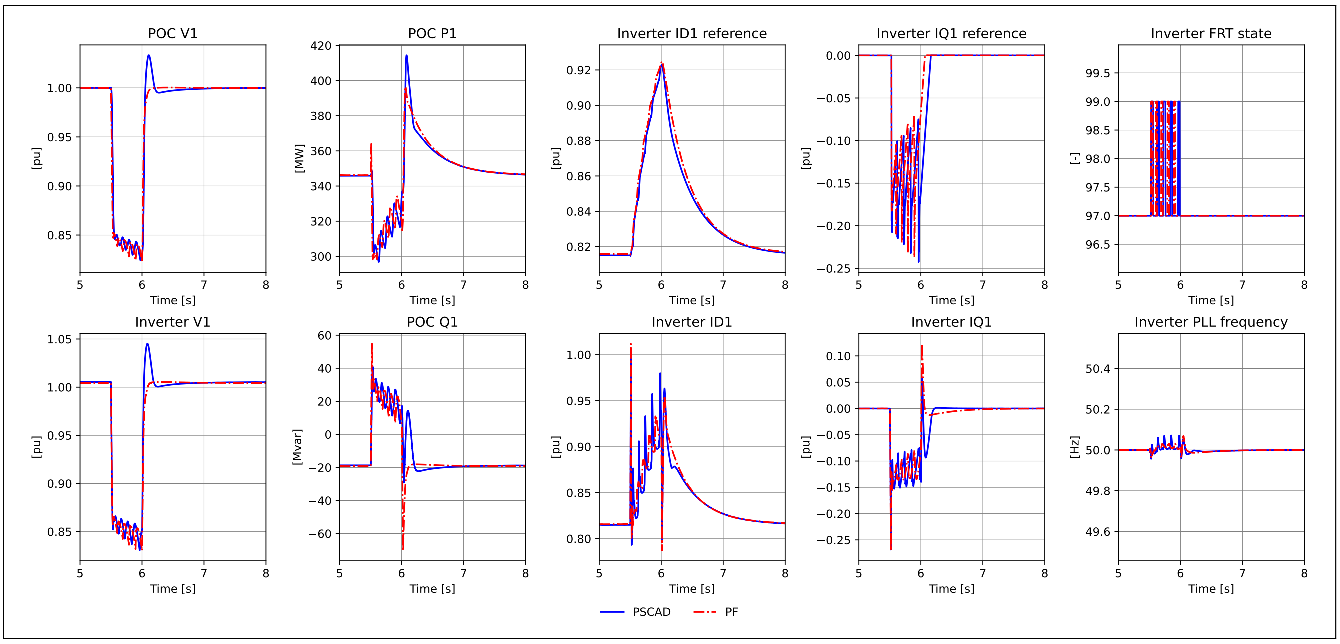

Figure 3.6: Example of a aggregate inverter response difference to a shallow fault which causes FRT retriggering

3.2.6 Grid disturbance tests

The alignment for grid disturbance tests is very good as shown in the example plots below (see Figure 3.7, Figure 3.8 and Figure 3.9 for voltage magnitude, voltage phase angle and frequency disturbances respectively). The slight differences in dynamics observed in POC active and reactive power for the voltage phase angle steps is due to the previously mentioned differences in metering. The POC frequency measurement discrepancy for the frequency disturbance cases is also caused by differences in metering.

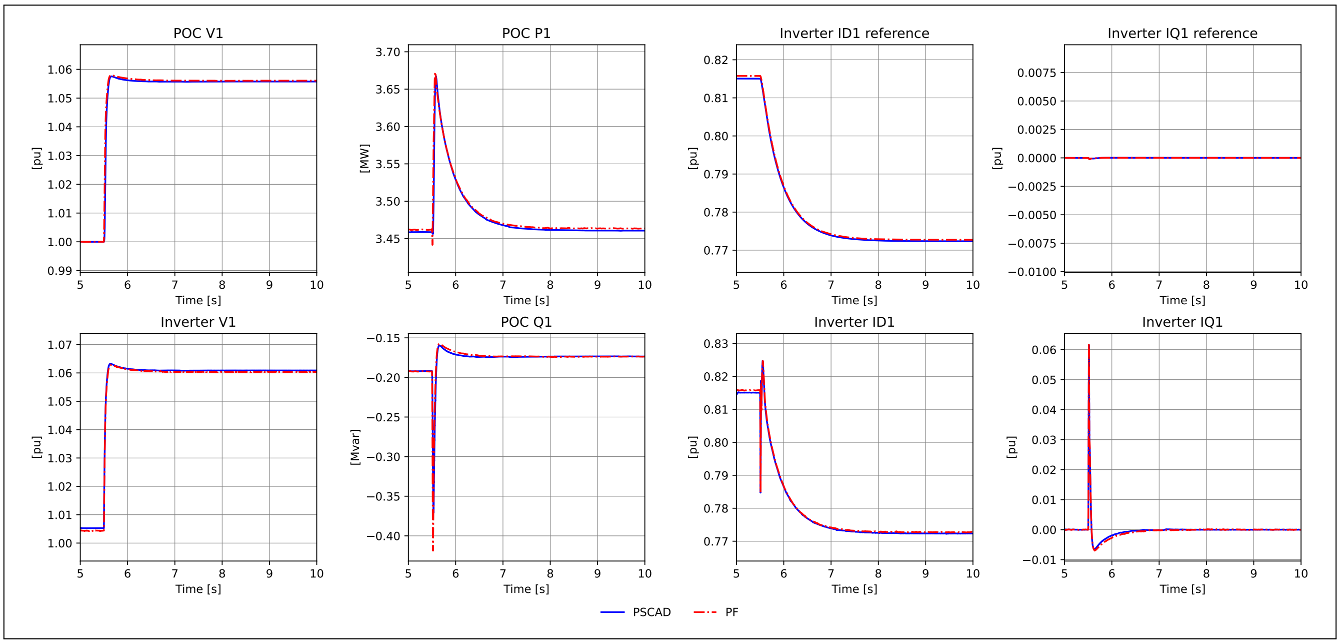

Figure 3.7: Example of a single inverter response to a voltage magnitude disturbance

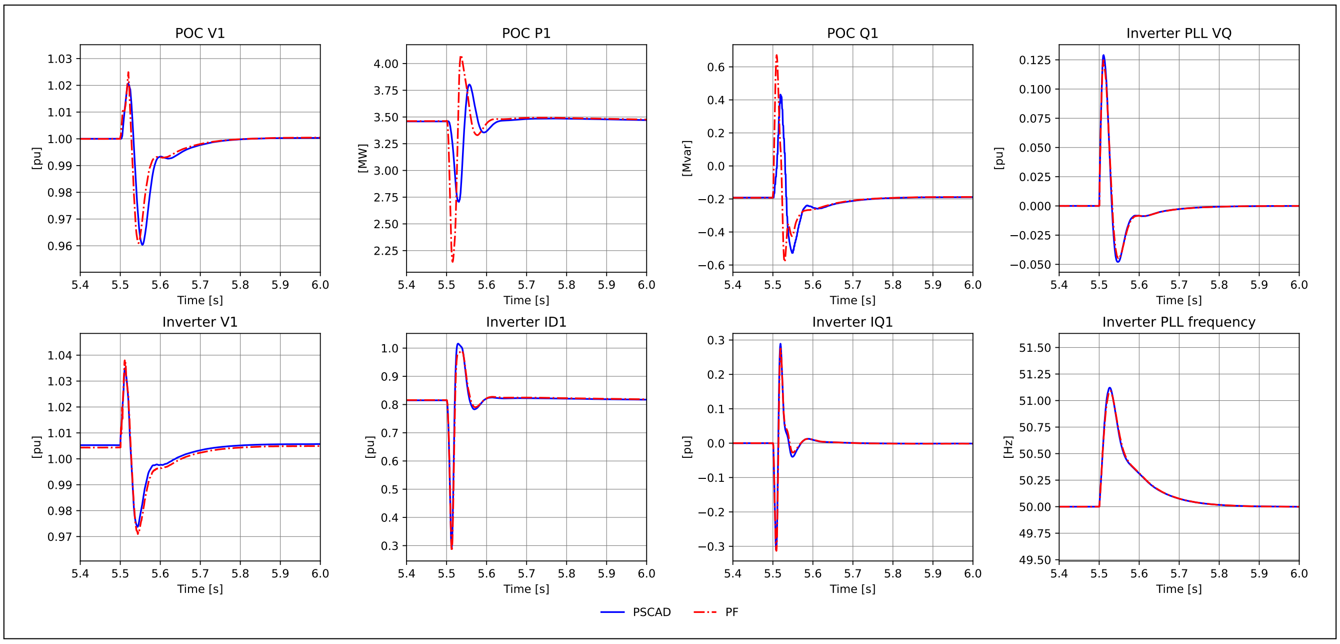

Figure 3.8: Example of a single inverter response to a voltage phase angle disturbance

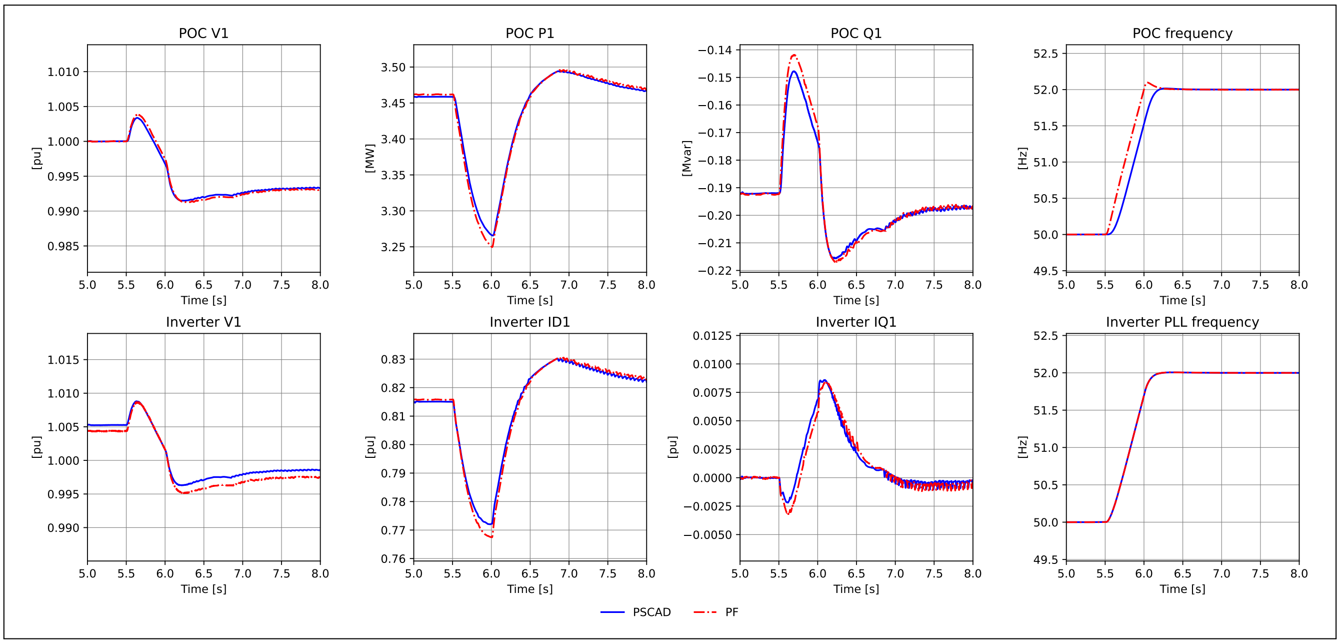

Figure 3.9: Example of a single inverter response to a frequency disturbance (4 Hz/s ROCOF)

3.2.7 Reference step tests

The alignment for grid disturbance tests is very good as shown in the example plots below (see Figure 3.10 and Figure 3.11 for active power and reactive power step responses respectively).

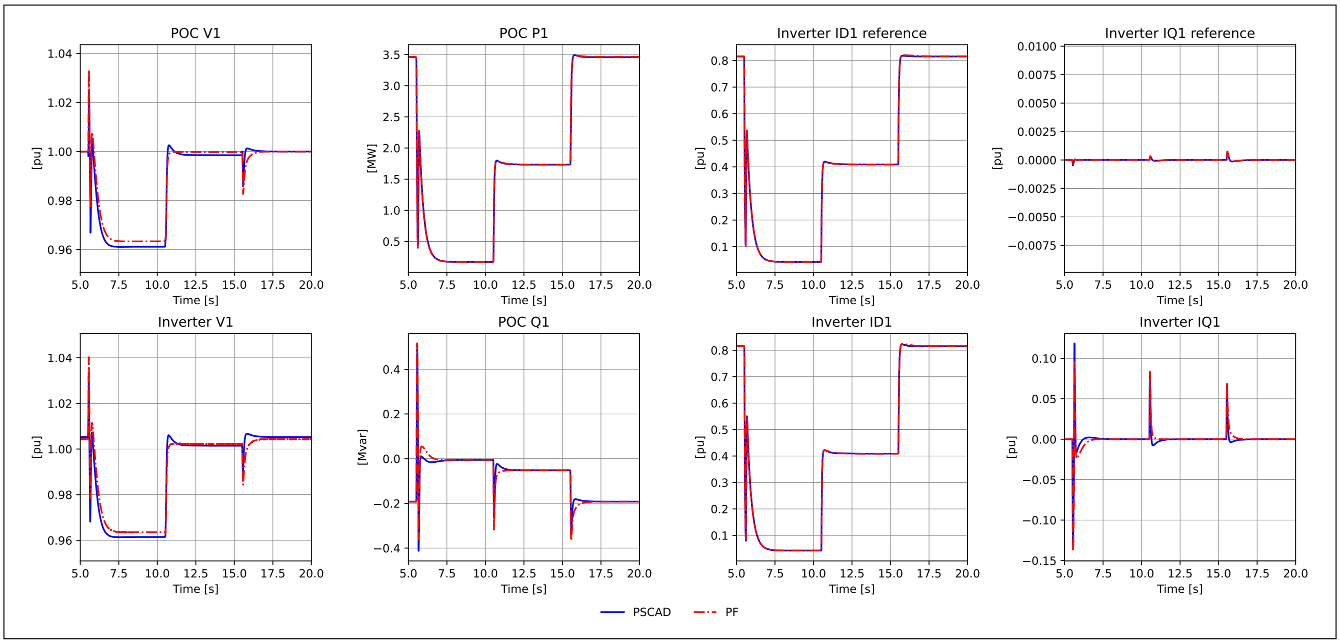

Figure 3.10: Example of a single inverter response to active power reference steps

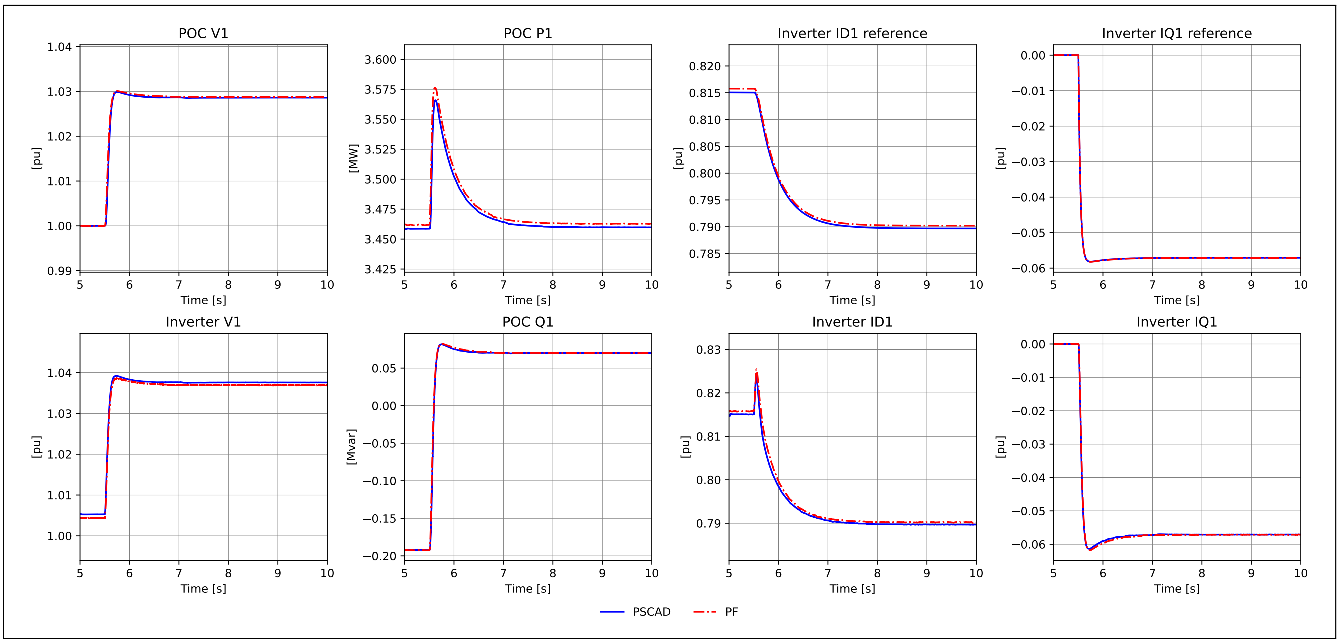

Figure 3.11: Example of a single inverter response to reactive power reference steps

3.2.8 Additional test cases

Several additional tests have been conducted to compare the performance of the model under likely use cases that go beyond the test model configured. These include:

- Start-up under very low grid SCR conditions
- Unstable behaviour under very low grid SCR conditions

- Inclusion of the PV array model
- PPC and multi-aggregate inverter plant test case

3.2.8.1 Start-up under very low grid SCR conditions

The start-up of the model under very low SCR conditions (below 1.0 at the inverter terminals) was tested using the PSCAD and PowerFactory models. Inherent differences in the solution algorithms between the two platforms can result in slightly less damping in the PowerFactory simulation compared to PSCAD. This can result in a slowly growing harmonic oscillation during start-up which eventually causes the inverter model to trip in the PowerFactory model. To address this issue, additional damping within the PowerFactory EMT simulation can be added via use of the “damping factor” setting under “Calculation of Initial Conditions” (see Figure 3.12). By adjusting this parameter slightly (from the default value of 0.99 to 0.95), a more accurate simulation response is achieved and the negative damping behaviour is avoided. An example response only with the PowerFactory models is shown in Figure 3.13.

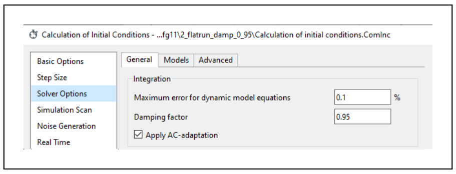

Figure 3.12: Damping factor simulation parameter in PowerFactory.

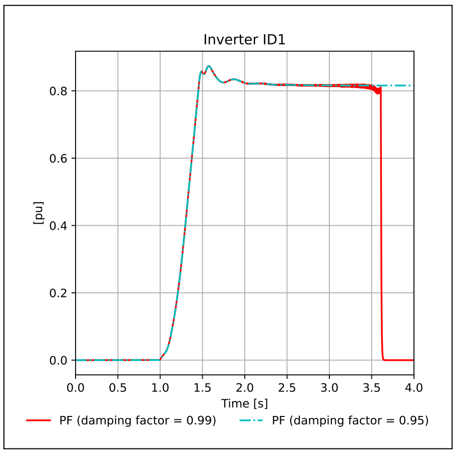

Figure 3.13: Comparison of model start-up for two PowerFactory cases with different damping factors for an SCR of 0.8.

3.2.8.2 Unstable behaviour under very low grid SCR conditions

To test the robustness of the models, a test case with extremely low SCR (SCR = 1.0 at the POC) demonstrating instability was executed. As can be seen in Figure 3.14, the response of the system is very well aligned for such a disturbance. After the system becomes unstable some slight differences in the oscillations which ensue can be observed, however the qualitative nature of the dynamics are captured in both models.

A modified set of inverter controller parameters were then developed to avoid the instability phenomenon and the same system conditions and disturbance were applied (see Figure 3.15). Again, both models display the same response though slight differences in voltage and direct current are observed.

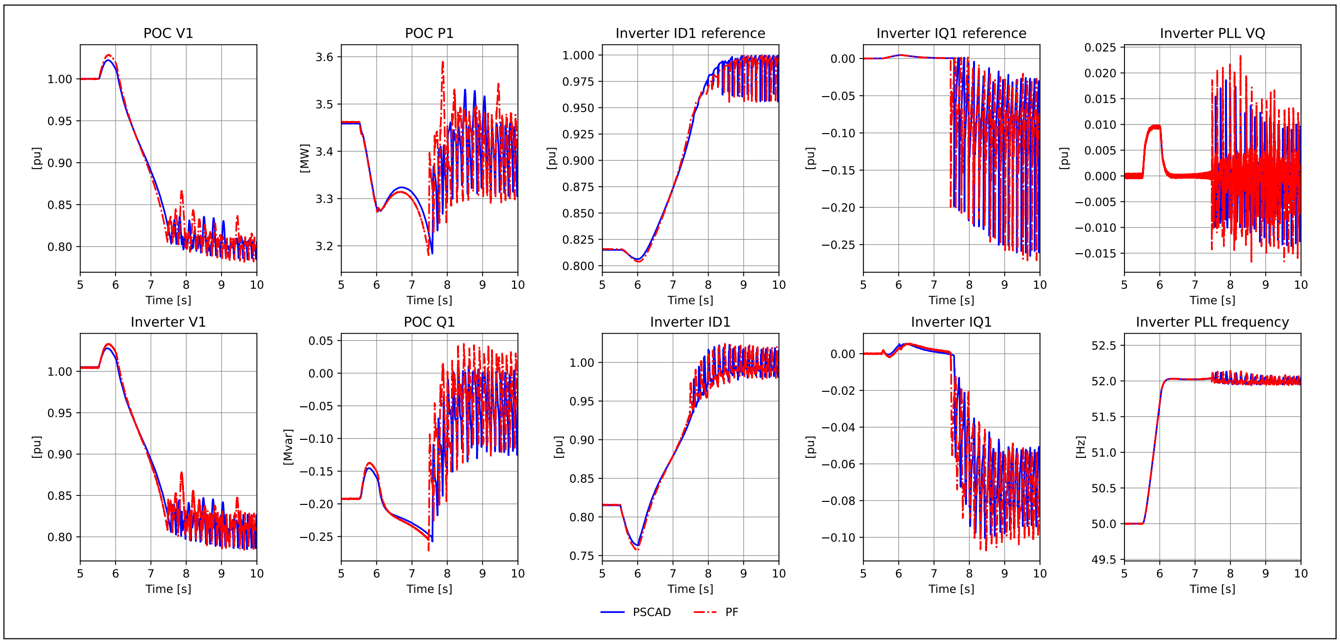

Figure 3.14: Example of a single inverter response to a frequency disturbance (4 Hz/s ROCOF) under extremely low SCR conditions

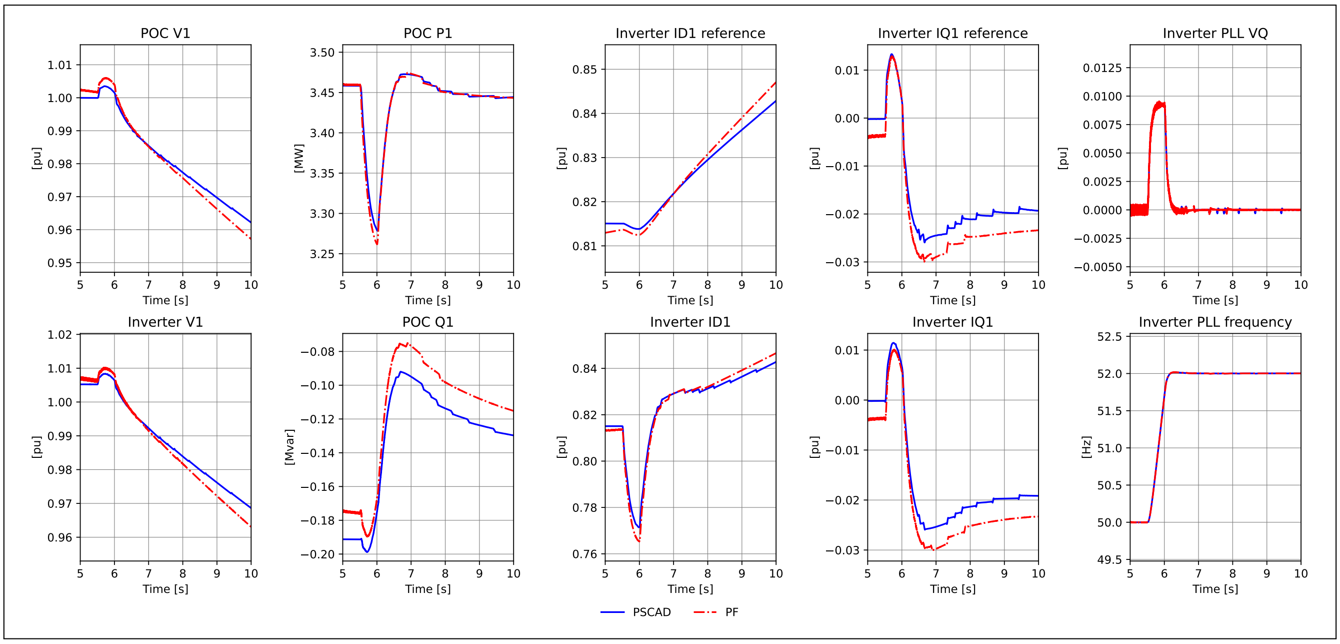

Figure 3.15: Example of a single inverter response to a frequency disturbance (4 Hz/s ROCOF) under extremely low SCR conditions and with modified inverter controller parameters

3.2.8.3 Inclusion of the PV array model

There are slight differences between the PSCAD and PowerFactory PV array model used by the SMA EMT models. To represent a full PV array, both PowerFactory and PSCAD PV models first require the reference temperature and reference irradiance. Then these models rely on defining individual cell / module characteristics and the numbers of parallel and series connections of these components to represent a full PV array. In PSCAD, a built-in master library model is utilised which additionally requires the short-circuit current, no-load current and several cell related parameters (series and shunt resistances, effective area per cell, diode ideality factor and band gap energy). In PowerFactory a user-defined model is used which requires the open circuit voltage, Maximum Power Point (MPP) voltage, short circuit current and MPP current. To generate equivalent parameters for the PowerFactory model, the PSCAD PV array model was configured within a test bed (with varying input DC side voltage) and the required open-circuit, short-circuit and MPP voltages and currents were measured. The resulting characteristics configured in PowerFactory compared to PSCAD are shown in Figure 3.16 and the parameters are detailed in Appendix A.

