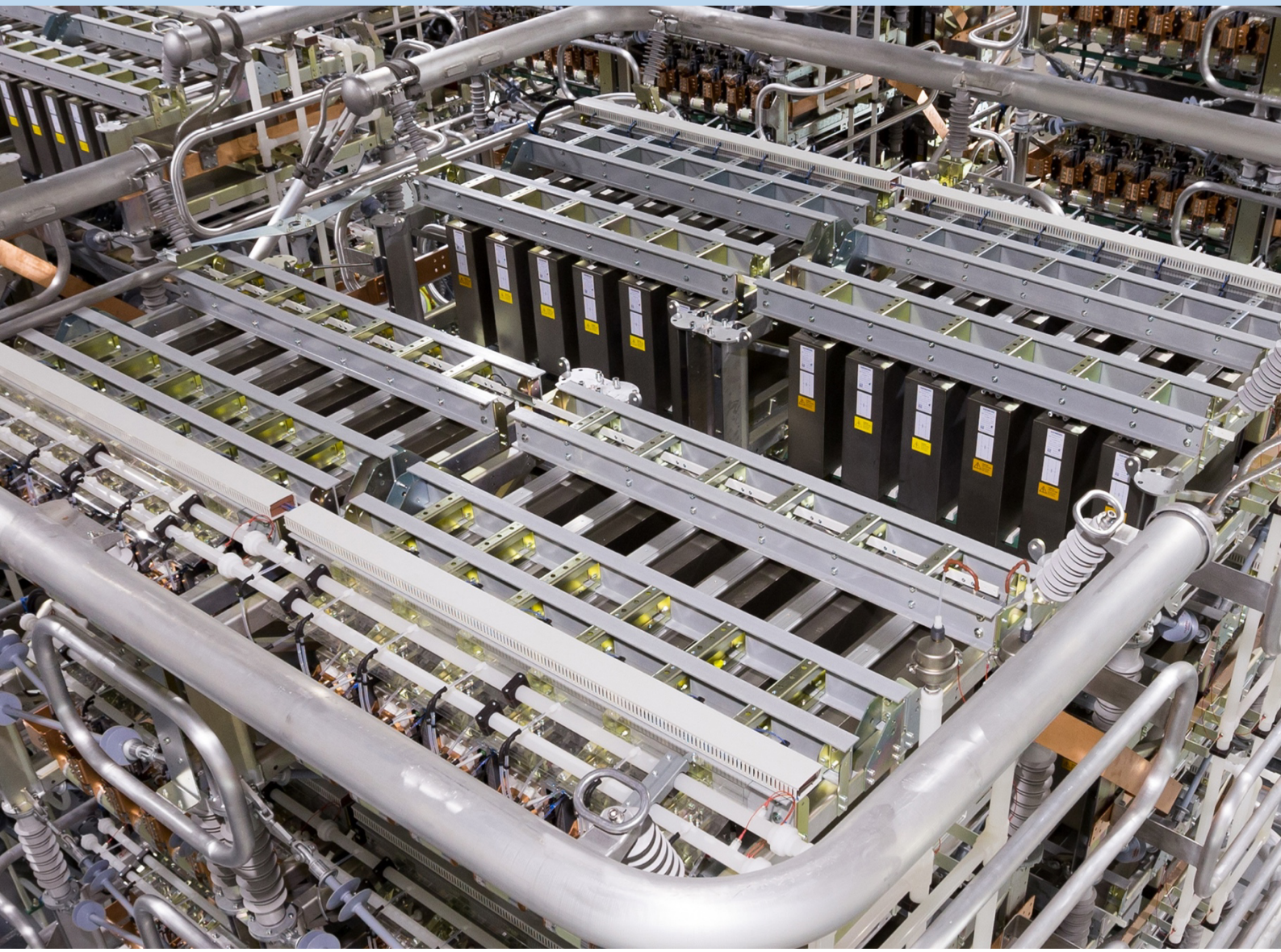
National Grid ESO – DETECTS II

Deliverable 2
Installation & Testing of TXSims



tx transmission excellence ltd

CHANGE RECORD

RESPONSIBILITY	NAME	DATE
Author	S. Kelly	2 August 2023
Checked	H. Obidinnu	4 August 2023