To test the impact of this characteristic, power reference step tests were carried out in both PowerFactory and PSCAD using the PV array model on the DC side. Both PV arrays were configured with irradiance and temperature equal to the reference values (1000 W/m^2 and 25 °C respectively). The results shown in Figure 3.17 demonstrate that slight differences in PV array characteristics have very little impact on the response as the active power and direct current responses between the two models are very closely aligned.

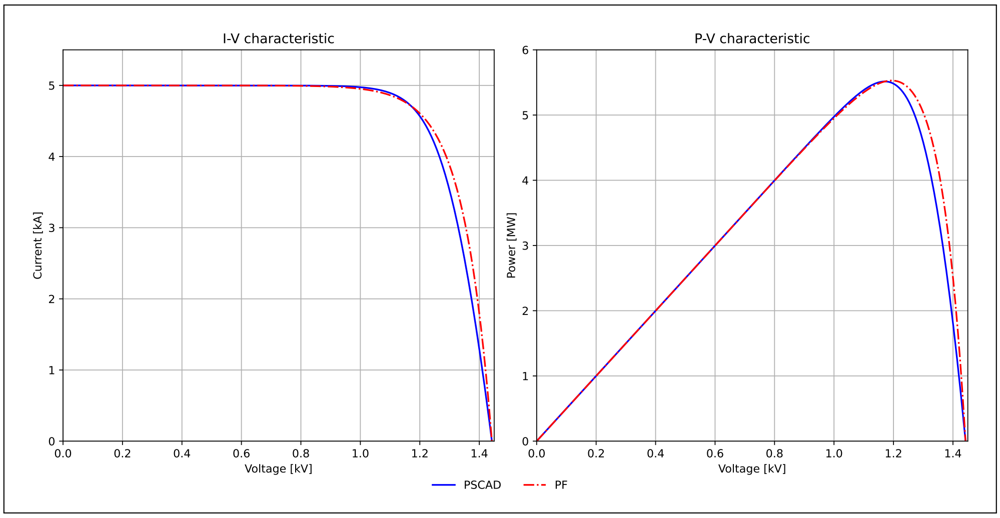

Figure 3.16: Comparison of the PV model characteristics between PSCAD and PowerFactory

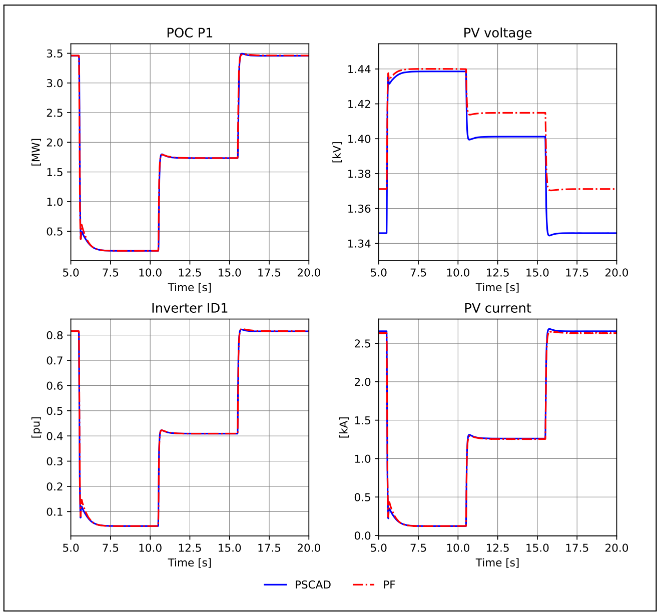

Figure 3.17: Example of a single inverter response to active power reference steps with a detailed PV array model

3.2.8.4 PPC and multi-aggregate inverter plant test case

A key test case for the PowerFactory and PSCAD models is their performance when representing a realistically large plant where multiple inverter aggregate units and a PPC are involved. To test this condition, a 100 inverter aggregate model was set-up in PowerFactory and PSCAD as per the following:

- The 100 inverters were grouped into two 50 inverter aggregates. In PSCAD this involved two separate inverter models with scaling components representing 50 inverters each. In PowerFactory this was achieved by having two separate inverter and parallel aggregate branches groups, with each aggregate branch representing 49 inverters.
- A PPC was configured to control the POC active and reactive power output by sending commands to the two aggregate inverter groups.

In PSCAD the above implementation required duplicating an existing aggregate inverter group, changing the number of inverters for each group (from 100 to 50) and then connecting the appropriate command and feedback signals between the PPC model and the inverters. In PowerFactory however, the following changes were required:

- Create two new aggregate inverter group (single inverter and parallel aggregate branch) from the template [8]
- Resize the parallel branches to represent 49 inverters and step-up transformers
- Modify the existing composite model frame for the PPC (Hybrid Controller) such that:
    - A new overall composite model frame that connects the PPC composite model output commands to two modified inverter composite models (see Figure 3.18).
    - The modified inverter composite models pass external command signals to the inverter controller models. An interposing dummy block with the sole purpose to initialise these signals at the start of the simulation was also required.
    - PPC measurement feedback signals from the inverters were set up such that these were representative of all 100 inverters.

[8] It is also possible to configure distributed signals using vector of objects elements within PowerFactory. However at present, the vector of objects cannot refer to composite models. See PowerFactory 2024 Manual Section 29.2.7.13

The simulation results in PowerFactory and PSCAD show good alignment for this test case (see Figure 3.19).

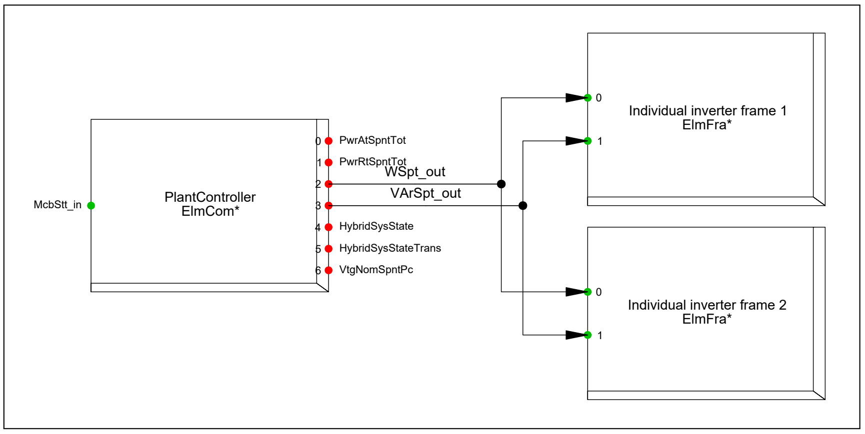

Figure 3.18: Example of a single inverter response to active power reference steps with a detailed PV array model

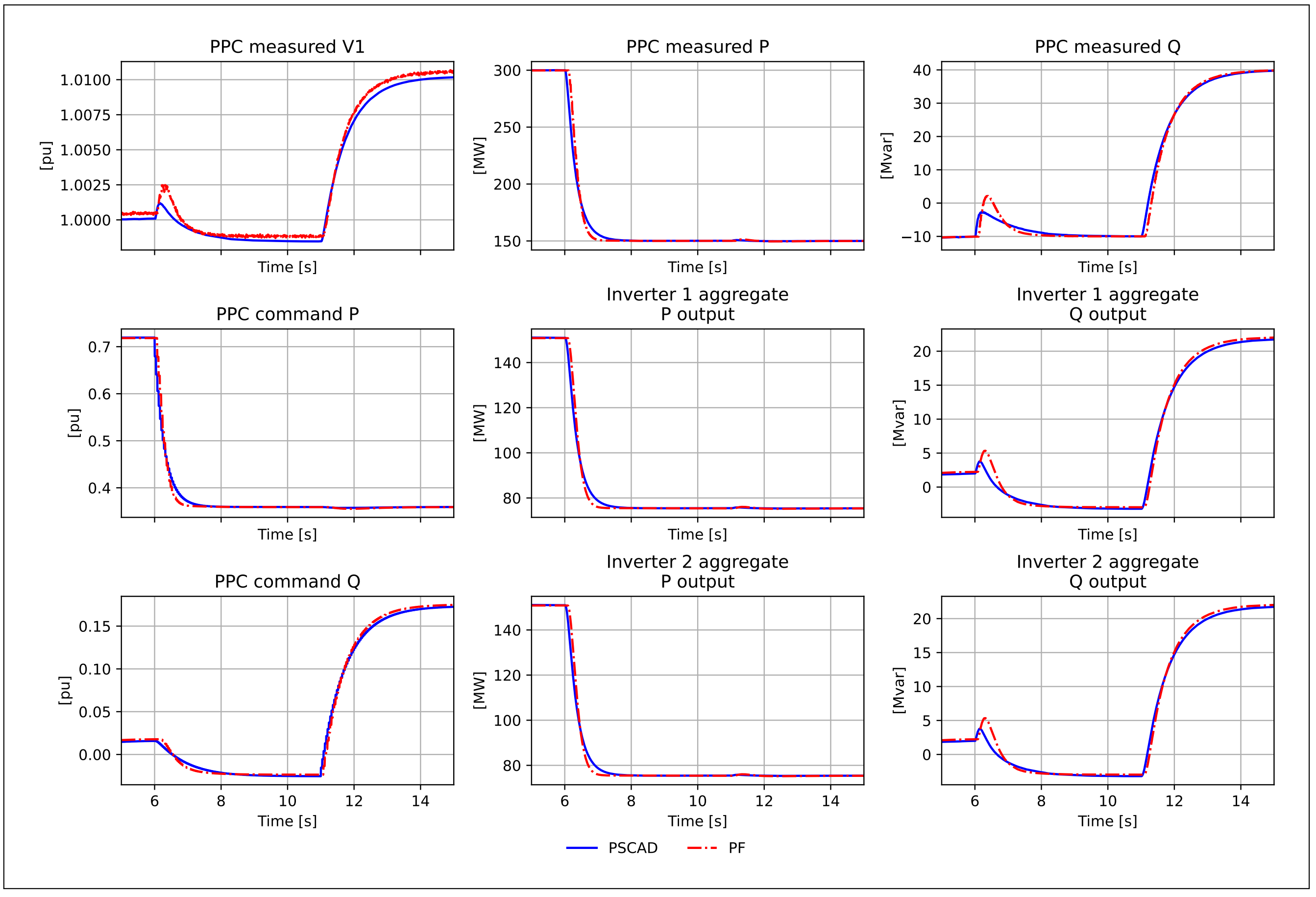

Figure 3.19: Example of response for PPC and multi-aggregate inverter model. The active power reference is changed from 300 MW to 150 MW at 6 s and the reactive power reference is changed from -10 Mvar to 40 Mvar at 11 s.

3.3 Simulation time comparison

This section details testing of the simulation time performance of the PSCAD and PowerFactory models conducted on the same hardware platform.

3.3.1 Methodology

The test cases were configured with the following conditions:

- SMIB case with an SCR of 2.3.
- Active power reference of 0.83 pu and reactive power reference of 0.0 pu.
- Simulation time step of 16.6666666667 µs (the default value suggested by SMA).
- Channel recording sampling time of 166.666666667 µs in PSCAD and 10 samples per simulation time-step in PowerFactory.
- Approximately 160 channels are configured for monitoring / recording in both platforms.

The following cases were tested:

- A single inverter system with a voltage source connected to the DC side (basecase).
- A single inverter system with a PV array model connected to the DC side.
- An aggregate inverter system with a voltage source connected to the DC side .

Two types of tests were conducted:

- A flat run test with a total simulation duration of 10 s, starting from initial conditions (no snapshot).
- A fault test with a total simulation duration of 15 s, starting from initial conditions (no snapshot). A three phase bolted fault is applied at 10.5 s and lasts for 0.5 s.

All test cases were repeated 10 times to ensure robustness of the results.

3.3.2 Computer hardware

The timing comparison tests were conducted on a laptop with the following specification:

- 12th Gen Intel(R) Core(TM) i7-1260P 2.10 GHz, with 12 cores and 16 logical processors
- 16.0 GB (15.7 GB usable)
- 64-bit operating system, x64-based processor
- Windows 10 Pro operating system

3.3.3 Timing results

The summary (average) and detailed timing results are shown in Table 3.2 and Figure 3.20 respectively.[9] These indicate that:

- In general there is a wider distribution of simulation times in PSCAD compared to PowerFactory.
- The base case results between PSCAD and PowerFactory are largely comparable, with the PSCAD model only being approximately 15% faster on average.

[9] The PowerFactory results were generated with the solver option “Accelerated solution of equation system” disabled (found in the “Calculation of Initial Conditions” command). With this option enabled, the PowerFactory simulation time is observed to speed up between 14% and 40% for the basecase and aggregate models.

- Compared to the base case, the aggregate model is comparatively slower in PowerFactory compared to PSCAD (about 25% to 40% on average).
- The PV array model has a significant impact on the performance of the PSCAD model but less so on PowerFactory. The PowerFactory model is 20% to 40% faster when the PV array model is used.

Table 3.2: Average timing results

	Flat run case, 10 s simulation			Fault case, 15 s simulation		
	PF [s]	PSCAD [s]	Diff [%]	PF [s]	PSCAD [s]	Diff [%]
Basecase	146	128	14%	245	214	14%
With PV model	229	282	-19%	312	541	-42%
Aggregate model	220	175	26%	297	212	40%

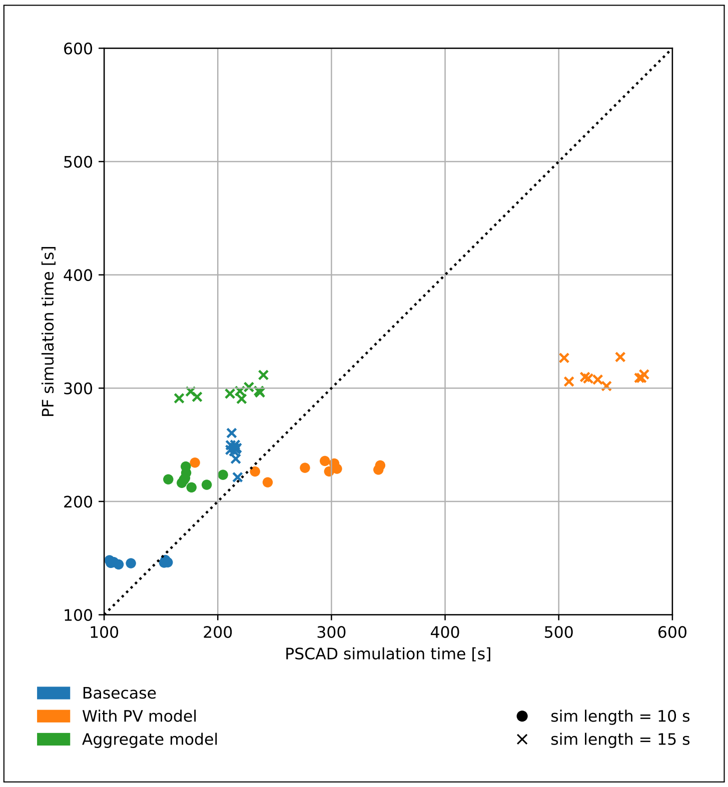

Figure 3.20: Time time taken for each simulation PowerFactory and PSCAD are shown for each case tested. If the simulation times were the same, they would sit on top of the dotted diagonal line.

4 Conclusion

In this report a comprehensive comparison of the SMA EMT PowerFactory and PSCAD models has been presented. The layout and structure of the two models was compared and it was shown that even though the two models are organised differently, their key features and functionality is essentially the same. One notable difference between the two models is the implementation of aggregation, which utilises a scaling component in PSCAD and a parallel controlled voltage source in PowerFactory. A further difference between the two models is the approach required for setting up the model from scratch, where templates and helper scripts in PowerFactory can be used to complete this task.

The performance comparison that was undertaken used a SMIB model and included a wide variety of disturbances such as faults of varying depth, grid voltage magnitude, phase angle and frequency disturbances and active and reactive power reference steps. A range of grid strengths were studied and the results demonstrated that the PowerFactory and PSCAD inverter models have dynamic responses which are practically identical, with discrepancies being very minor in nature. This included additional test cases involving extremely low SCR conditions exhibiting instability, the inclusion of the PV array model on the DC side and a test case representing a complex plant with multiple inverter aggregate units and a PPC.

With regard to simulation speed performance, the PowerFactory model response was observed to be largely comparable to that of the PSCAD model for the single inverter case as it is on average only 15% slower. However, the performance of the aggregate PowerFactory model observed to be slower than PSCAD (approximately 25% to 40%), whereas it is faster than PSCAD when the PV array model is included (approximately 20% to 40%).

In all, this assessment has shown that the PowerFactory SMA EMT model is fit for purpose for modelling and stability studies in the same manner as its PSCAD counterpart.

5 References

[1] SMA Technologies AG, “Description of the model of the SMA Sunny Central solar inverters and SMA Sunny Central Storage battery inverters for EMT studies in PSCAD, Model Revision 9.0.33.02, Document Revision 10.1,” tech. rep., 11-05-2022.

[2] SMA Technologies AG, “Description of the model of the SMA Hybrid Controller for EMT studies in PSCAD, Model Revision 02.16.16.R.02, Document Revision 3.4,” tech. rep., 5-05-2022.

[3] SMA Technologies AG, “Description of the model of the SMA SCXXXX inverter for EMT studies in PowerFactory, Model Revision R09003703, Document Revision 1.09,” tech. rep., March 2023.

[4] SMA Technologies AG, “Description of the model of the SMA Hybrid Controller for RMS studies in PowerFactory, Model Revision 02.17.16.A.00, Document Revision 1.17,” tech. rep., November 2022.

[5] DIgSILENT GmbH, “DIgSILETN PowerFactory User Manual, Version 2023,” tech. rep., September 2023.

[6] Manitoba Hydro International, “Simple Solar Farm Model, Written for PSCAD Version X4 4.6.3, Revision 2,” tech. rep., June 2019.

[7] Electranix Corportation, “ETRAN Runtime Library for PSCAD.” `https://www.electranix.com/software/e-tran-runtime-library-for-pscad/`, 2023. [Online; accessed 27-November-2023].

[8] DIgSILENT GmbH, “How can I calculate transformed phasor quantities from an EMT simulation using a DSL model.” `https://www.digsilent.de/en/faq-reader-powerfactory/How-can-I-calculate-transformed-phasor-quantities-from-an-EMT-simulation-using-a-DSL-model.html/`, 2023. [Online; accessed 27-November-2023].

Appendix A Model parameters

A.1 Network model parameters

A.1.1 Step up transformer

Table A.1: Inverter step up transformer model parameters

Parameter	Unit	Value
Rated power	MVA	4.2
HV side rated voltage	kV	33
LV side rated voltage	kV	0.63
Reactance x1	pu	0.065376
Reactance r1	pu	0.007143
Vector group	-	Dyn
No load current	%	0.15
No load losses	kW	3.78

A.1.2 PSCAD scaling component parameters

Note that the inverter step up transformer reactance is reduced by the scaling component reactance in PSCAD for the aggregate cases. This is to ensure that the combined reactance of the inverter transformer and scaling component is equal to intended reactance of the inverter transformer alone. If this step is not carried out, the scaling component will add a fictious reactance which can result in noticeable differences in reactive power loss and voltage drop.