REPORT/REVISION NUMBER	DESCRIPTION	DATE
DETECTS2-D2-R0	Issued for Client Comments	4 August 2023
DETECTS2-D2-R1	Incorporating Client Comments	4 September 2023

1 TERMS & ABBREVIATIONS

Term or Abbreviation	Description / Explanation
DETECTS	Developing Enhanced Techniques to Evaluate Converter-dominated Transmission System operability
EMT	Electromagnetic Transient
ESO	Electricity System Operator
IDE	Integrated Development Environment
IFA	France-England Interconnector (in French)
IFA-2000	2000MW LCC HVDC link from France to UK (Sellindge 400kV)
IFA-2	1000MW VSC HVDC link from France to UK (Chilling 400kV)
msec, µs	Millisecond, Microsecond
MVA, MVAr	Mega Volt-Amps, Mega Volt-Amps reactive
NGET	National Grid Electricity Transmission plc
PSCAD	Power System Computer Aided Design [EMT software]
PyPI	Python Package Index
PyPSA	Python [for] Power System Analysis
RMS	Root Mean Squared [method of measurement, type of stability study]
SVC	Static Var Compensator
TX	Transmission Excellence
V, kV	Volts, Kilovolts
VSC	Voltage Source Converter

2 EXECUTIVE SUMMARY

This report describes:

i) Work undertaken by TX[1] to install their TXSims software on the computers of ESO[2]. TXSims software automates the creation, execution, and analysis of large grid models. It is built on top of PSCAD version 4.6, a commercially available electromagnetic transient simulation package.

ii) Execution of a model of the British grid previously created by TX (and described in the DETECTS report NGESO-WP1-R1) on the computers of ESO. This model is run using the TXSims software referred to in (i) above.

iii) Validation that the results of the model described in (ii) above are the same on the computers of ESO and the computers of TX.

iv) Work undertaken by TX to allow its model and software, which was written to use PSCAD version 4.6 to instead run on PSCAD version 5.0.

[1] Full name: Transmission Excellence
[2] Full name: National Grid Electricity System Operator

This report concludes that:

i) TXSims and TX's model of the British grid are now ready for use of ESO's computers with PSCAD version 4.6 and Intel Fortran version[3] 15.0.287.

ii) PSCAD version 5.0 was tested with Intel Fortran version 19.2.46319. This newer version of PSCAD and/or this version of Fortran appear to have been modified in ways that make it incompatible with some of the black box models previously provided by converter manufacturers. We concluded that PSCAD version 5.0 is not suitable for use with TX's model of the British grid until one of the following happen:

   a. Tests of PSCAD 5.0 with older Fortran compilers replicate the results seen in version 4.6. In this case PSCAD 5.0 would be suitable for use – but only with the older compiler.
   b. Updates to PSCAD 5.0 remove the incompatibilities.
   c. Converter manufacturers issue new black box models that have been redesigned/recompiled to run with PSCAD 5.0 and newer Fortran compilers.

iii) Further work that, subject to ESO decision, might be undertaken as part of DETECTS II (i.e. work that would form part of Deliverable 3) includes:

   a. Modifying the TXSims software so that it can work with either version 4.6 or version 5.0 of PSCAD (rather than having two slightly different versions of the TXSims code, one for each version of PSCAD).

   b. Modifying the TXSims software to avoid needing to use "Run as Administrator".

3 SOFTWARE INSTALLATION (FOR USE WITH PSCAD 4.6)

TX provided the TXSims software as a set of open-source Python files (.py files). These were run on ESO's computer using the Spyder integrated development environment (IDE). While this differs from the environment that is used by TX, this did not result in any issues.

One of the functions of TXSims is running a loadflow study: this is necessary in order to find the voltages and angles in the pre-fault stead state condition. These are then used to fix voltages and angles in the PSCAD simulation until the converters have started up and reached their target outputs. The loadflow calculations are undertaken using the open-source PyPSA library. PyPSA is not present in Anaconda or other popular distributions and must be downloaded from PyPI (Python Package Index).