Table A.2: PSCAD scaling component parameters

Parameter	Unit	Value
Xpu	pu	0.025
Vbase	kV	33
Sbase	MVA	4.2

Appendix B Performance benchmark plots

B.1 Single inverter model simulations

B.1.1 Flat run tests

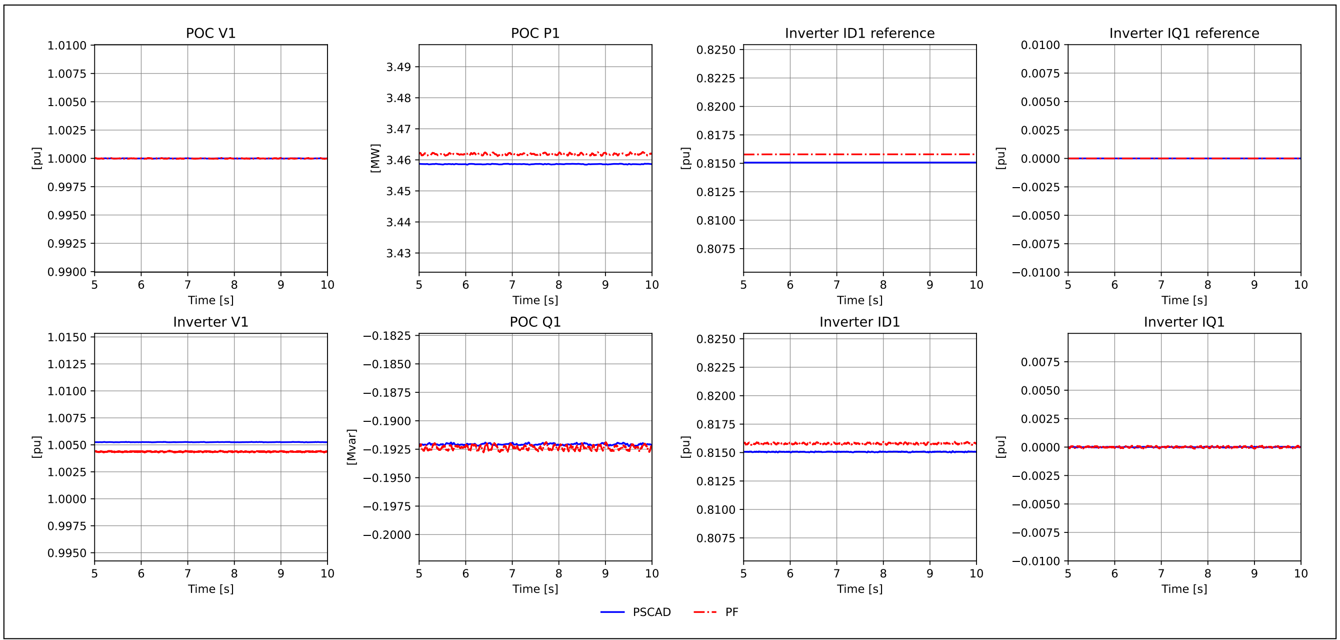

Figure B.1.1: Single inverter model test, SCR=2.3, P=0.83, Q=0, Flat run

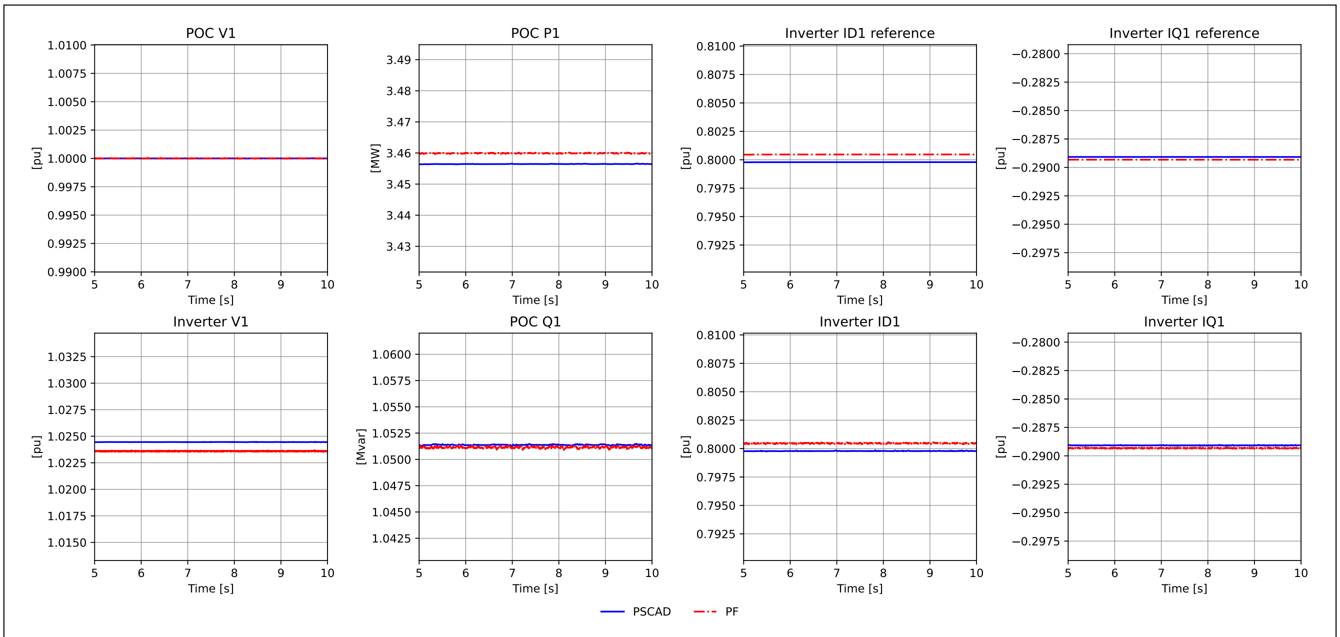

Figure B.1.2: Single inverter model test, SCR=2.3, P=0.83, Q=0.5, Flat run

B.1 Single inverter model simulations

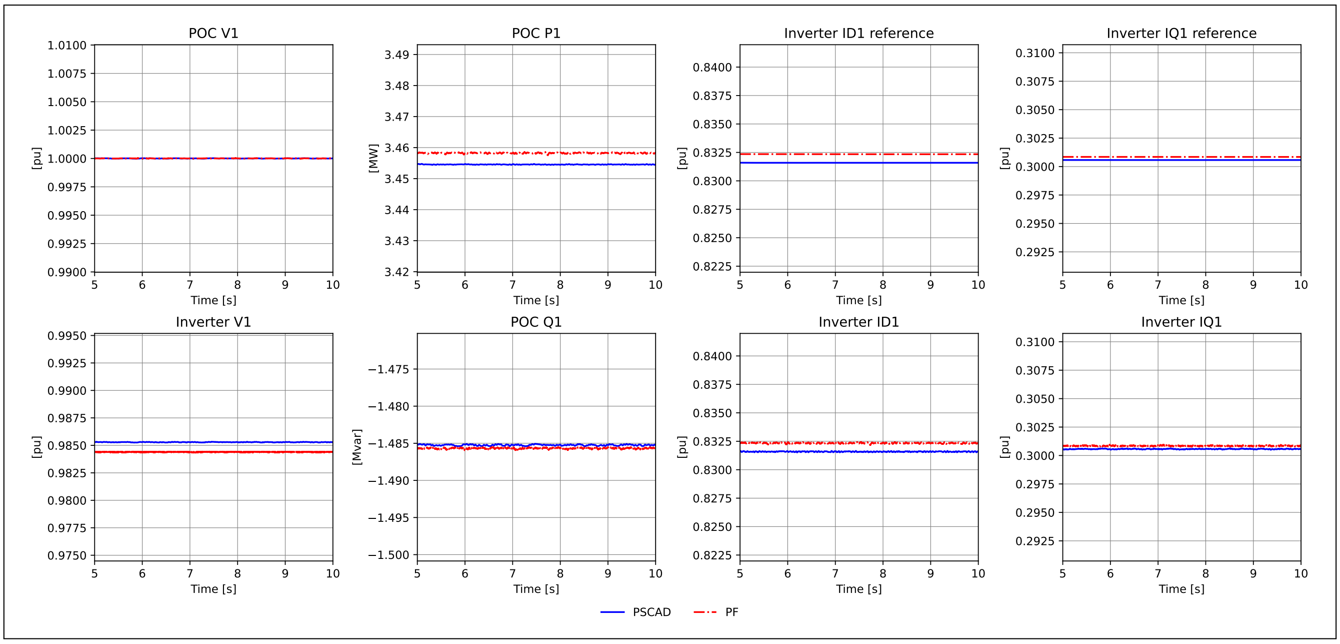

Figure B.1.3: Single inverter model test, SCR=2.3, P=0.83, Q=-0.5, Flat run

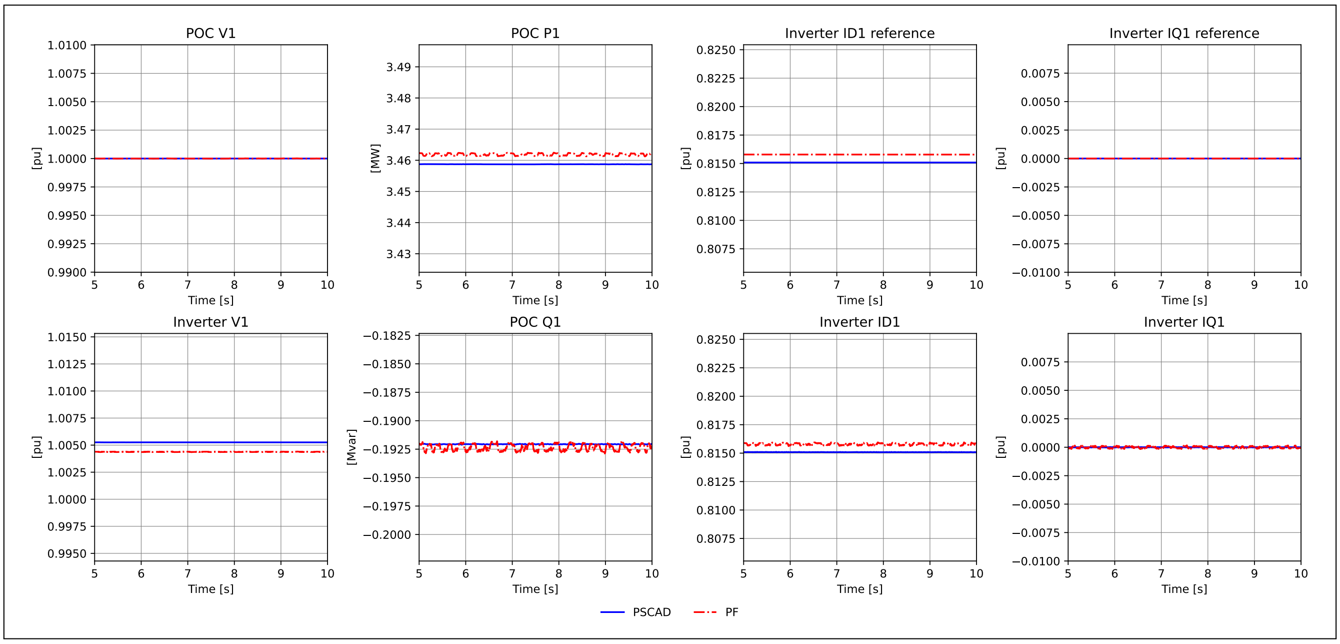

Figure B.1.4: Single inverter model test, SCR=7.5, P=0.83, Q=0, Flat run

B.1.2 Fault tests

B.1.2.1 Fault 3L

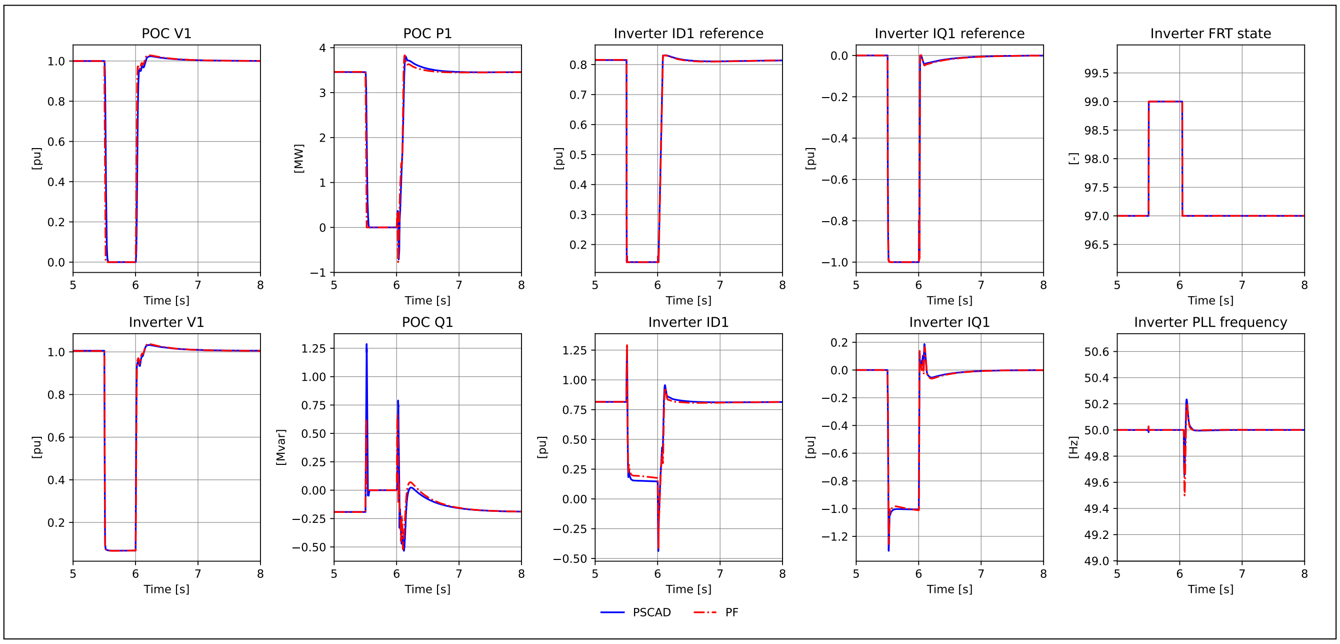

Figure B.1.5: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.0 pu

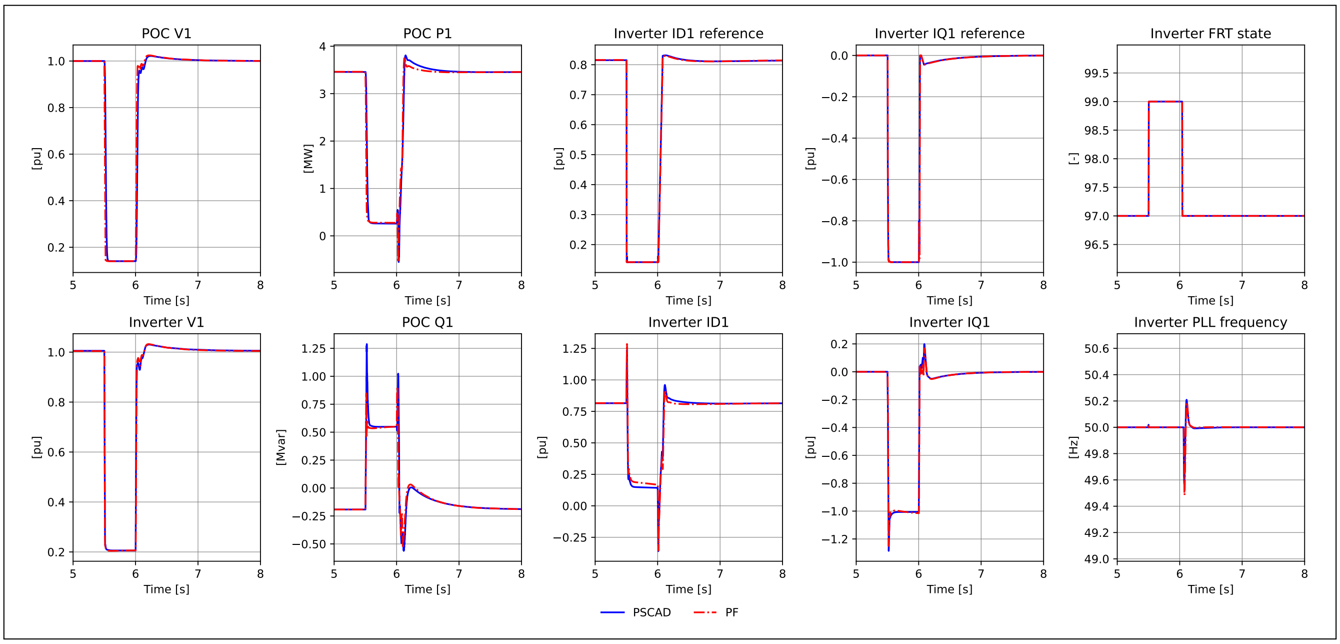

Figure B.1.6: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.1 pu

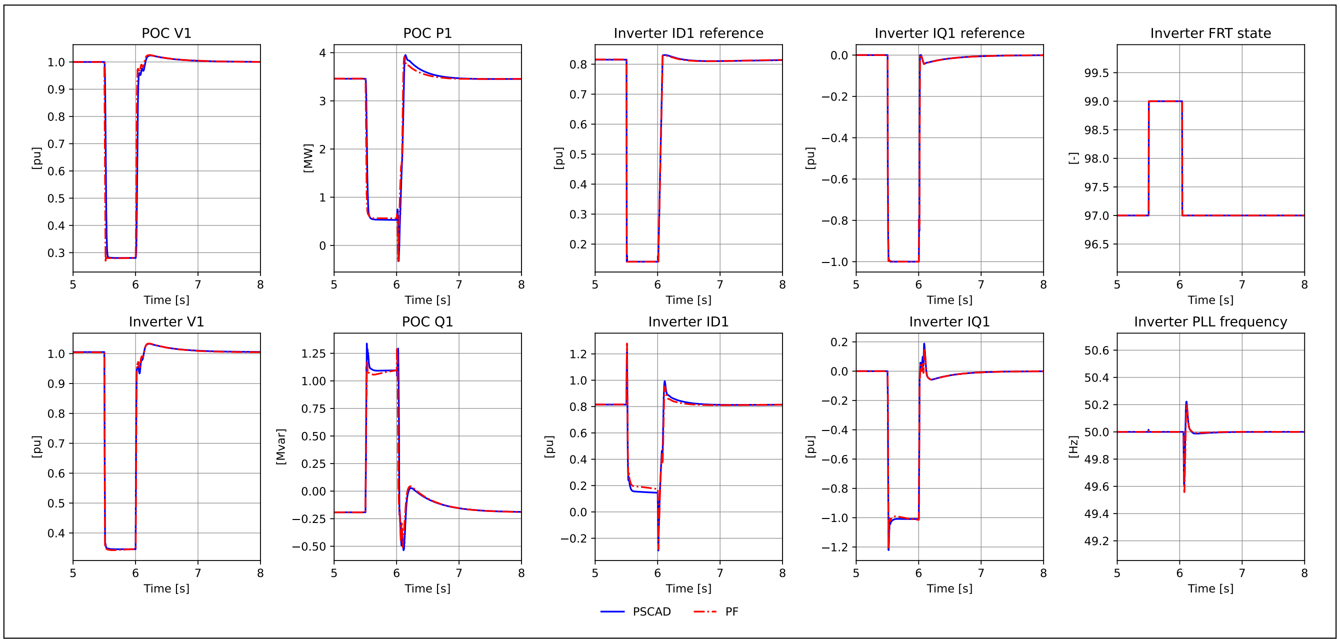

Figure B.1.7: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.2 pu

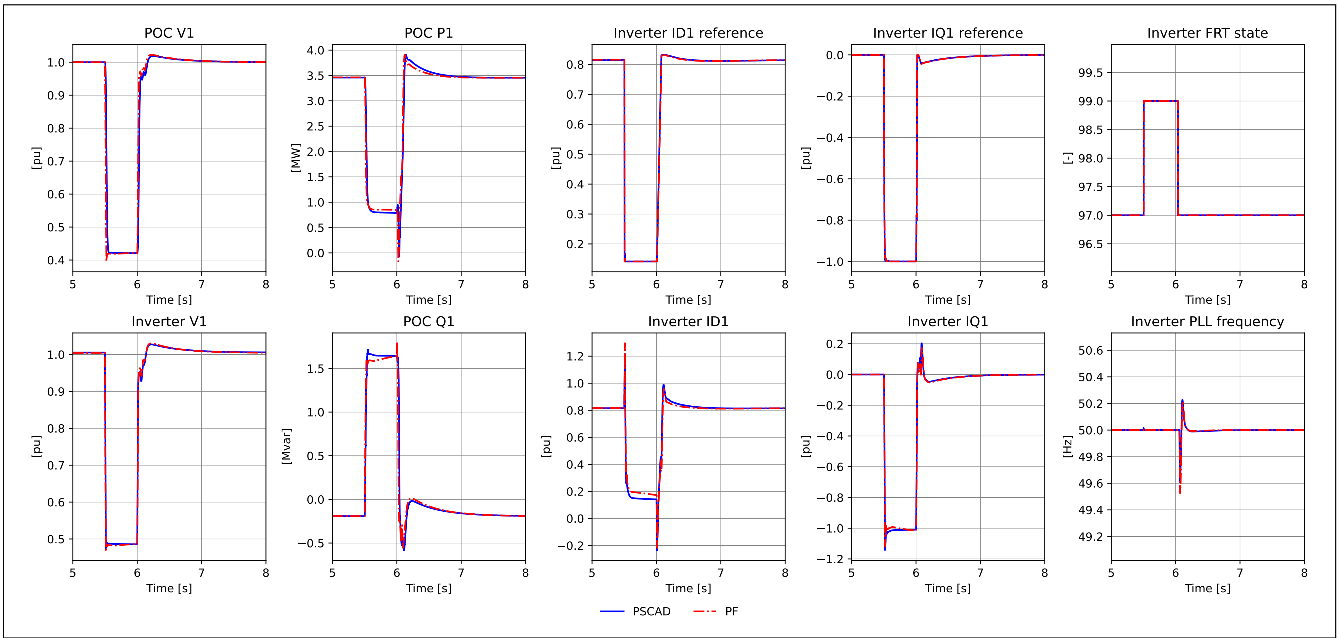

Figure B.1.8: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.3 pu

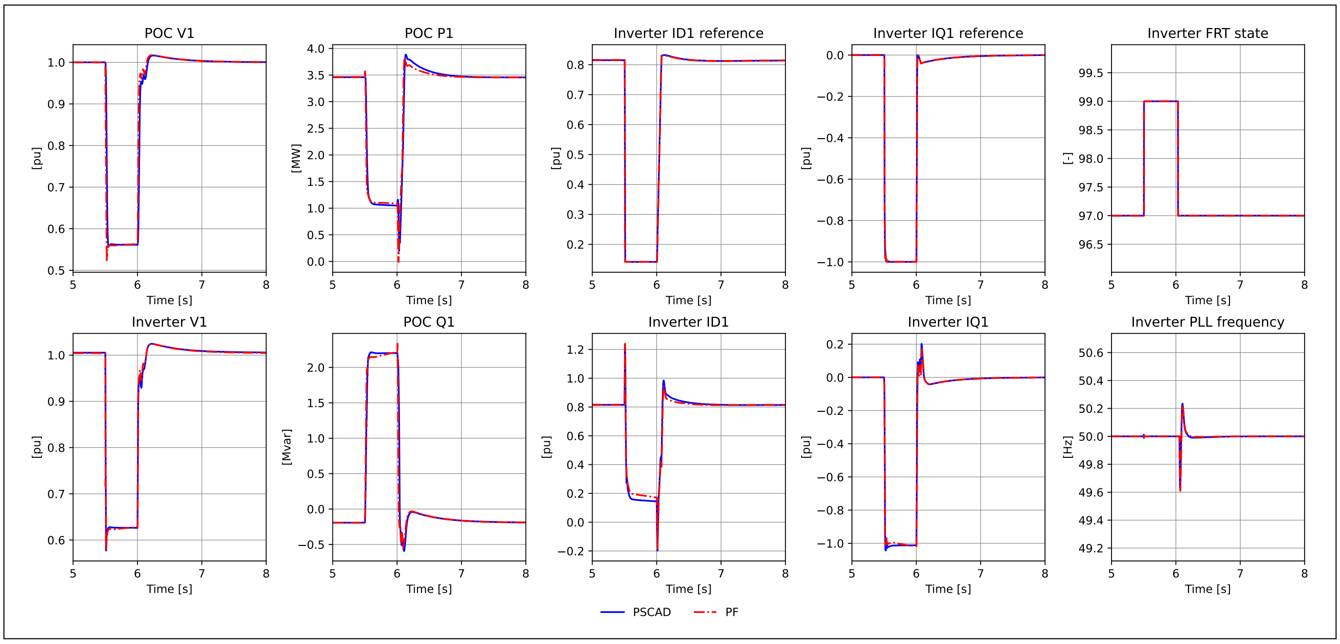

Figure B.1.9: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.4 pu

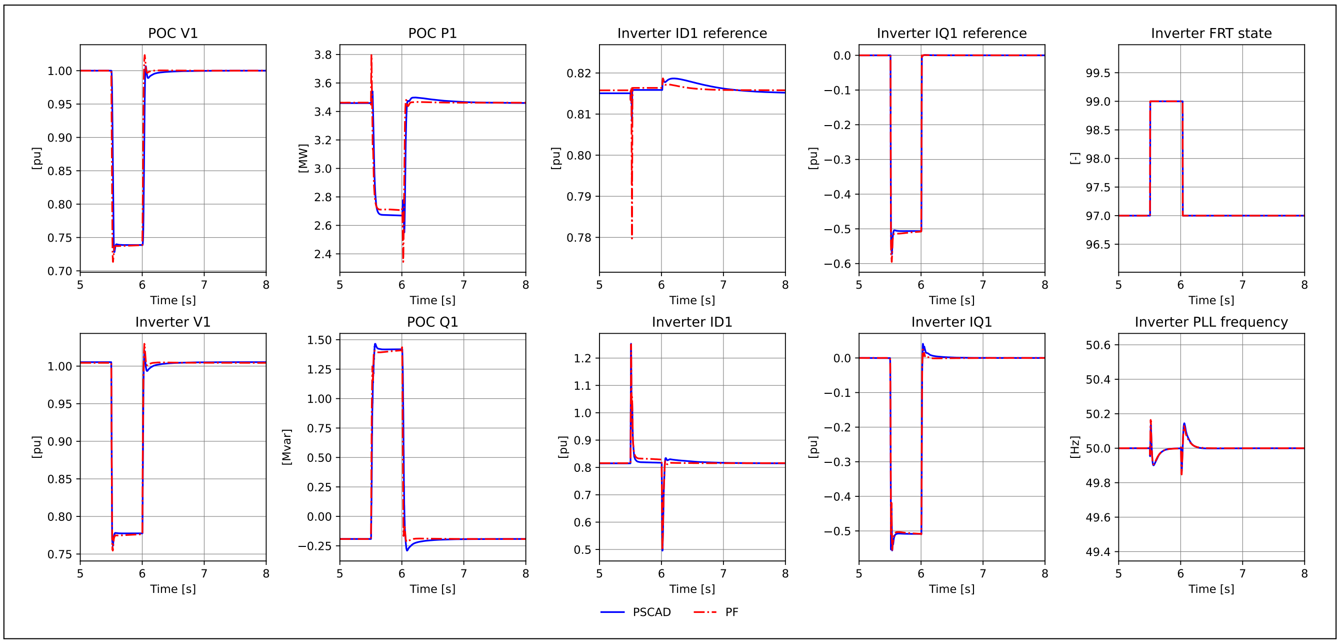

Figure B.1.10: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.6 pu

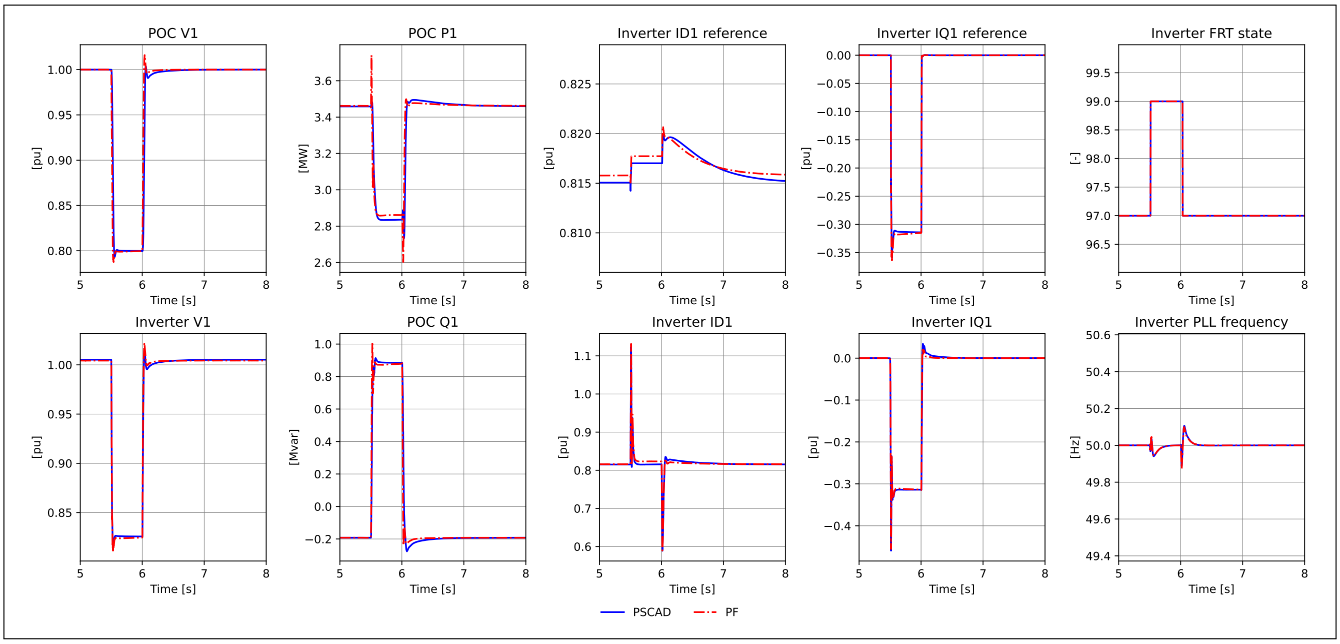