At present the "user interface" of TXSims takes the form of a set of library functions that can be called by the user. The user is expected to provide a short python script that indicates where the model data can be found and where the output files are to be saved. The user's script can

[3] Note that these version numbers are the "fortran_version" used by PSCAD's Python interface. It is not clear how they relate to the marketing names given to these compilers by Intel (for instance version 19.2.46319 has a marketing name of "Intel Fortran Compiler Classic 2021".

also make various modifications to the model, such as changing demand or generation patterns. This means that where numerous studies are required, for instance to explore the effect of having more or less power flow across a boundary, all of the studies can be executed without human intervention (e.g. overnight).

When a simulation is run, the TXSims software takes the model data specified in the user's script and uses it to create the input files needed by PSCAD (primarily .pscx files). When PSCAD is run it will create numerous files (Fortran code, object code, executable code, output files, etc). In order that these files do not fill up the disk drive, TXSims stores them in a special area on the disk and removes them whenever a new study is run. It was found that on ESO's computer this approach required administrator access privilege, which in turn required that Spyder have administrator privileges (i.e. Spyder must be started using the "Run as Administrator" option). If this is likely to be a problem for ESO, then TX may be able to avoid it by modifying the TXSims code to store the temporary files in a different location. If requested by ESO any such modifications would form part of the third milestone work under the DETECTS II contract.

One change was needed to the TXSims code to allow it to run on ESO's computers. TXSims maintains a list of valid Fortran versions and the directory names used by each version[4]. TX uses Intel Fortran version 16.0.254 while ESO uses Intel version 15.0.287, and the list of valid Fortran compilers held within TXSims needed to be updated.

The user script must be changed to refer to suitable file paths for the input and output files. In addition, the location of the TXSims code files (which is referred to in the sys.path.insert command) must also be changed to a suitable path on the ESO machine.

A simulation comprises several dozen processes running in parallel. These processes communicate with each other using the internet protocol. When a simulation with a new name is run for the first time, the use of the internet protocol by programs that have not previously been encountered triggers multiple alerts from Windows Defender which must be accepted manually. This should not occur if the study name is not new.

4 MODEL VALIDATION (WITH PSCAD V4.6)

TX has constructed an EMT model of the British grid; the details of this model are given in the DETECTS report NGESO-WP1-R1. This model was validated (at least in respect of the behaviour of the grid and synchronous machines) by comparing predicted and actual currents and voltages for an actual fault on the grid. The steady-state behaviour of the model was also validated by comparing per-fault power flows in southern England with the flows indicated by ESO PowerFactory model.

As part of the original DETECTS project the original generic converter models in the South-East Coast area were replaced with manufacturer-provided models. The performance of the resulting model is described in DETECTS report NGESO-WP1-R1.

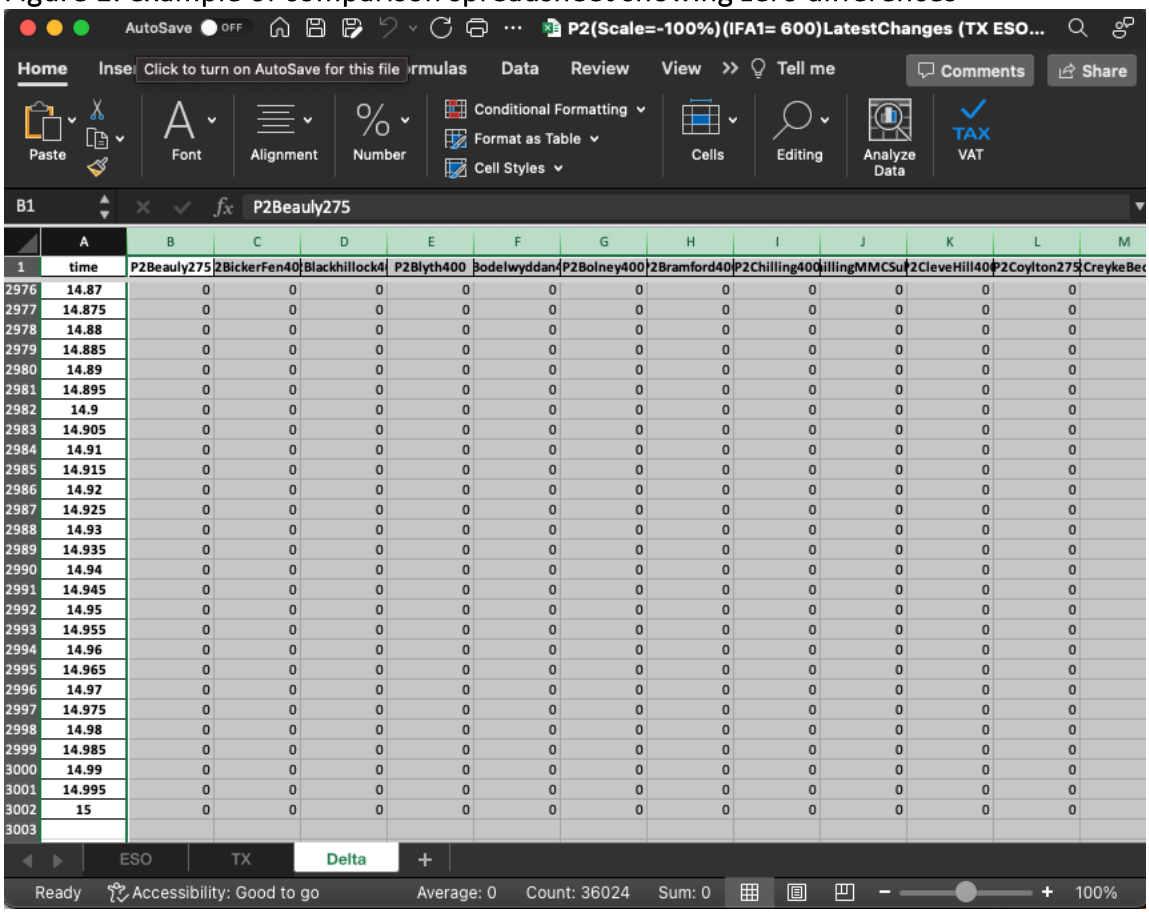
[4] The directory names do not always follow logically from the version number, so a lookup list needs to be used.

As part of DETECTS-II this model was transferred to ESO's computers and run using the TXSims software package. On ESO's machines the model was run using the same PSCAD version as TX (v4.6.3) but with a slightly different version of the Fortran compiler (v16.0.254 for TX and v15.0.287for ESO).

A set of studies, each with different amounts of VSC and IFA-2000 converter infeeds in the South-East Coast were run on the ESO machine[5]. These were then compared to the results from the same studies when they had been executed on TX's machines as part of the original DETECTS project.

Visual comparison of the output files from ESO and TX machines showed no difference in results. As an additional check the spreadsheets holding snapshot outputs recorded every 5ms were compared by pasting TX and ESO results into two tabs in a spreadsheet, and then adding a third tab ("Delta") where every value in the TX tab was subtracted from the corresponding value in the ESO tab. This was done with the VSC output-power and RMS voltage data for several studies. As can be seen in Figure 1 below, this resulted in the finding that the TX and ESO outputs were identical.

Figure 1: example of comparison spreadsheet showing zero differences



[5] The studies are designated "V38-NatioanlGridTest". Studies were undertaken with VSC infeeds in the South-East Coast set with scaled factors from -2.5 to -1.0 in steps of 0.5 (these numbers equate to flows into Britain on Nemo and Eleclink from about 550MW on each link to about 700MW on each link), while for IFA-2000 flows into Britain were set to 600MW, 1000MW, 1300MW and 2000MW.

In Figure 1 above each cell contains the difference between TX and ESO results (with the exception of the time-stamp in column A, which runs from 0 seconds to the 15 seconds seen here in 5ms steps). All cells (other than column A) have been highlighted – this includes many columns not visible here and all rows back to 0 seconds. At the bottom of the screen the "Sum: 0" shows that all highlighted cells add up to zero. In other words, all highlighted cells are zero, meaning that TX and ESO results are identical.