Figure B.1.11: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.7 pu

B.1 Single inverter model simulations

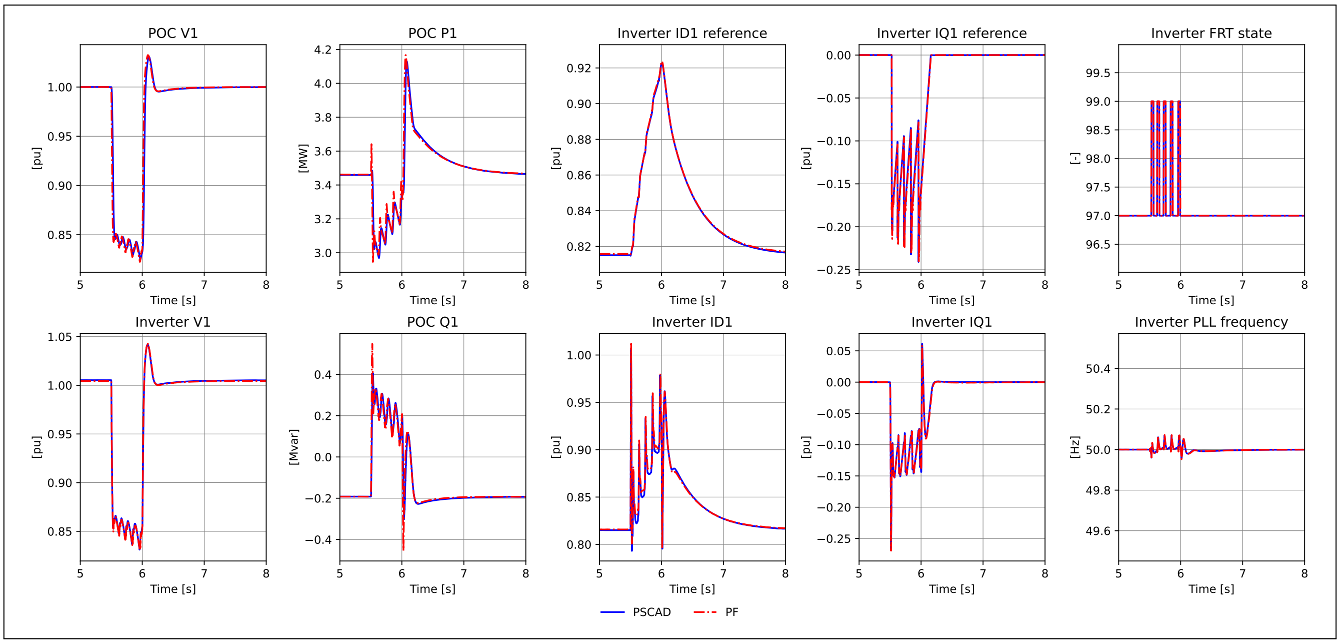

Figure B.1.12: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.8 pu

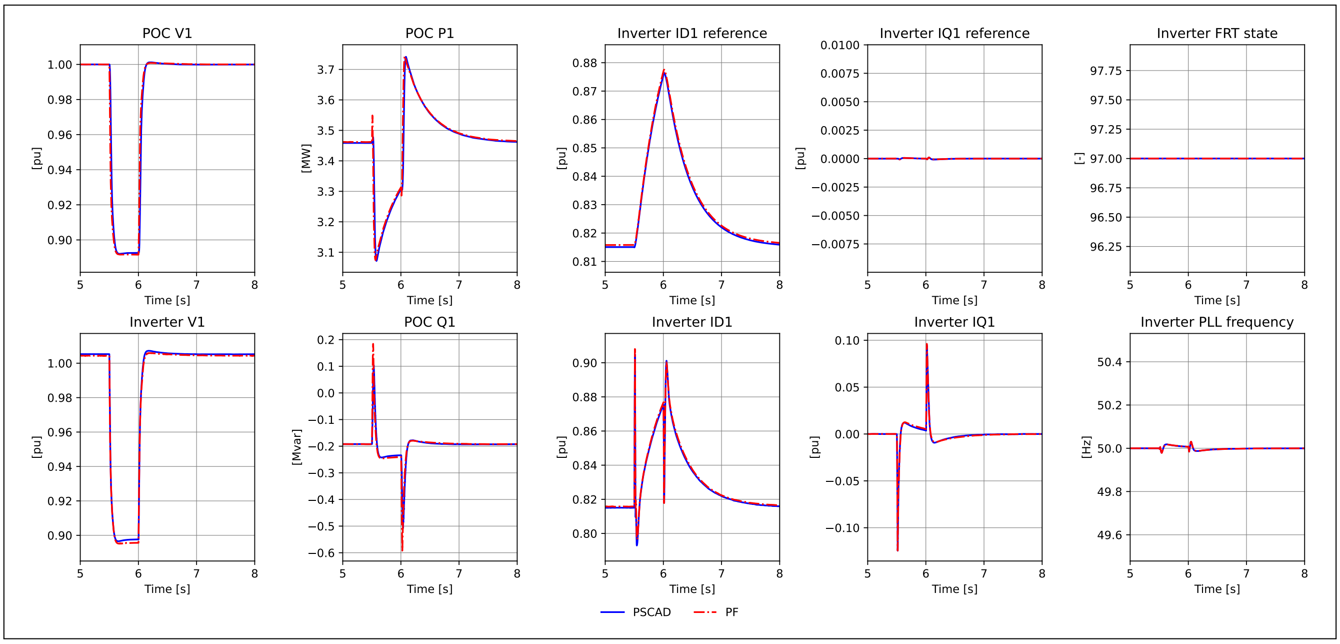

Figure B.1.13: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.9 pu

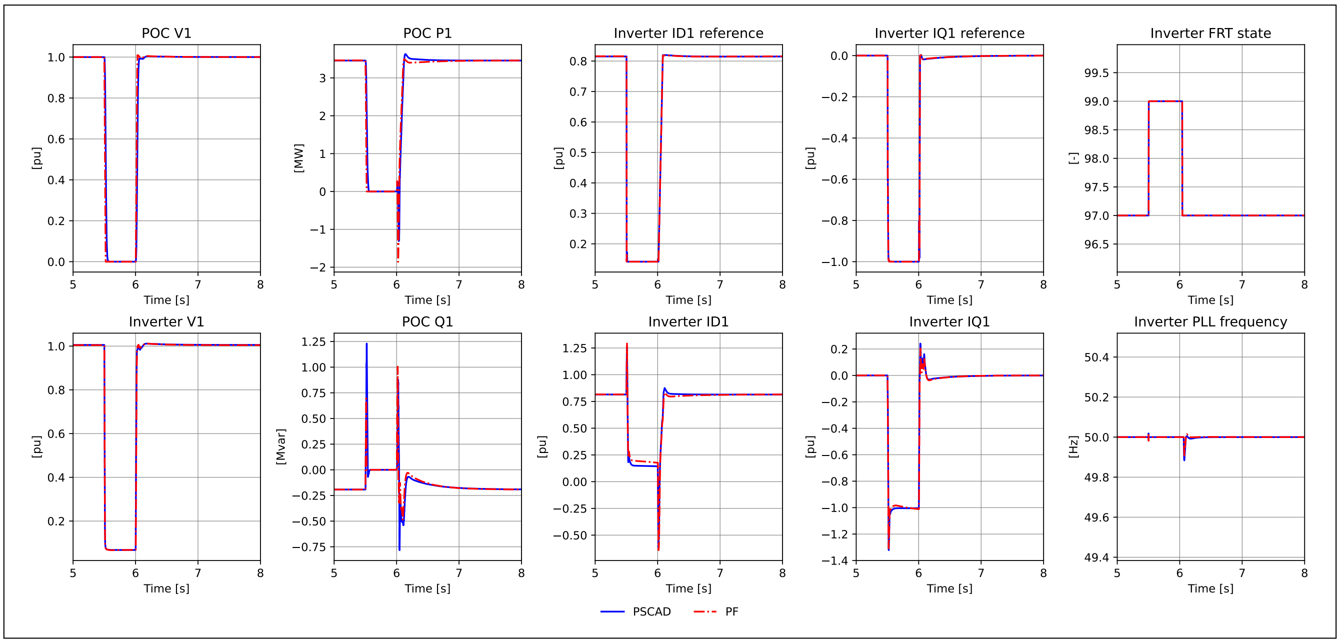

Figure B.1.14: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault 3L, v=0.0 pu

B.1 Single inverter model simulations

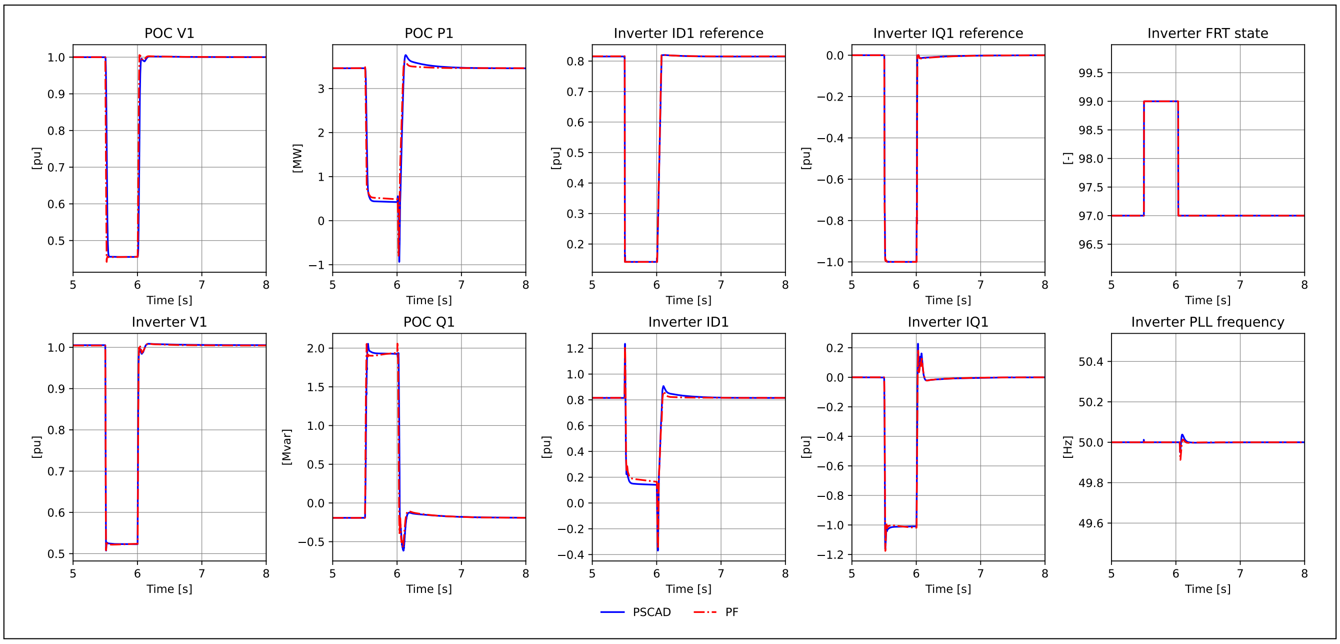

Figure B.1.15: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault 3L, v=0.4 pu

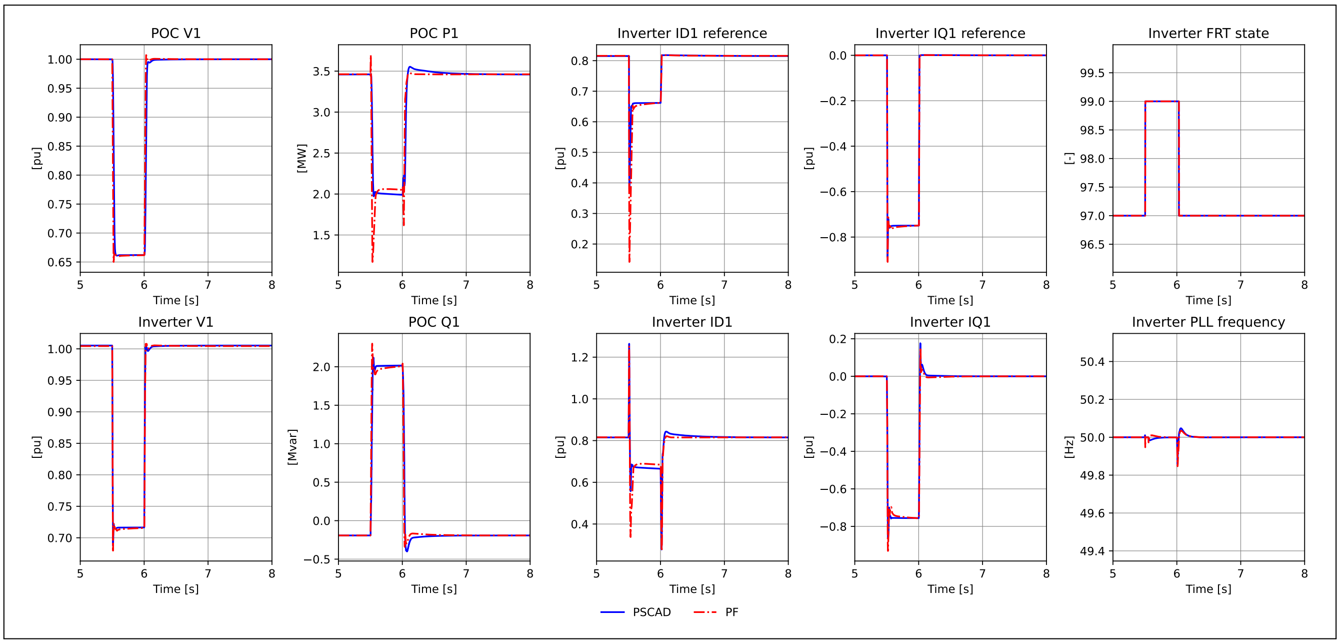

Figure B.1.16: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault 3L, v=0.6 pu

B.1 Single inverter model simulations

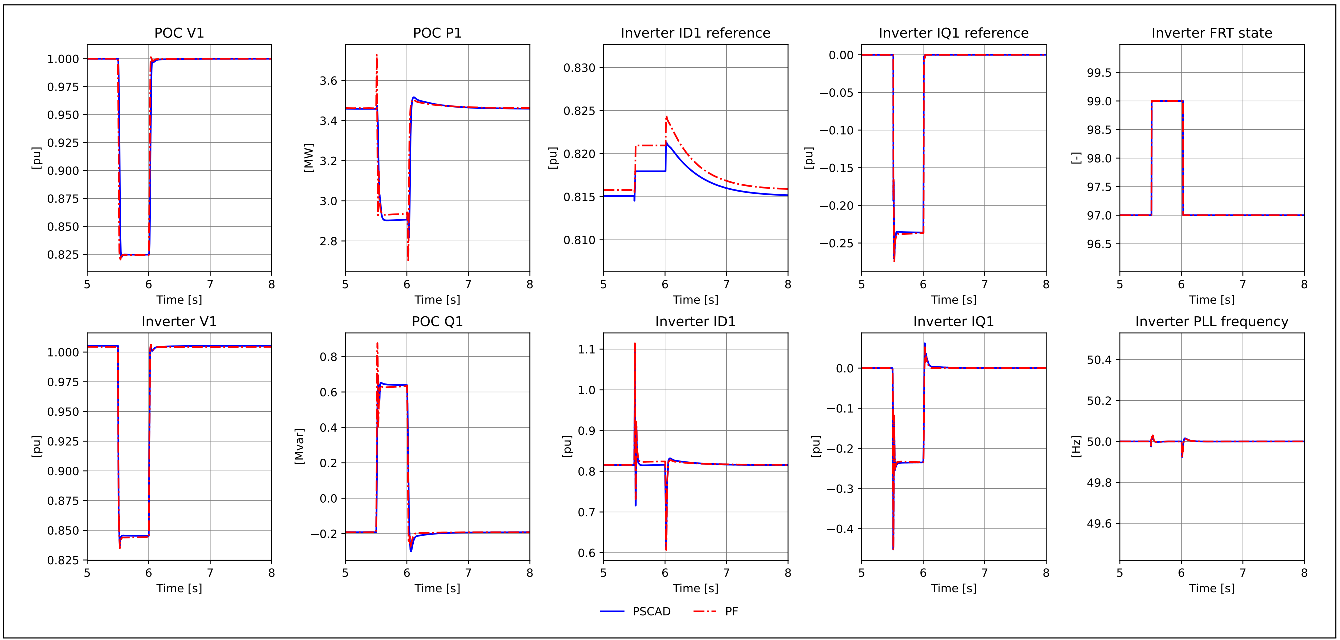

Figure B.1.17: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault 3L, v=0.8 pu

B.1.2.2 Fault 2LG

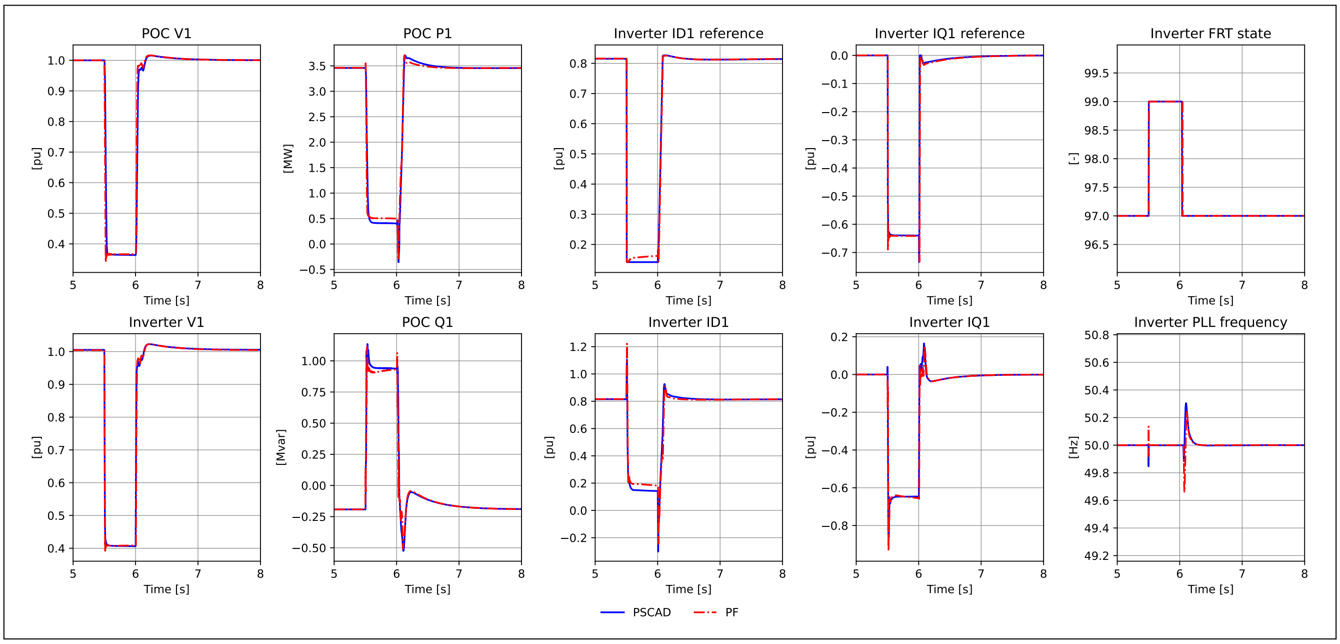

Figure B.1.18: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.0 pu

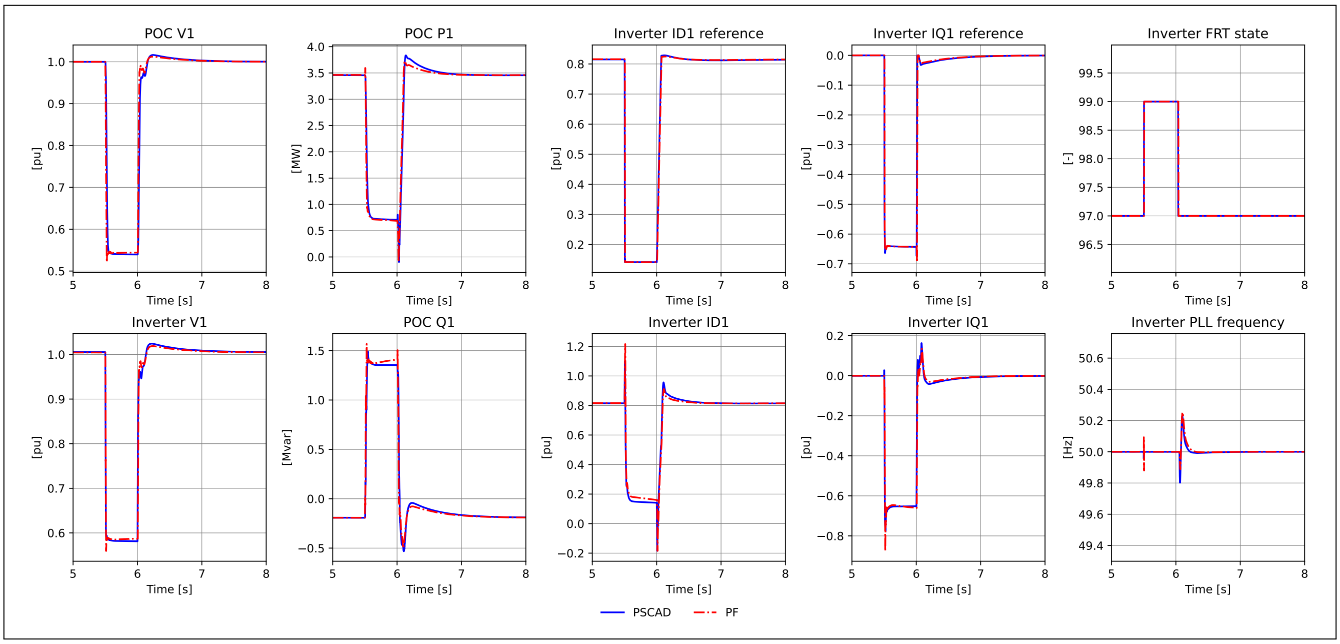

Figure B.1.19: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.2 pu

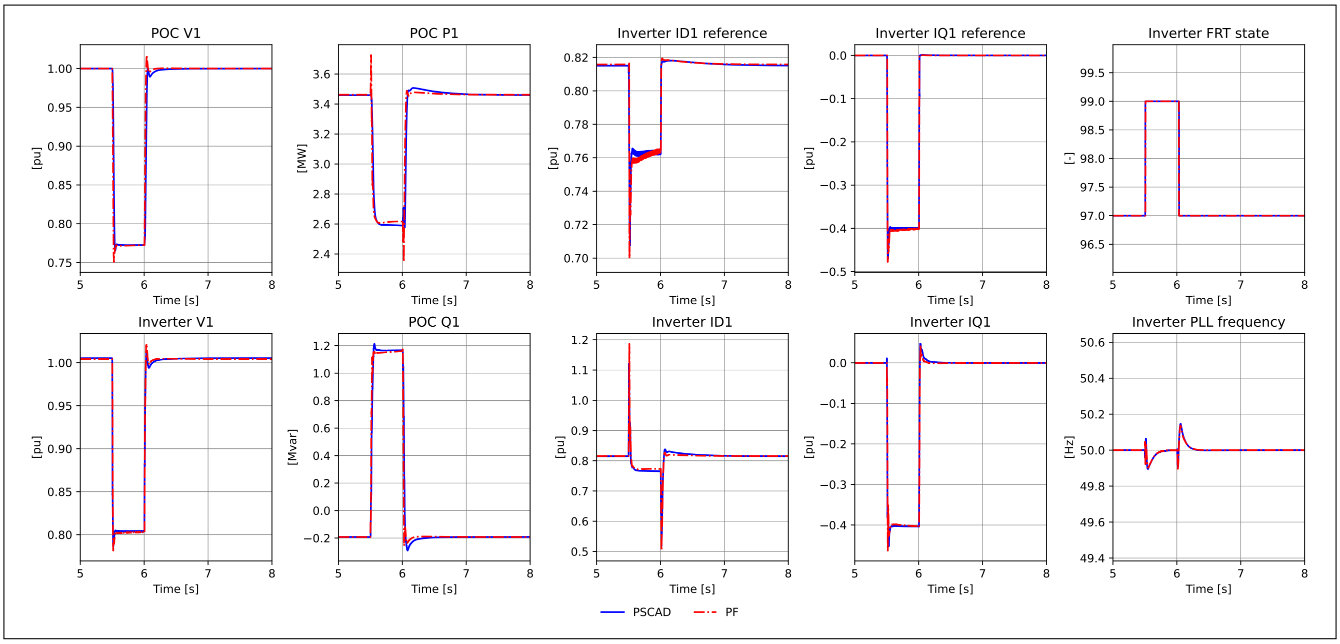

Figure B.1.20: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.5 pu

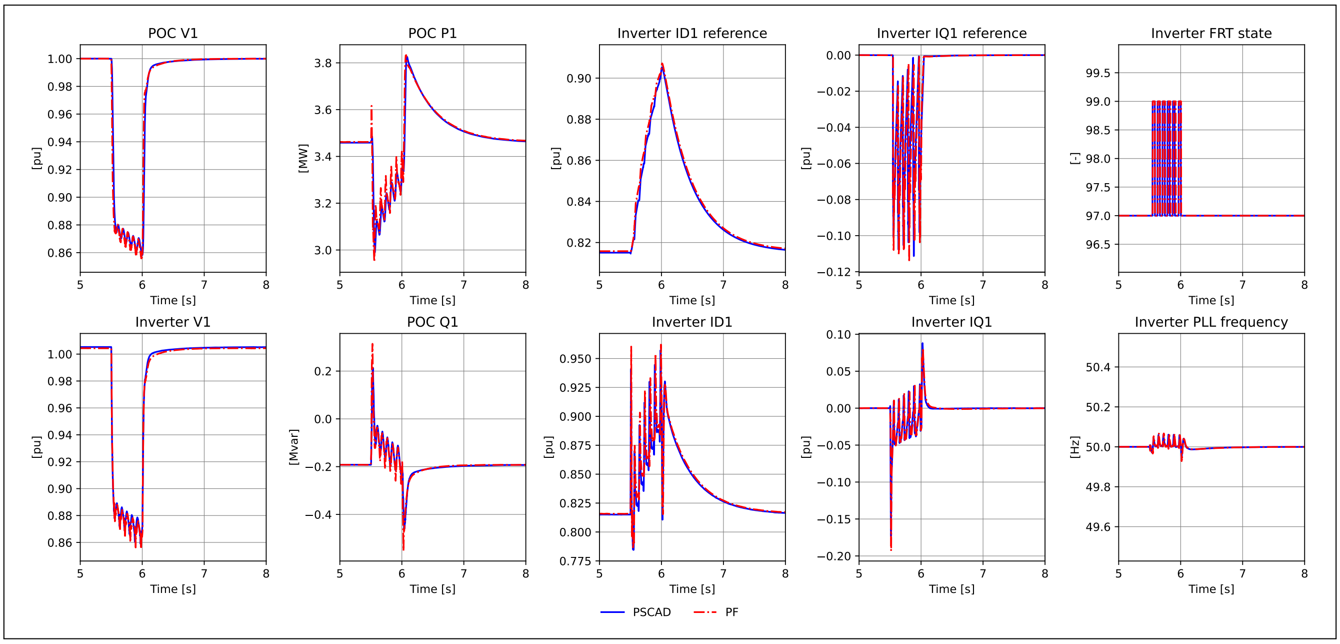

Figure B.1.21: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.8 pu

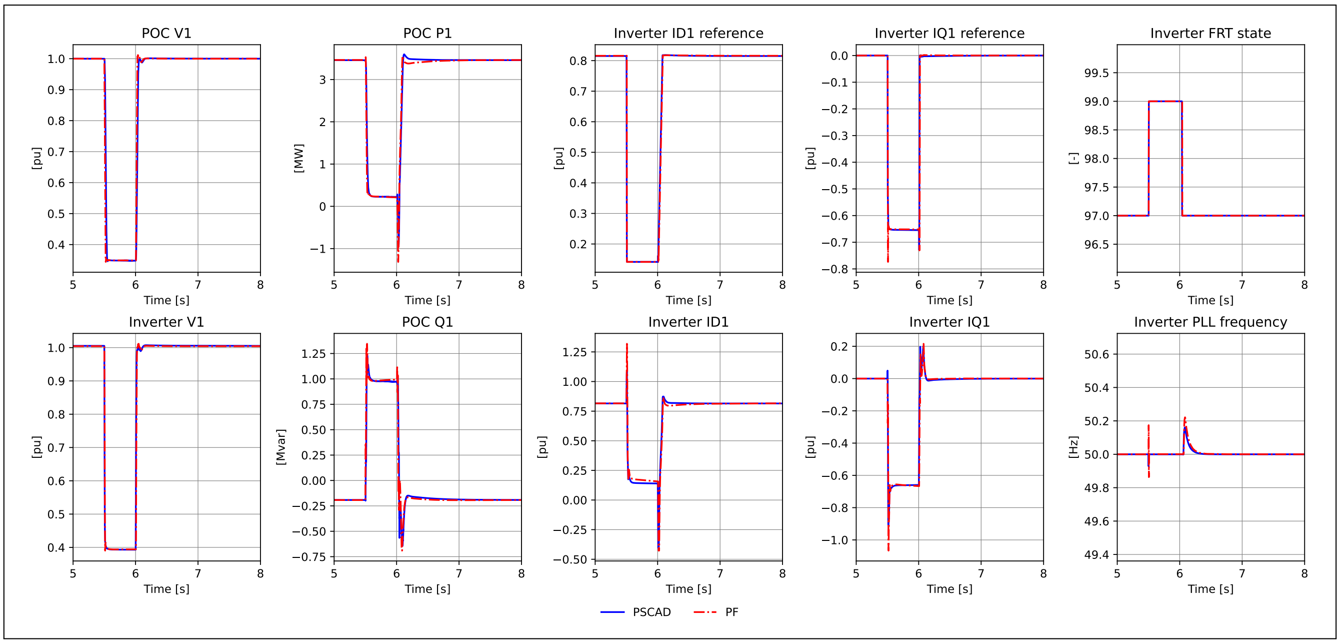

Figure B.1.22: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault 2LG, v=0.0 pu

B.1.2.3 Fault LG

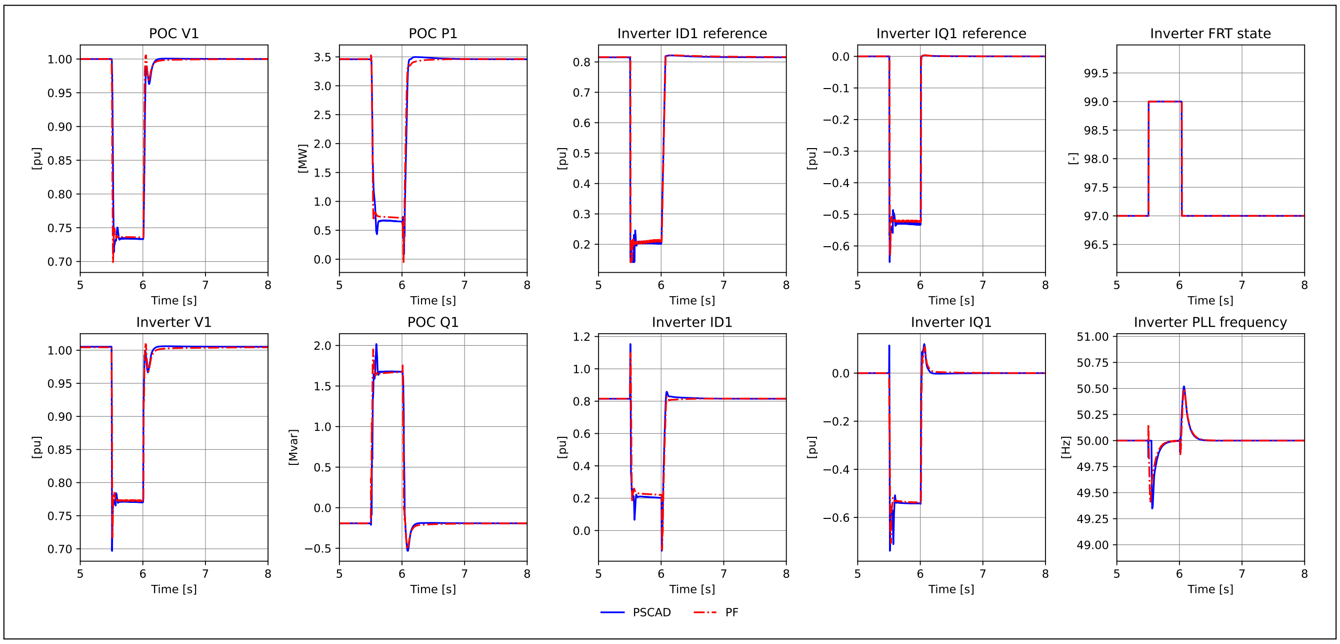

Figure B.1.23: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.0 pu

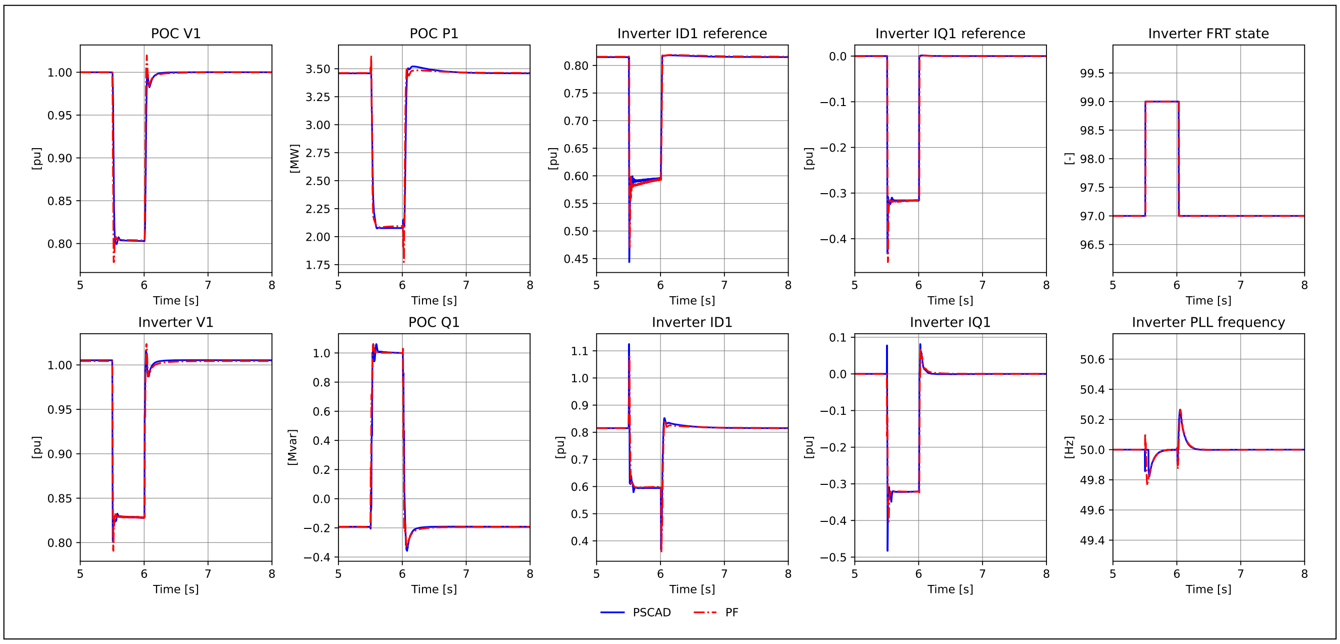

Figure B.1.24: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.2 pu

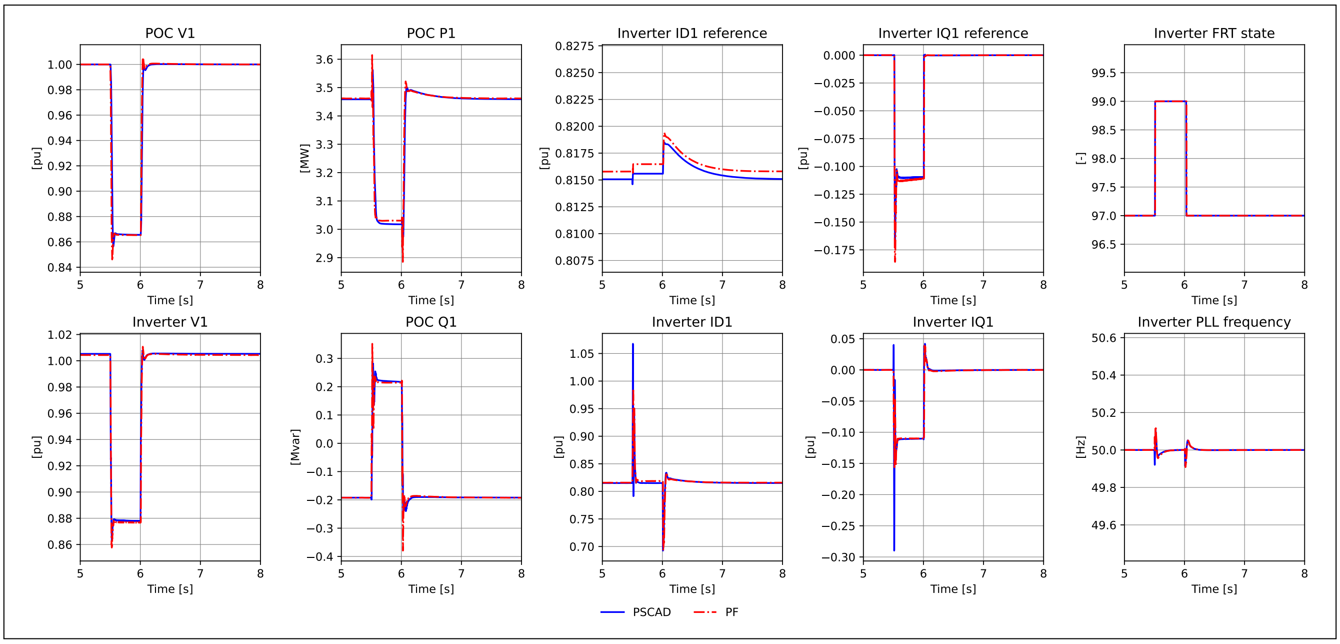

Figure B.1.25: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.5 pu

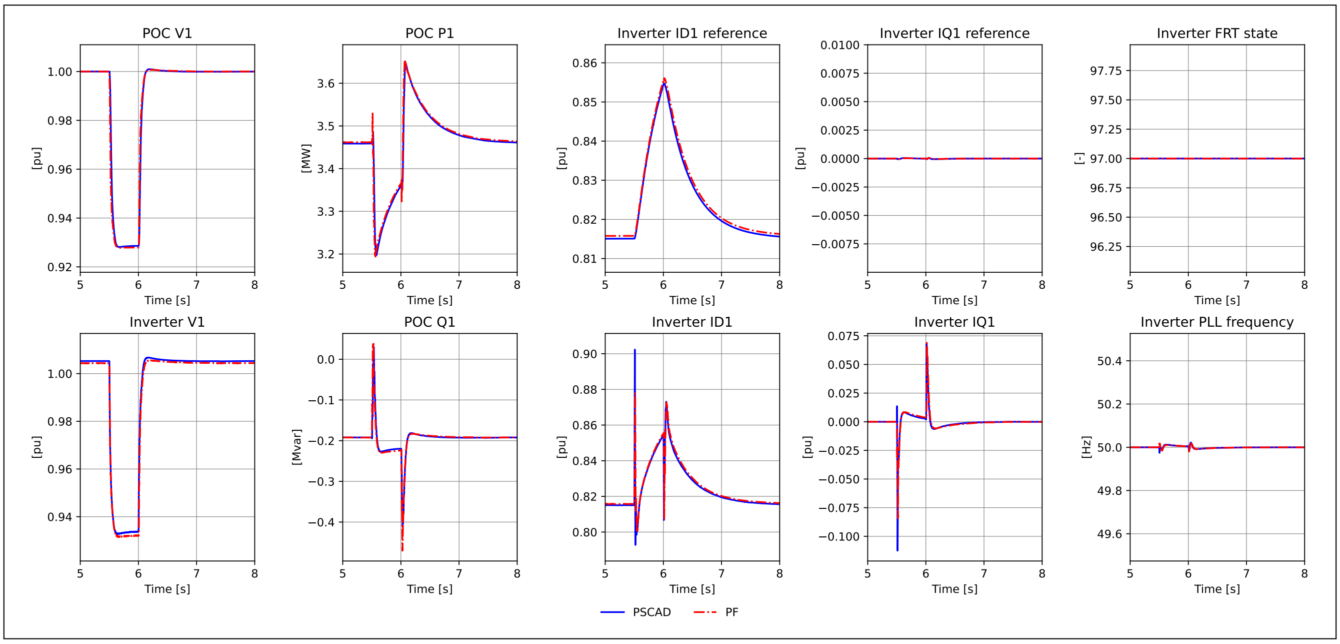

Figure B.1.26: Single inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.8 pu

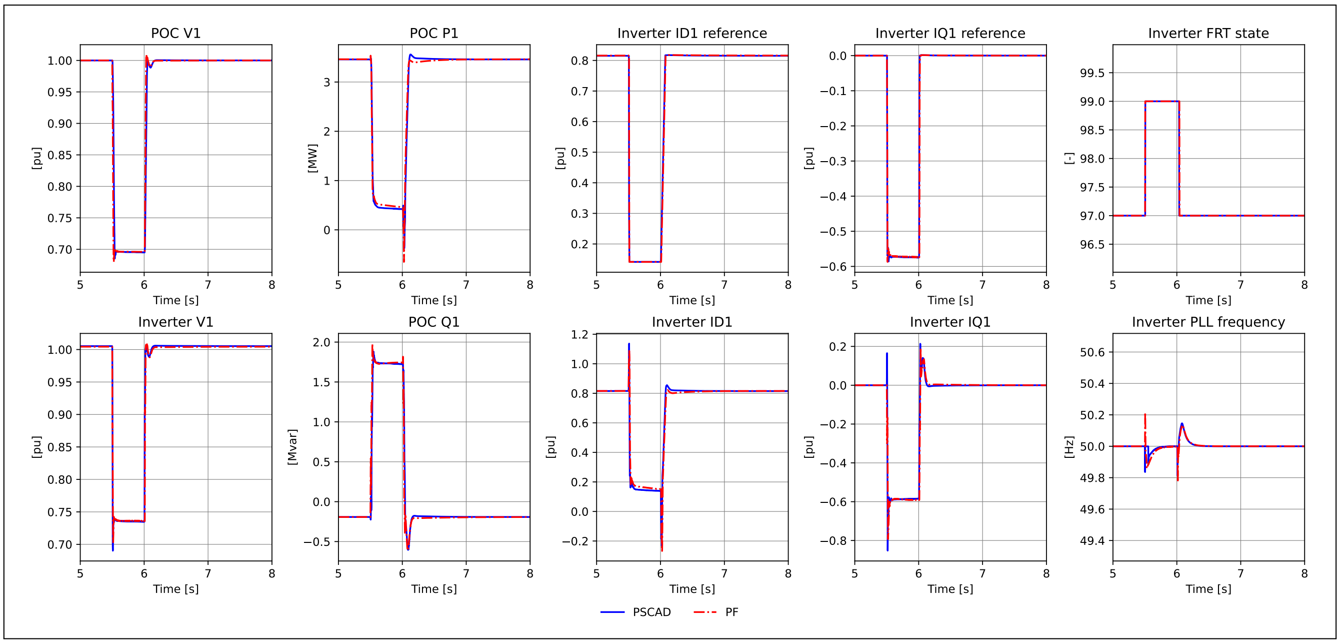

Figure B.1.27: Single inverter model test, SCR=7.5, P=0.83, Q=0, Fault LG, v=0.0 pu

B.1.3 Grid disturbance tests

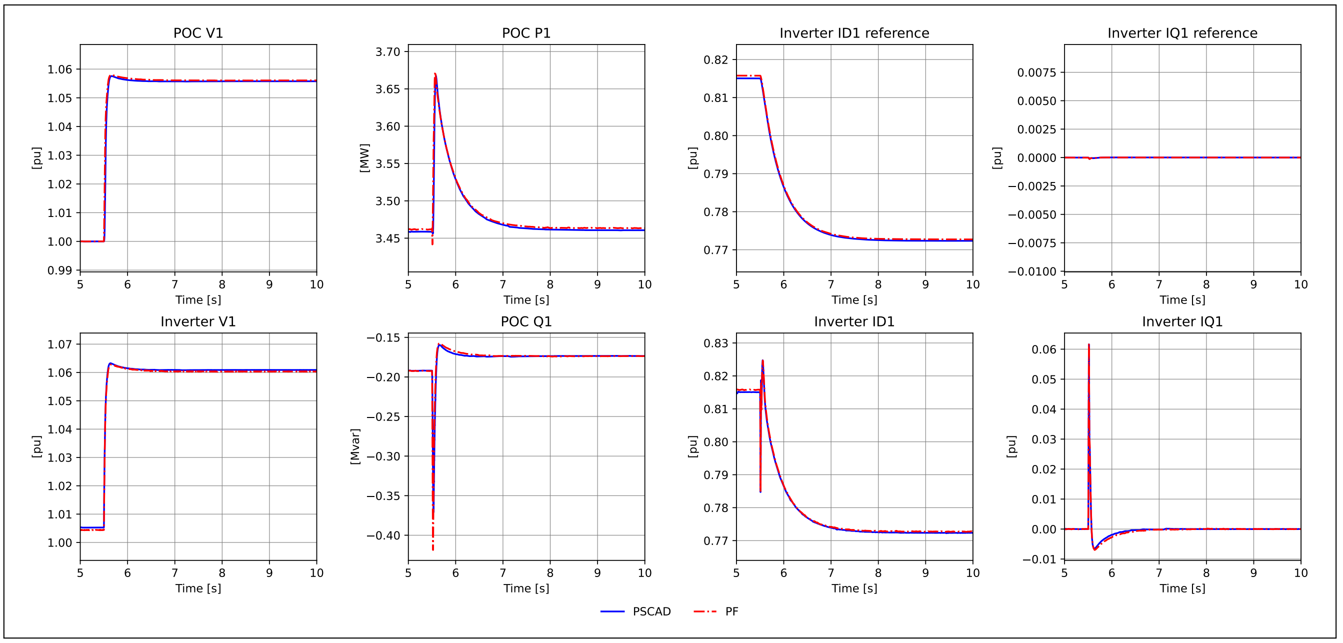

Figure B.1.28: Single inverter model test, SCR=2.3, P=0.83, Q=0, Vmag dist, $\triangle$vmag=+0.05 pu

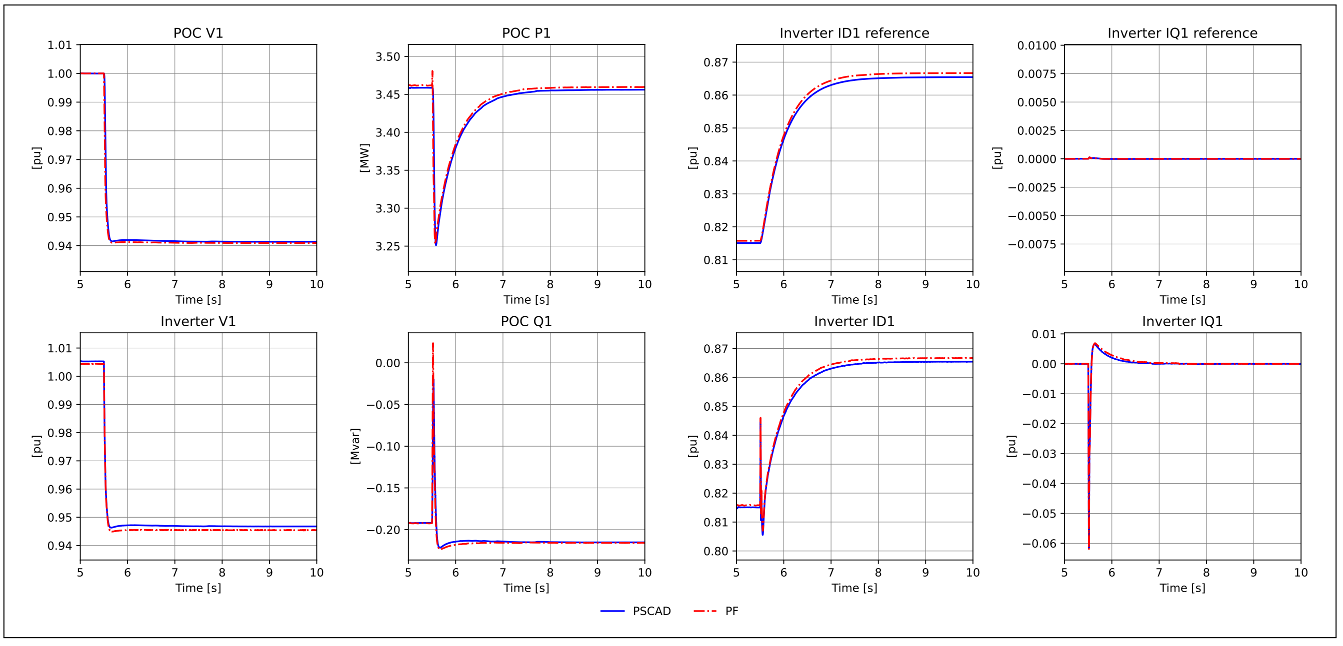

Figure B.1.29: Single inverter model test, SCR=2.3, P=0.83, Q=0, Vmag dist, $\triangle$vmag=-0.05 pu

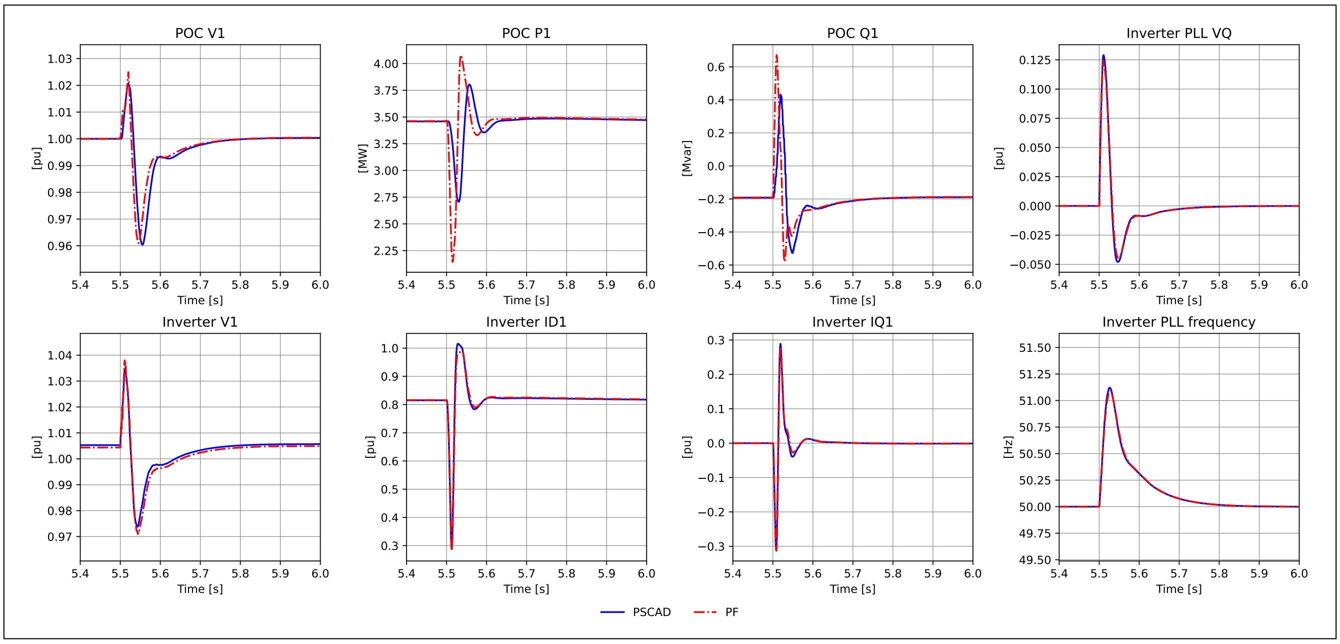

Figure B.1.30: Single inverter model test, SCR=2.3, P=0.83, Q=0, Vphs dist, △vphs=+30 deg

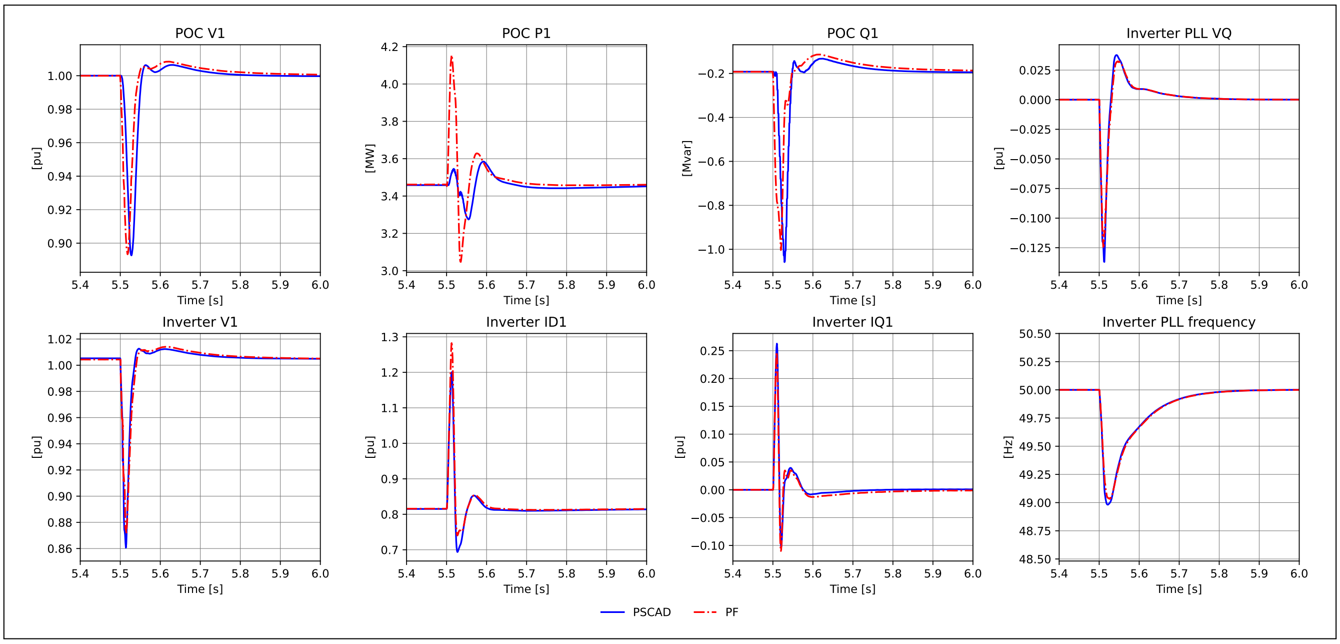

Figure B.1.31: Single inverter model test, SCR=2.3, P=0.83, Q=0, Vphs dist, △vphs=-30 deg

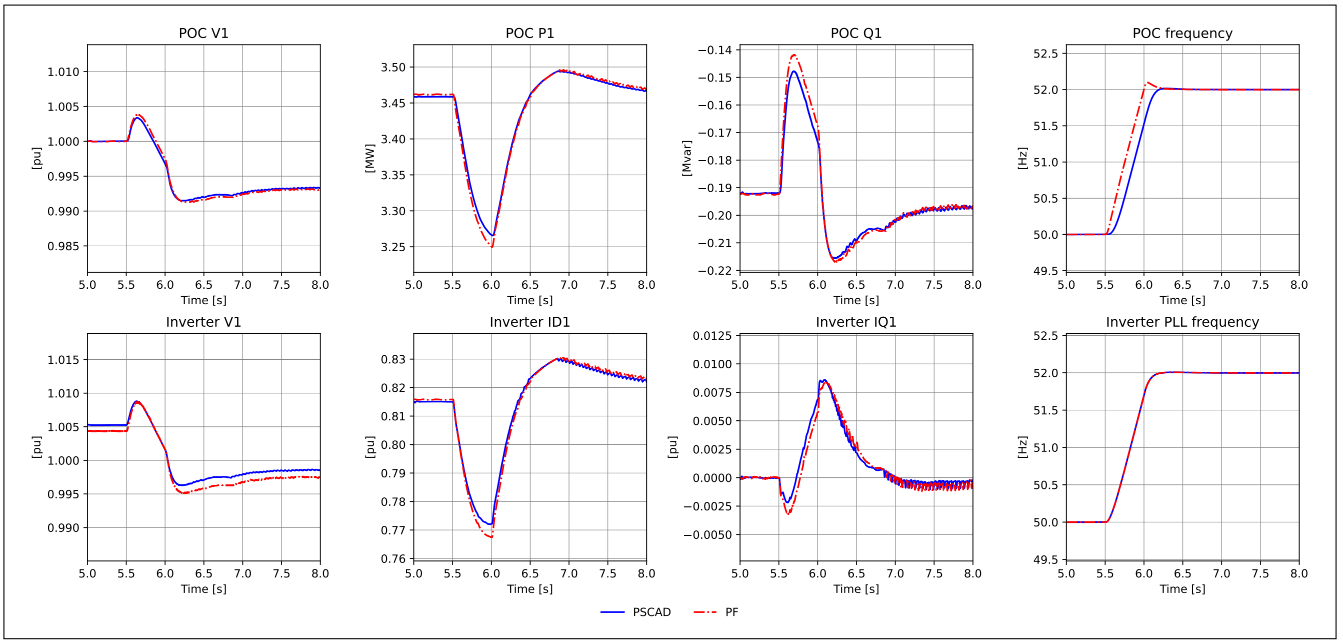

Figure B.1.32: Single inverter model test, SCR=2.3, P=0.83, Q=0, Freq dist, △freq=+2 Hz

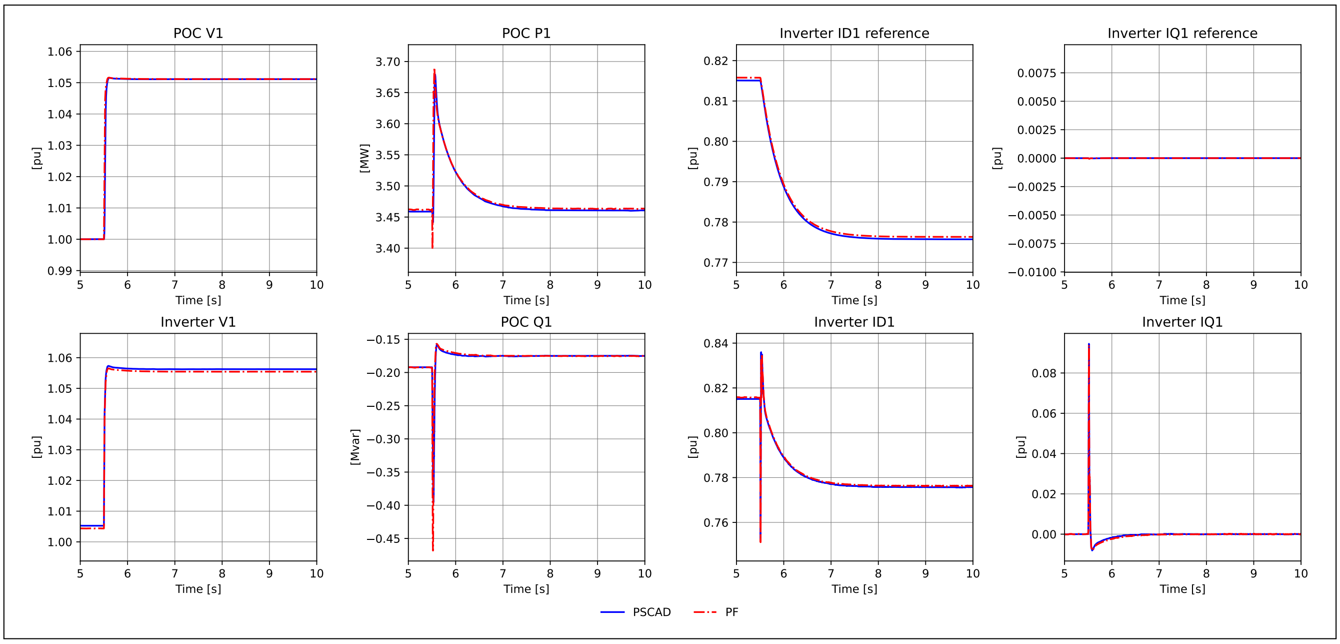

Figure B.1.33: Single inverter model test, SCR=7.5, P=0.83, Q=0, Vmag dist, △vmag=+0.05 pu

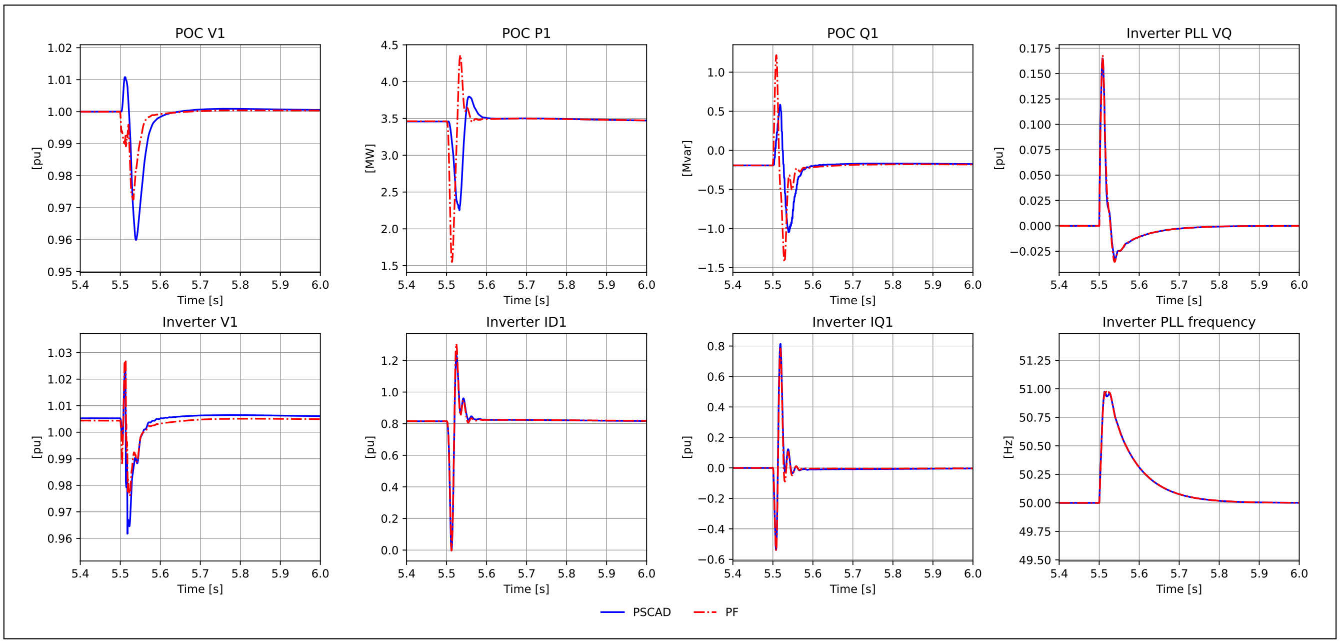

Figure B.1.34: Single inverter model test, SCR=7.5, P=0.83, Q=0, Vphs dist, △vphs=+30 deg

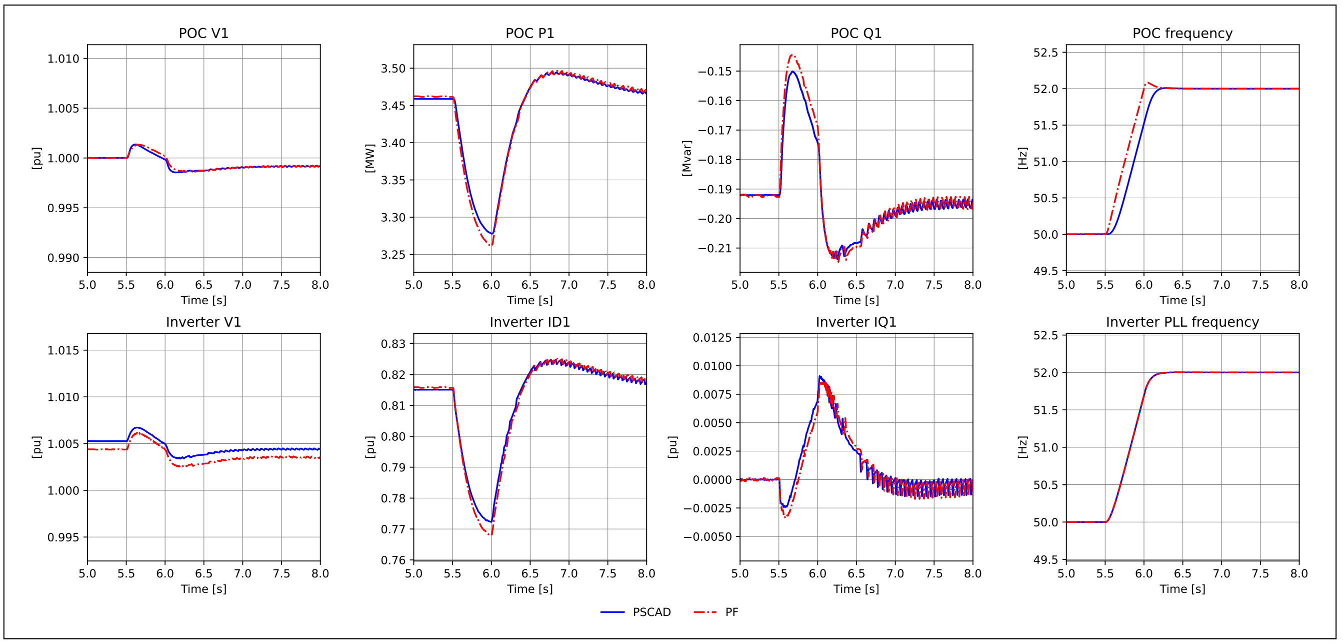

Figure B.1.35: Single inverter model test, SCR=7.5, P=0.83, Q=0, Freq dist, △freq=+2 Hz

B.1.4 Reference step tests

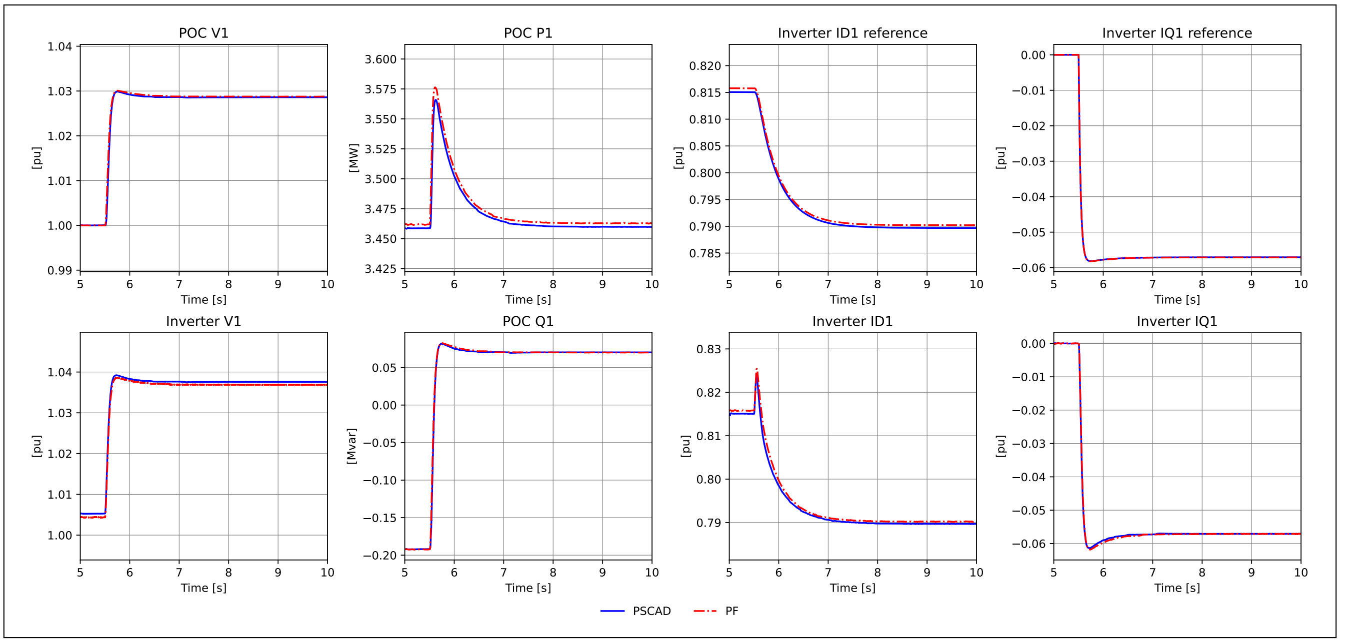

Figure B.1.36: Single inverter model test, SCR=2.3, P=0.83, Q=0, Qref step, △qref=+0.1 pu

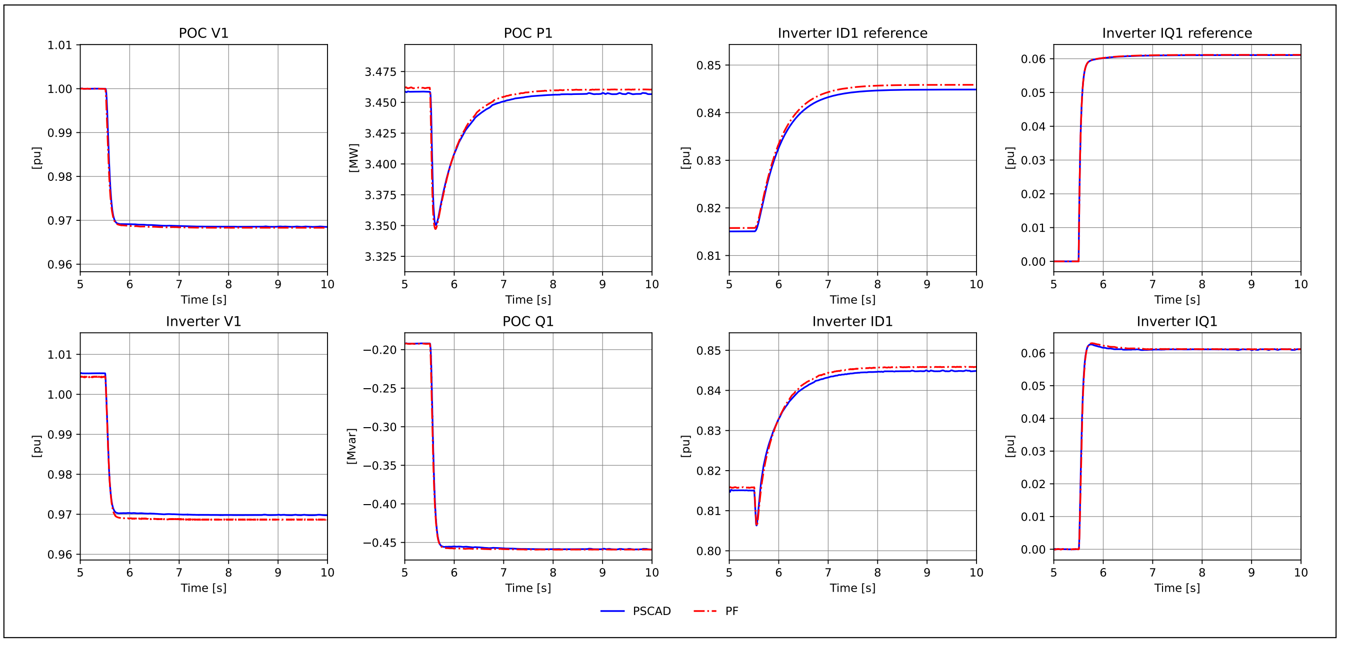

Figure B.1.37: Single inverter model test, SCR=2.3, P=0.83, Q=0, Qref step, △qref=-0.1 pu

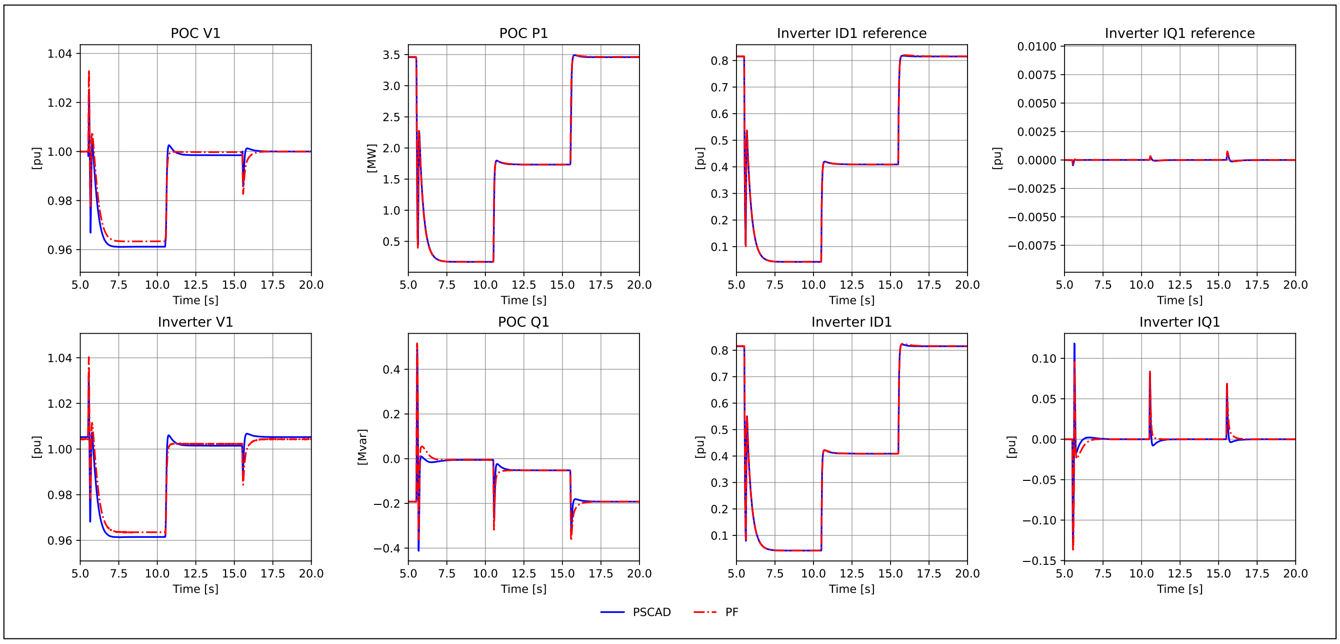

Figure B.1.38: Single inverter model test, SCR=2.3, P=0.83, Q=0, Pref steps, pref = 1.0, 0.05, 0.5, 1.0 pu

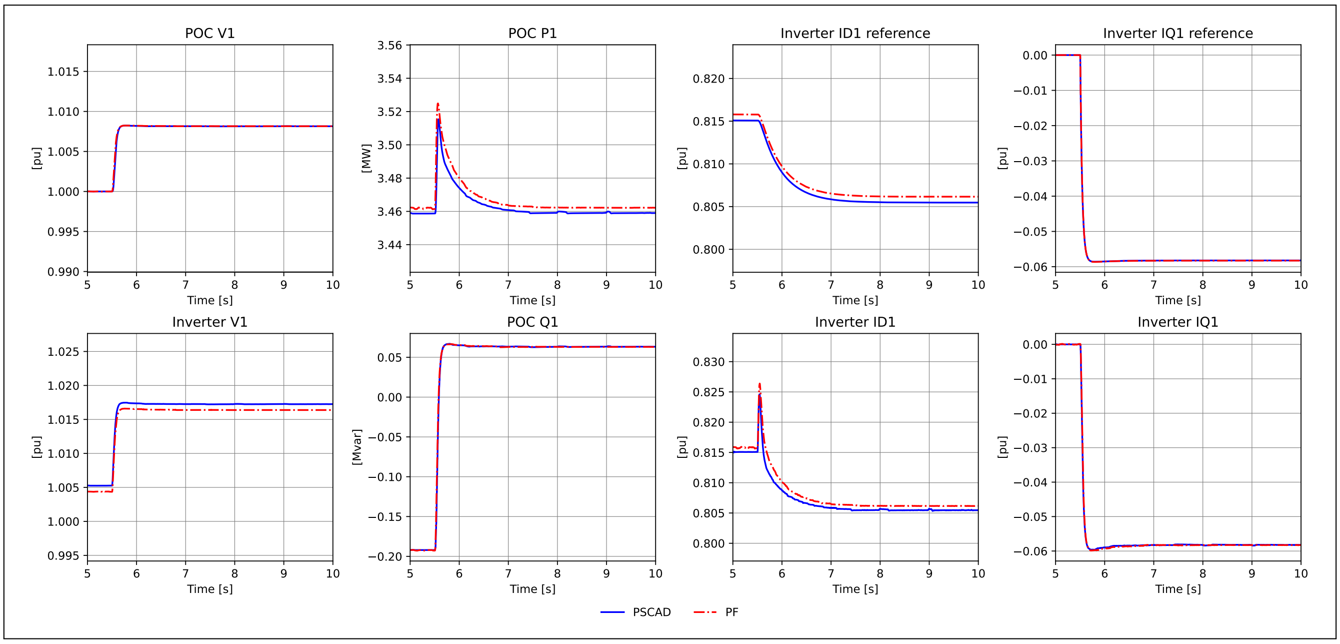

Figure B.1.39: Single inverter model test, SCR=7.5, P=0.83, Q=0, Qref step, Δqref=+0.1 pu

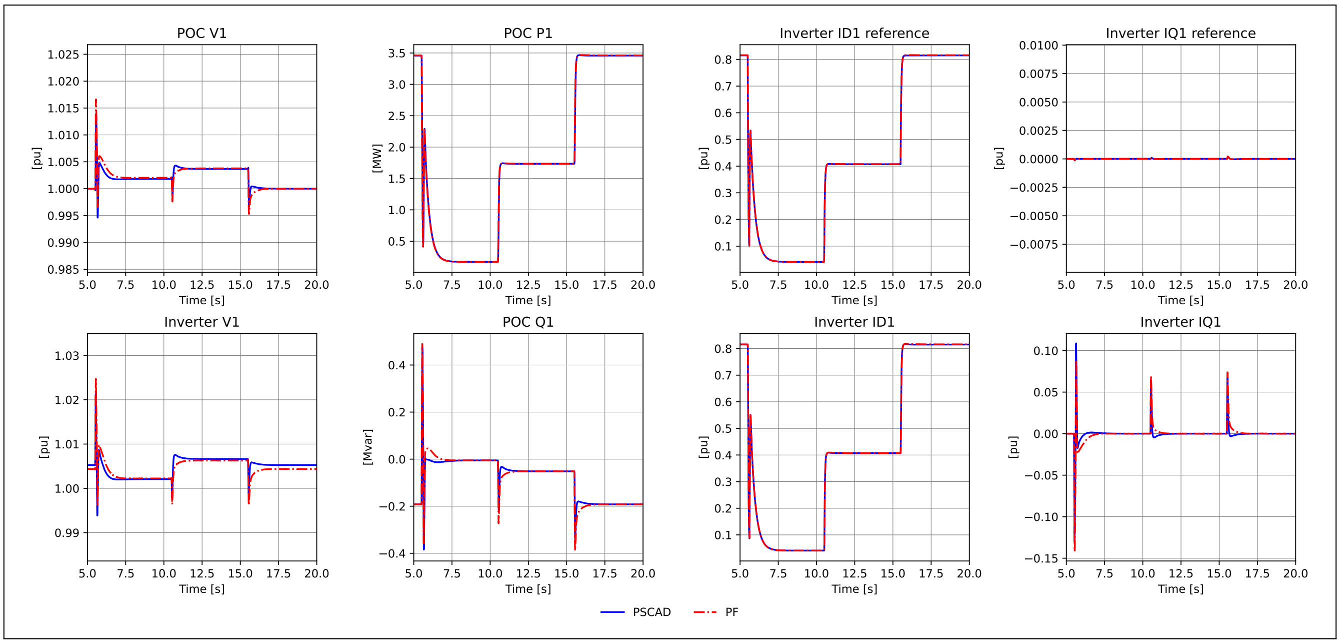

Figure B.1.40: Single inverter model test, SCR=7.5, P=0.83, Q=0, Pref steps, pref = 1.0, 0.05, 0.5, 1.0 pu

B.2 Aggregate inverter model simulations

B.2.1 Flat run tests

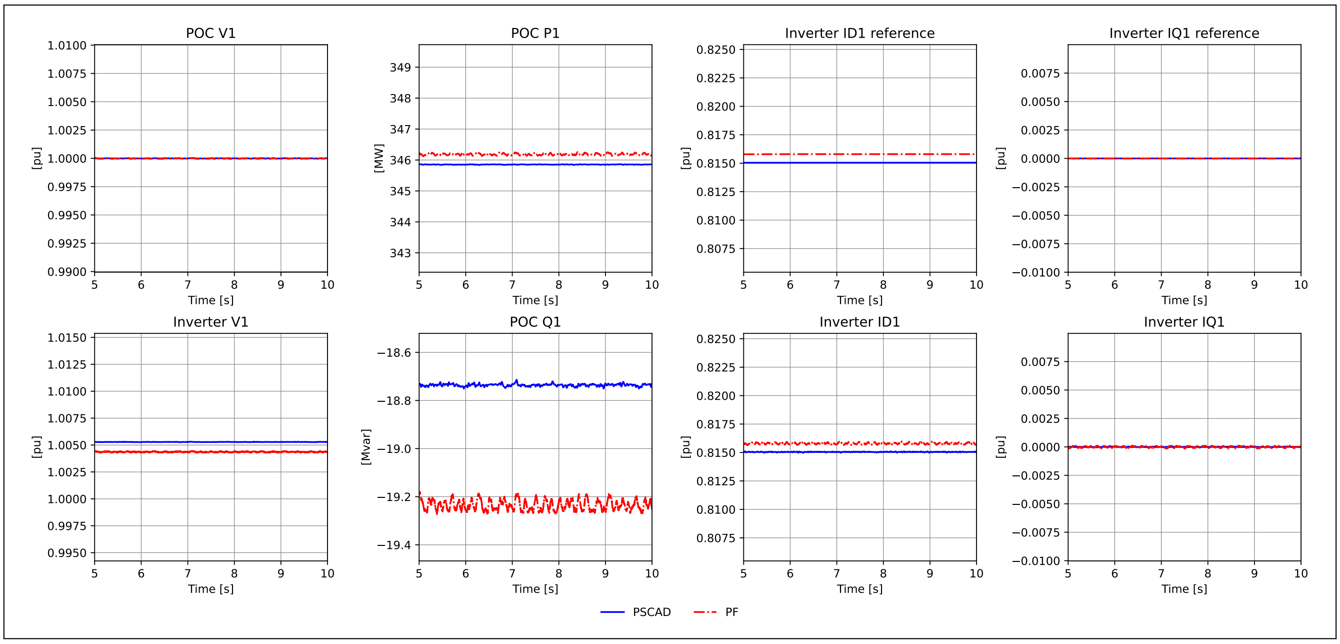

Figure B.2.41: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Flat run

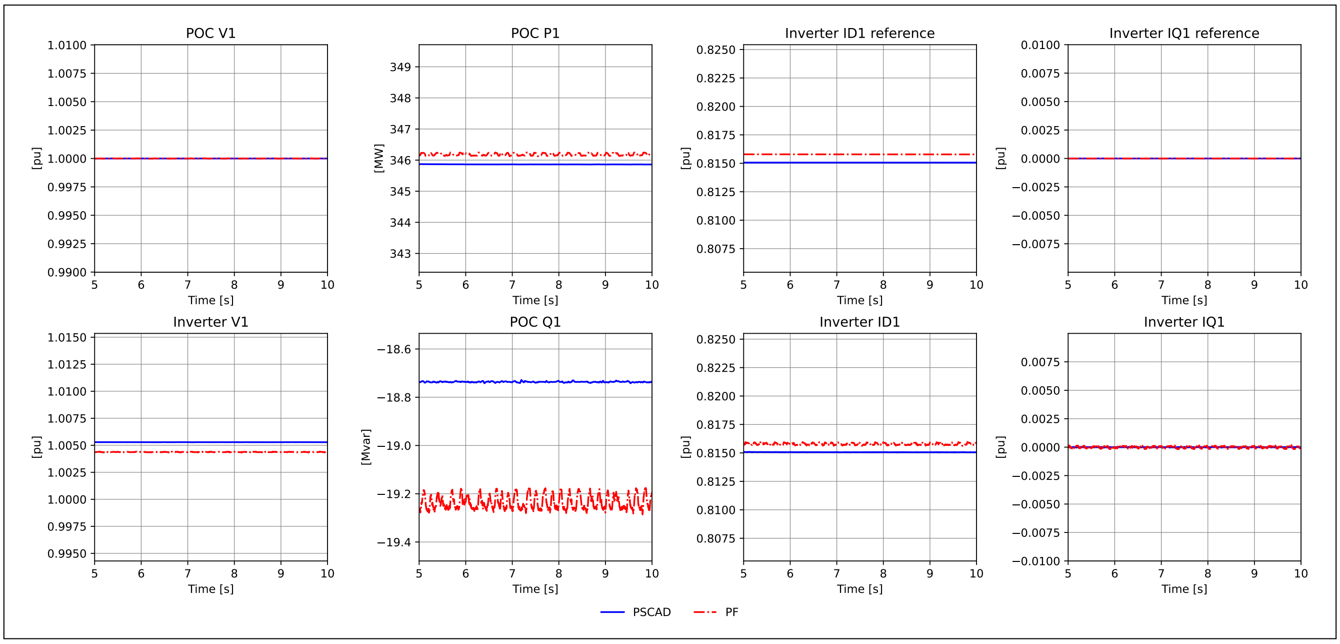

Figure B.2.42: Aggregate inverter model test, SCR=7.5, P=0.83, Q=0, Flat run

B.2.2 Fault tests

B.2.2.1 Fault 3L

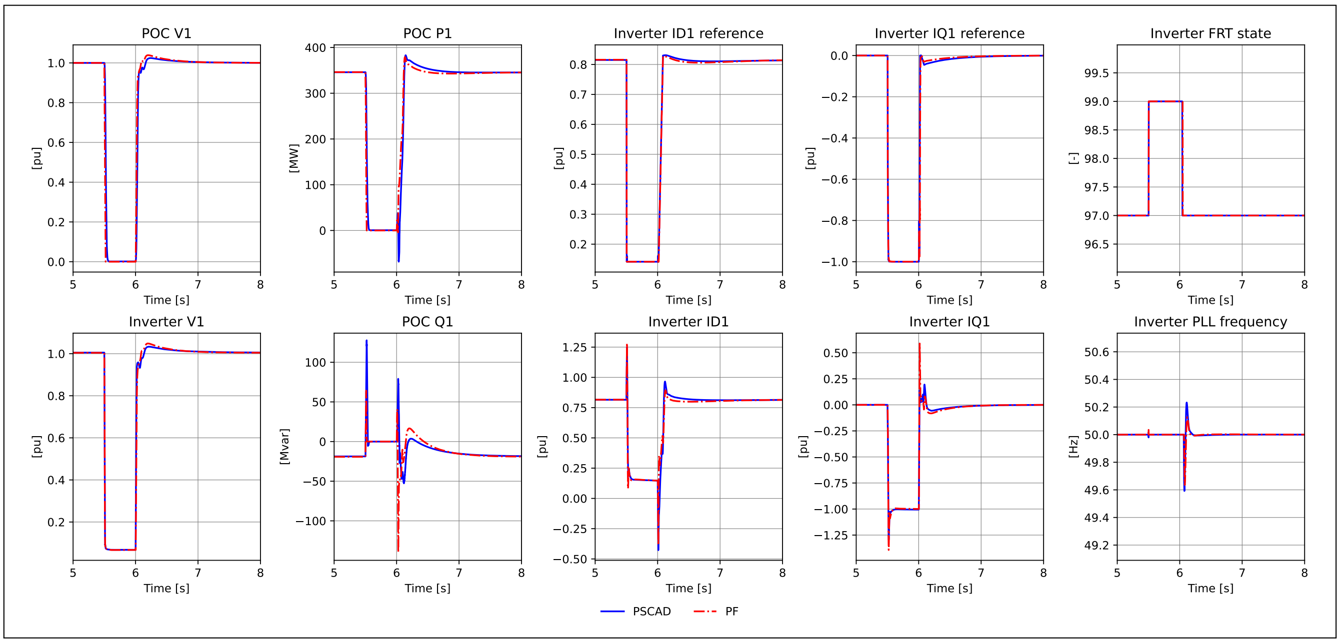

Figure B.2.43: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.0 pu

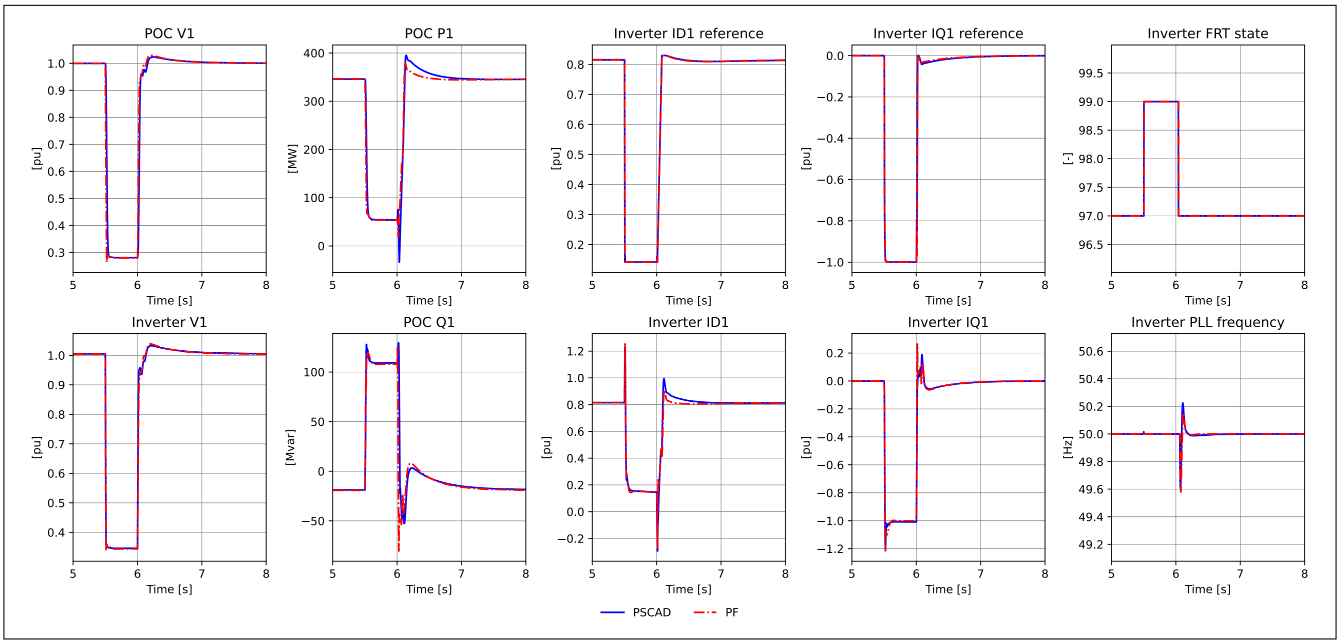

Figure B.2.44: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.2 pu

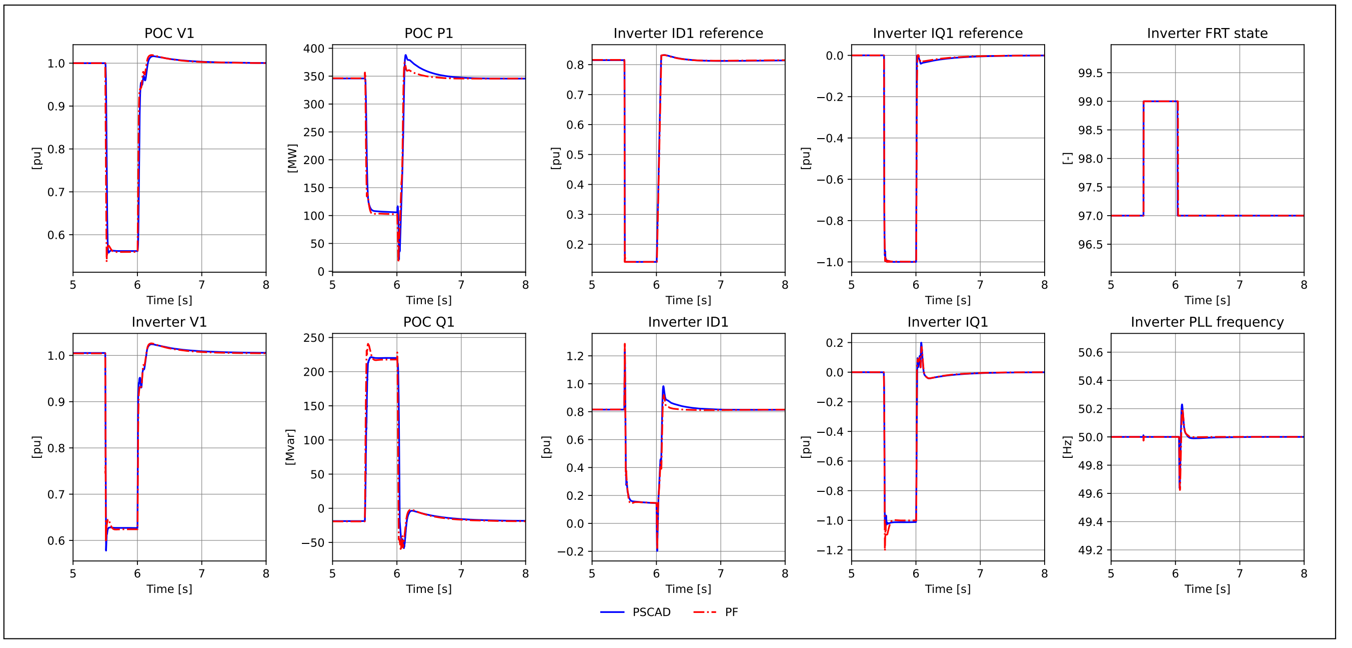

Figure B.2.45: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.4 pu

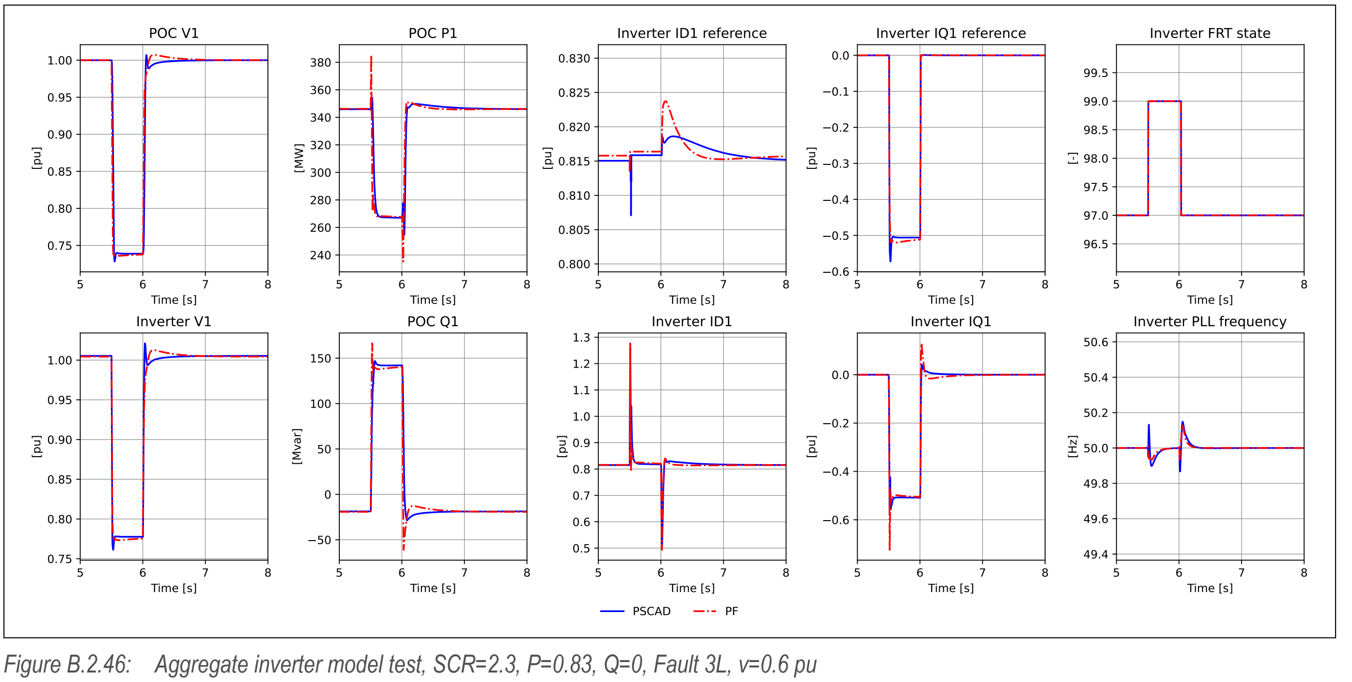

Figure B.2.46: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.6 pu

B.2 Aggregate inverter model simulations

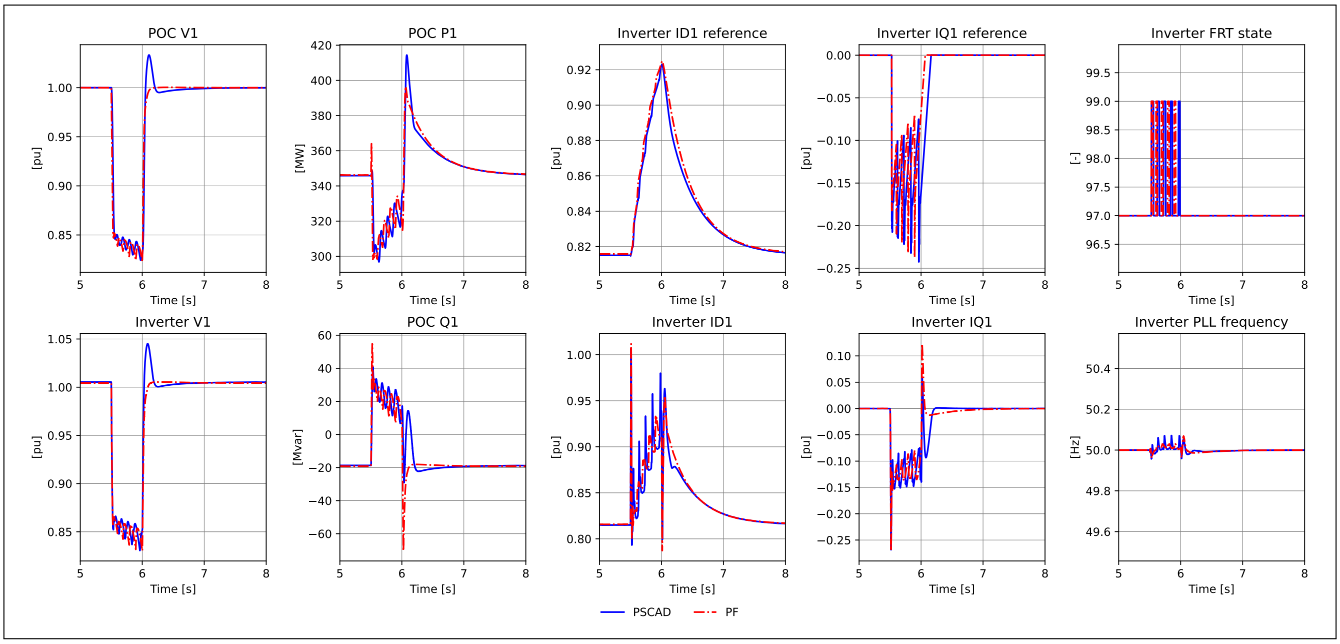

Figure B.2.47: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 3L, v=0.8 pu

B.2.2.2 Fault 2LG

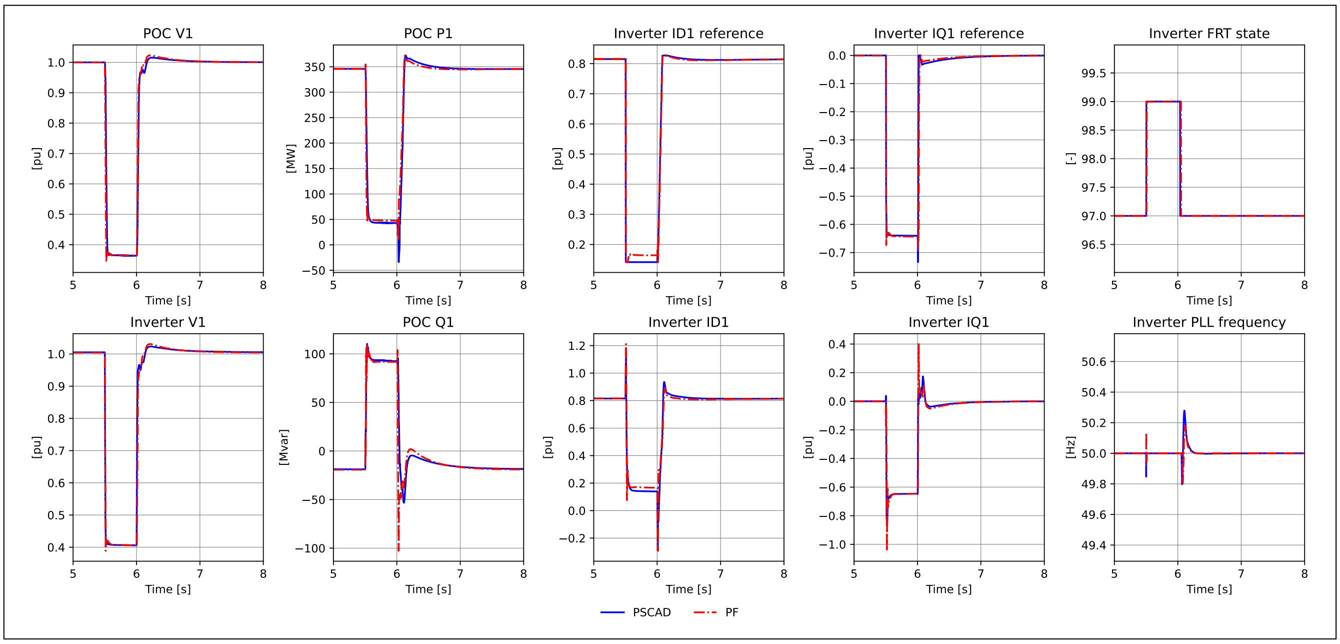

Figure B.2.48: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.0 pu

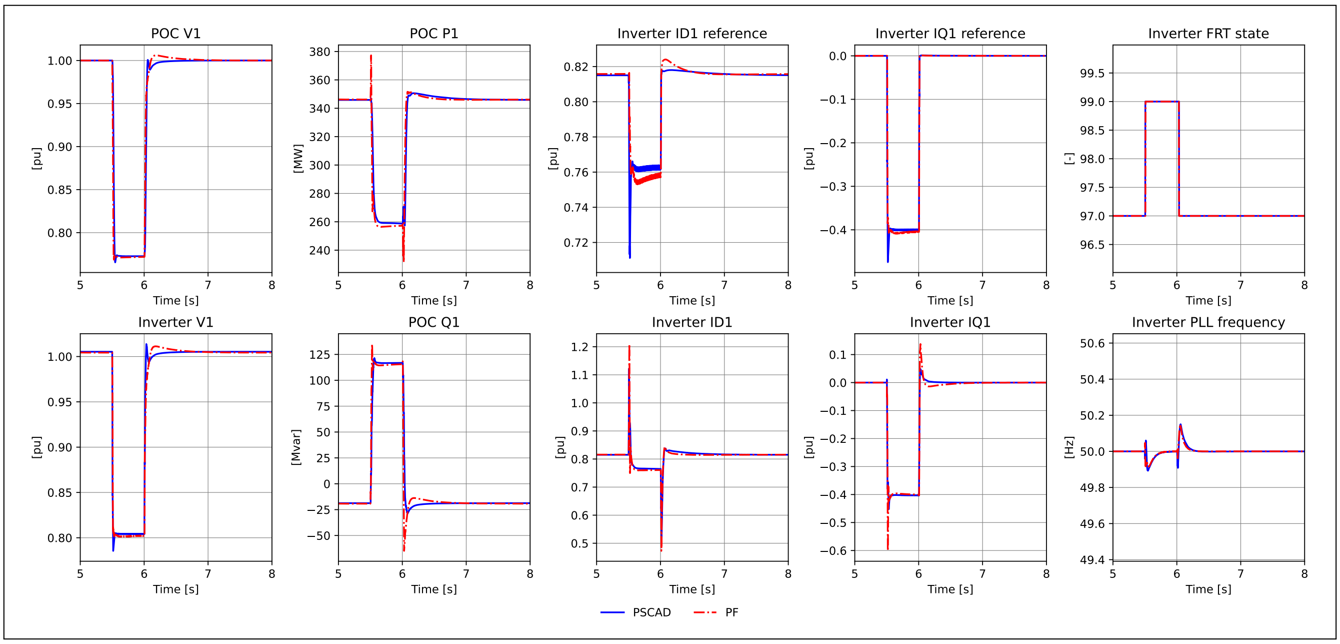

Figure B.2.49: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault 2LG, v=0.5 pu

B.2.2.3 Fault LG

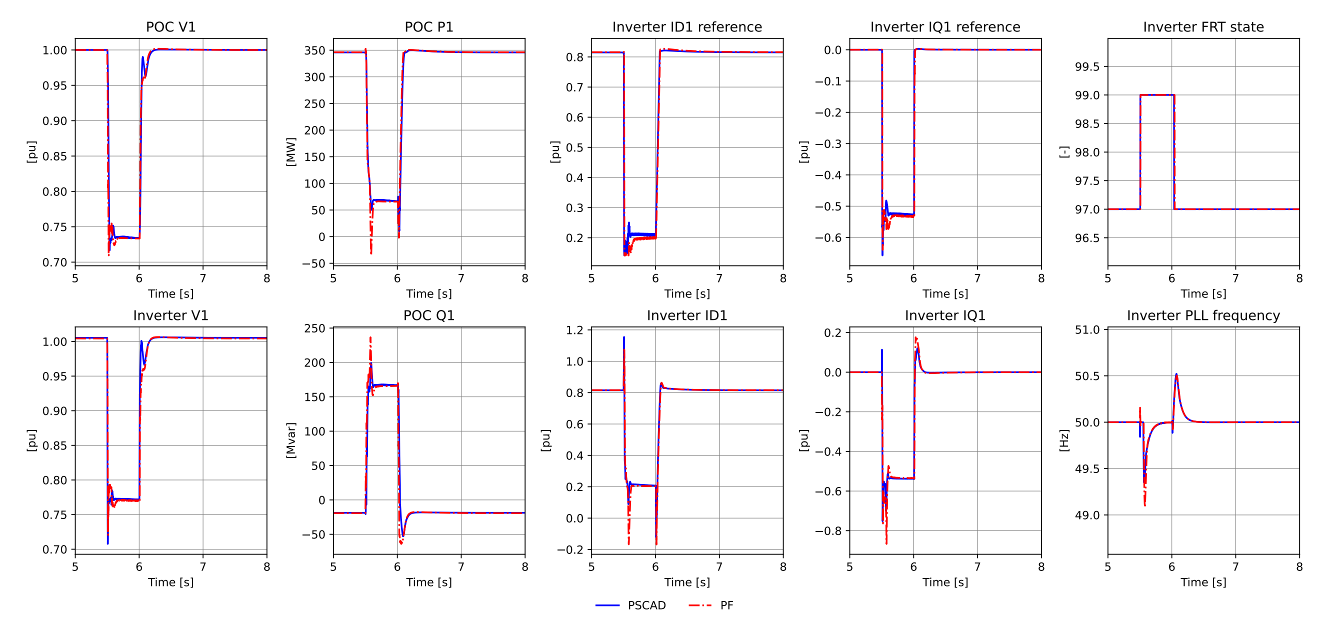

Figure B.2.50: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.0 pu

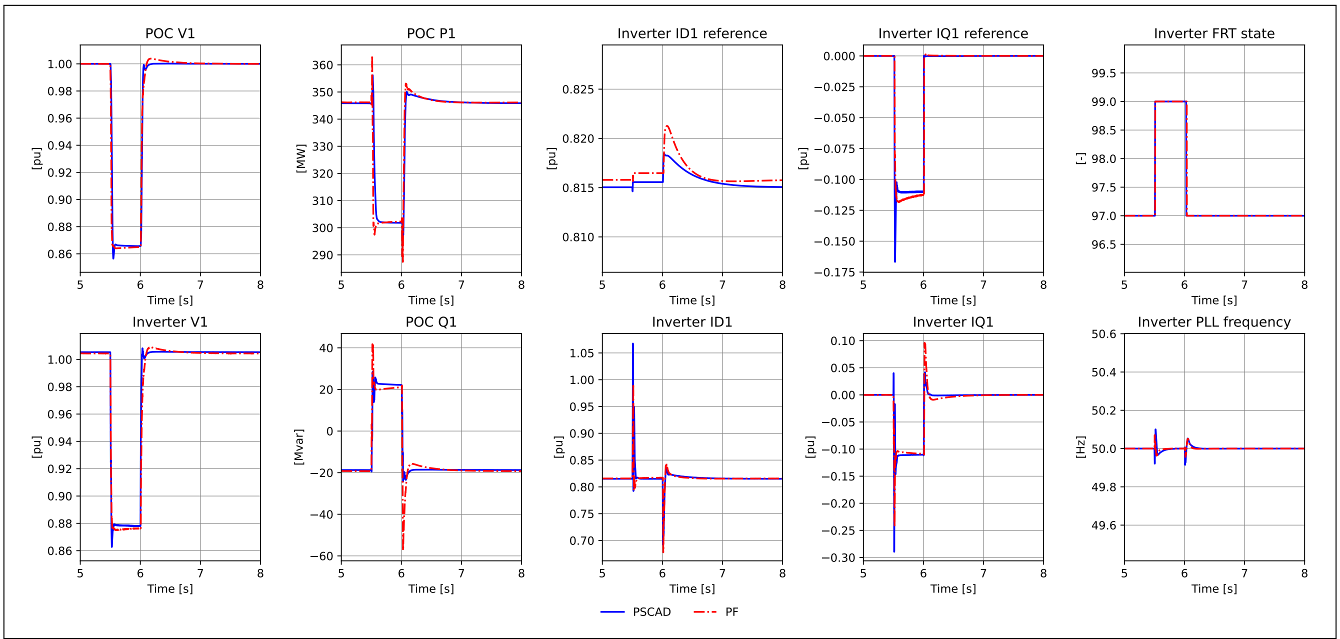

Figure B.2.51: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Fault LG, v=0.5 pu

B.2.3 Grid disturbance tests

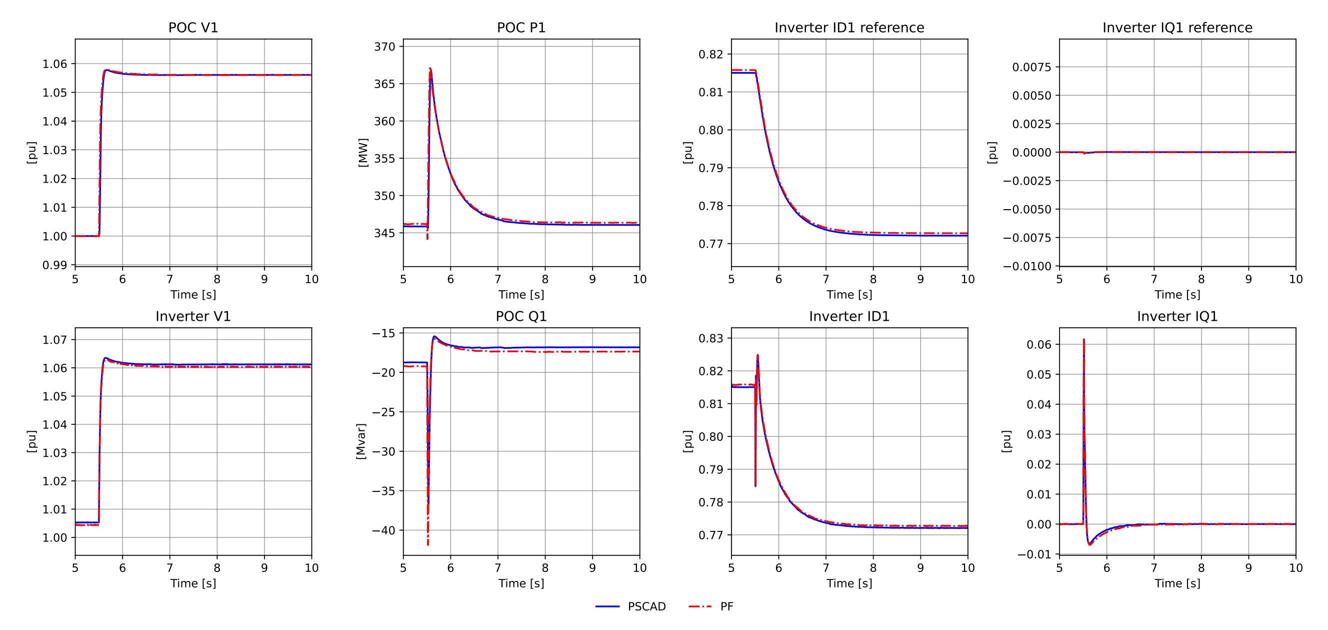

Figure B.2.52: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Vmag dist, △vmag=+0.05 pu

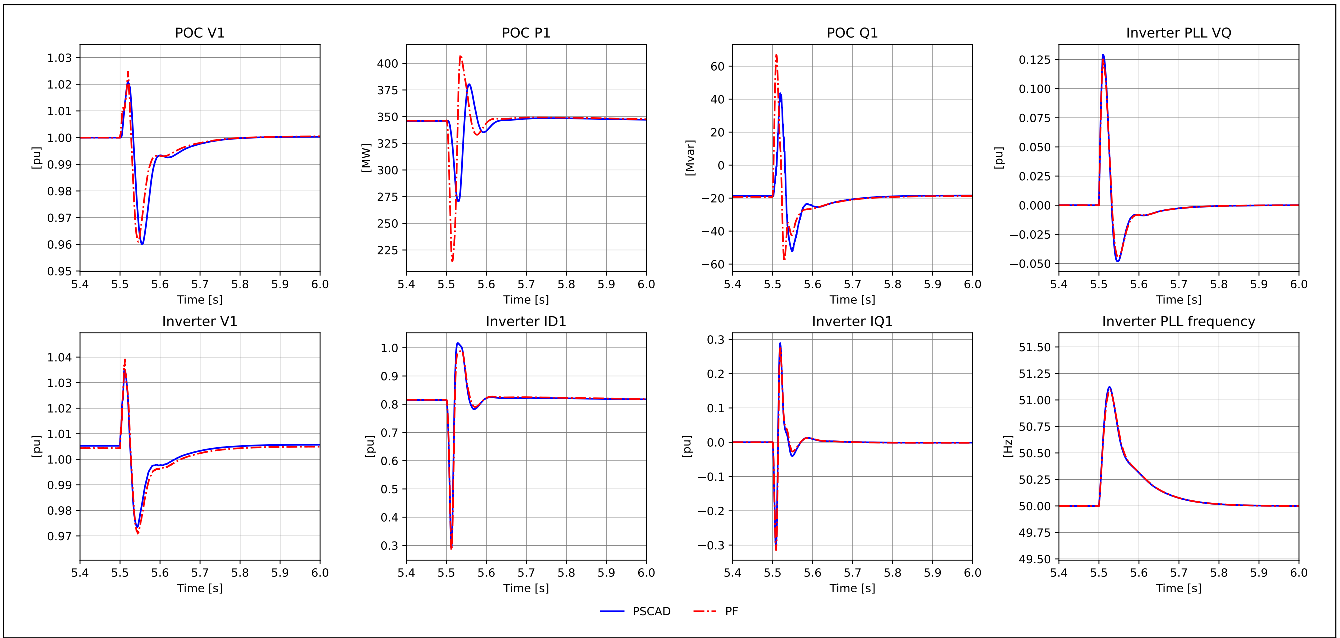

Figure B.2.53: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Vphs dist, △vphs=+30 deg

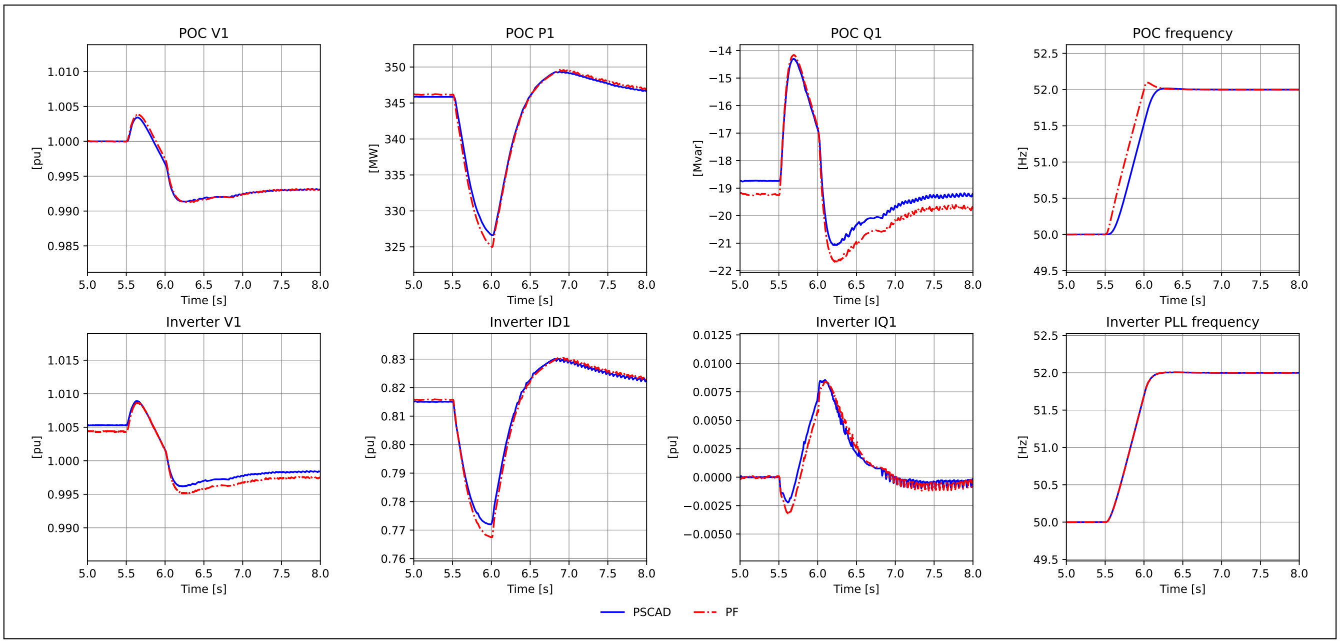

Figure B.2.54: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Freq dist, ∆freq=+2 Hz

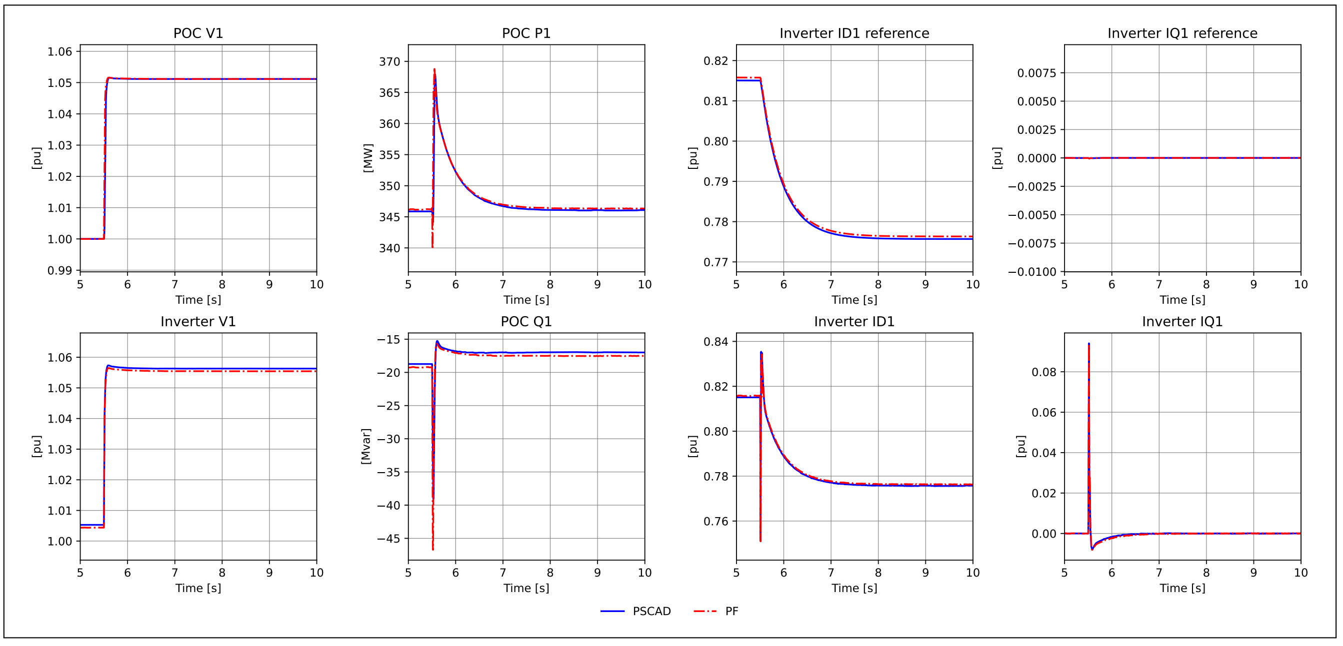

Figure B.2.55: Aggregate inverter model test, SCR=7.5, P=0.83, Q=0, Vmag dist, ∆vmag=+0.05 pu

B.2 Aggregate inverter model simulations

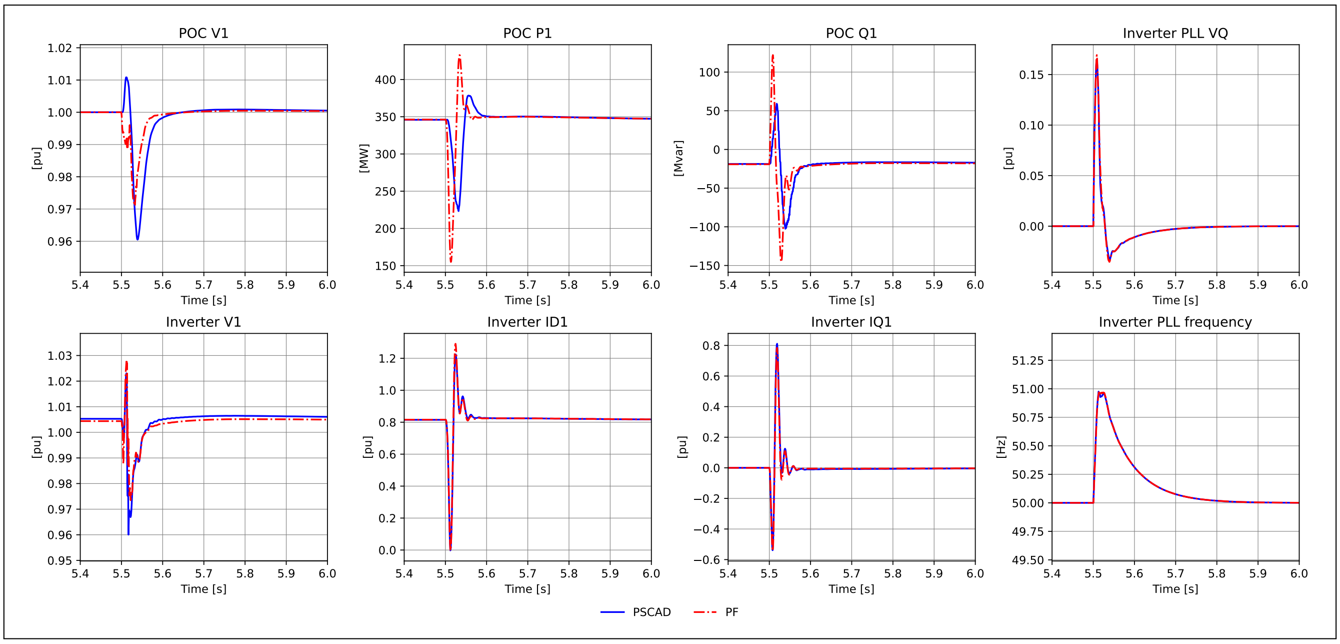

Figure B.2.56: Aggregate inverter model test, SCR=7.5, P=0.83, Q=0, Vphs dist, ∆vphs=+30 deg

B.2.4 Reference step tests

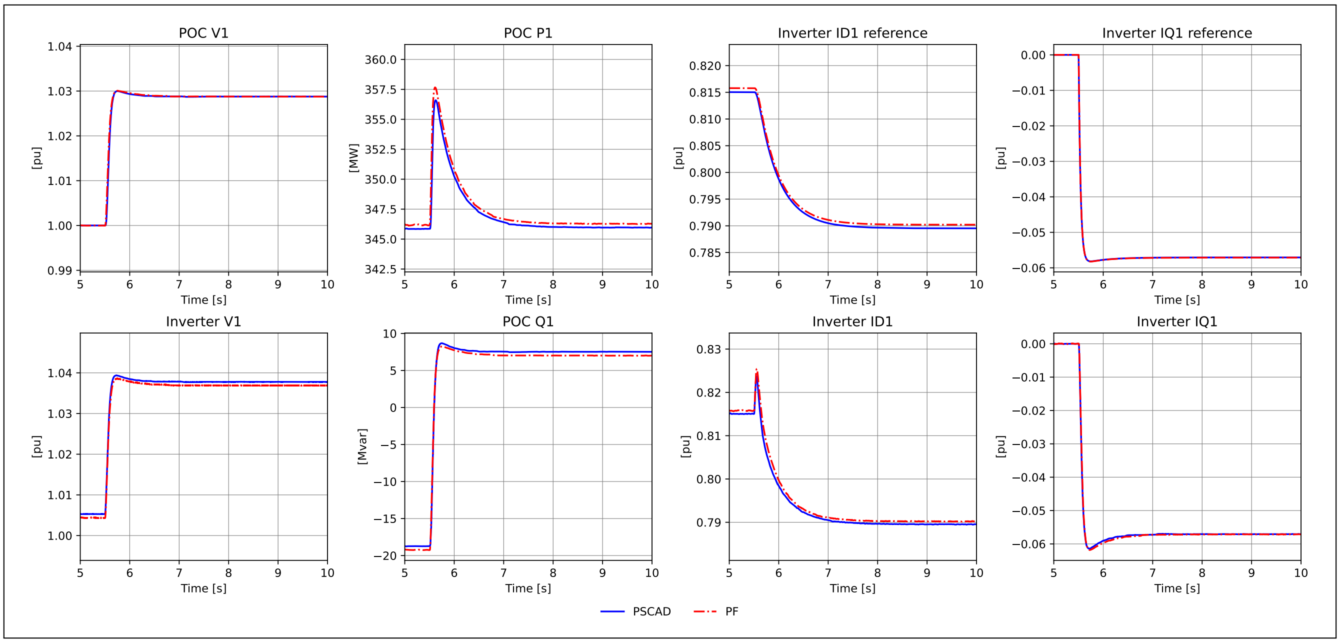

Figure B.2.57: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Qref step, △qref=+0.1 pu

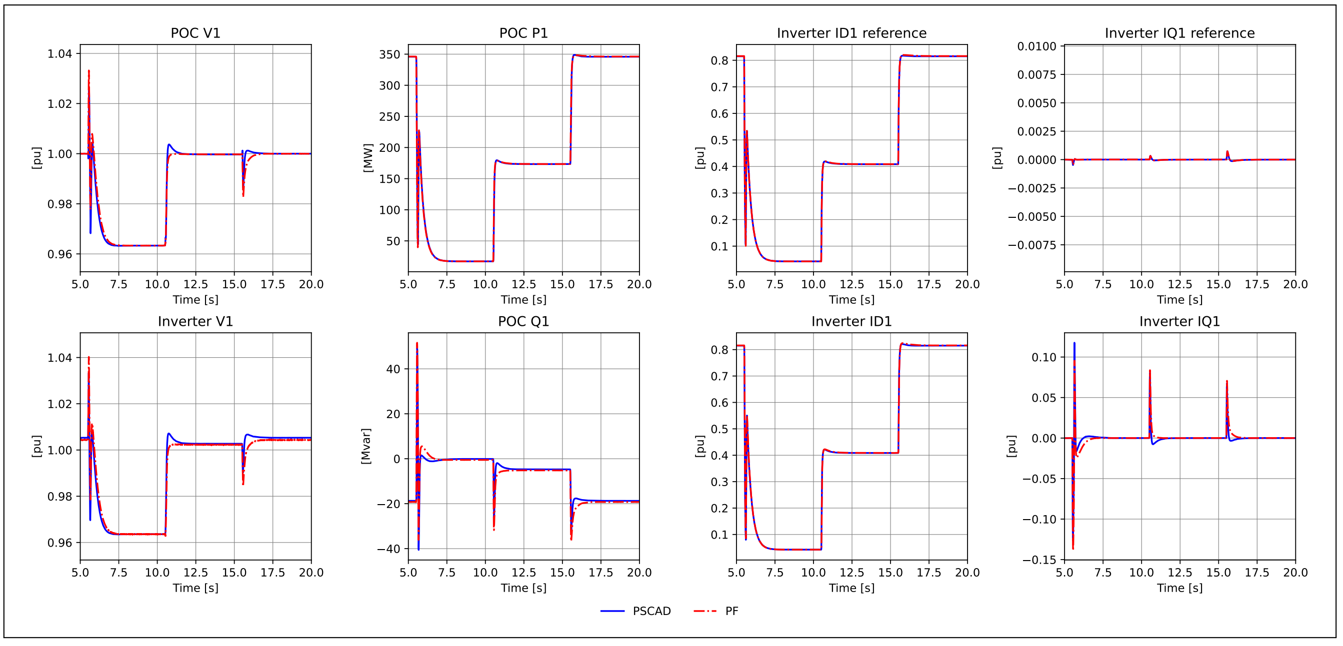

Figure B.2.58: Aggregate inverter model test, SCR=2.3, P=0.83, Q=0, Pref steps, pref = 1.0, 0.05, 0.5, 1.0 pu

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