5 ADDITIONAL INVESTIGATION OF PSCAD V5.0

In addition to installing and validating TXSims and our model of the British grid with PSCAD version 4.6, we also went further and tested it with PSCAD version 5.0[6].

The changes listed below were required before the model could be run on PSCAD version 5.0:

i) Manitoba Hydro (the publishers of PSCAD) provide Python libraries that allow PSCAD to be launched and control from a Python programme. For PSCAD v4.6 the library is called "mhrc.automation". For PSCAD v5.0, however, it is called "mhi.pscad" and some of the method names are different. There does not appear to be any backward compatibility – if the newer "mhi.pscad" module is used then PSCAD v4.6 cannot be launched[7].

ii) The model contained a reference to the ETRAN library[8] which needed to be removed. Even TX had deleted all components from the ETRAN library some time ago, and they no longer appeared on the display, it appears that one reference remained in the "Resources" section of the "DoggerTees" project. TX has noted this phenomenon – where deleted components disappear from the screen but are retained in the files - before, and it appears to be due to a bug in PSCAD. In this case the deleted component caused no issues in v4.6 but caused v5.0 to fail. This was cured by deleting the component from the Resources section of the affected project.

iii) The model of IFA2 used by TX would not compile, with the linker[9] complaining about the version of the C runtime used. ESO was able to correct this problem by switching to a newer version of the IFA2 black-box model.

iv) The black-box model of Nemo appeared to be corrupted by the conversion to V5.0, causing it to fail to compile. A fixed input value needed to be re-created in the form that had been visible on v4.6.

v) Because the black-box model for IFA-2000 needs to run with a different time step to all other black-box models, it is isolated in a separate process which connects to

[6] The contract between TX and ESO refers only to version 4.6.

[7] ESO has asked TX to modify its code so that it can work with either v4.3 or v5.0. This will be undertaken as part of the Deliverable 3 work.

[8] A publicly available library of PSCAD components produced by the company Electranix.

[9] A linker is a piece of software that takes "object files" (in this a mix of files produced the Fortran compiler, and files comprising the black box model) and outputs an executable file (".exe file").

the other process via a "multirate adaptor". TX used an early version of this adaptor which had been provided to us by Manitoba Hydro; this early version was not compatible with v5.0. A newer version of the multirate adaptor is provided with v5.0. This proved very difficult to use, but we were eventually able to get it to work by following exactly the example given in the documentation – even though this meant pretending that there was a lengthy overhead line between Sellindge and the IFA-2000 converters.

vi) With the adaptations listed above in place, it was possible to run TX's model of the British grid on version 5.0. However, the model executed much more slowly than in v4.6. The reason for this is not known[10].

vii) Most seriously, substantial discrepancies were found between the study results depending on whether the study was executed in v4.6 or v5.0. There may be multiple reasons for this, but one that became clear was that at least one black box model does not operate correctly when run in v5.0. This is described further below.

One example[11] of a black box model originally compiled for use with v4.6 failing in version 5.0 is the Ninfield Statcom. When run in v5.0 there is a period that lasts for about 100ms[12] shortly after the fault where reactive power goes in the wrong direction, producing MVAr even though the voltage is well over 400kV. Figure 2 below shows v4.6 results on the left and v5.0 on the right, with the period where the statcom model misbehaves in 5.0 being highlighted in yellow. The brown trace on the bottom is the voltage at Ninfield 400kV, which is broadly comparable in the two studies, both being in the range 400-460kV, though somewhat higher in v5.0. The green and pink lines show the MVAr output of Ninfield's old saturable reactor SVC (green) and the new statcom (pink). In v4.6 both devices absorb MVAr over this period – as would be expected given the high voltage. In v5.0, however, while the saturable reactor absorbs MVAr (as expected), the Statcom model incorrectly shows MVAr production.

[10] In contrast, in version 4.6 the model executed at approximately the same speed on TX and ESO's computers.

[11] Other issues may exist, but after finding this clear example of incompatibility no further investigations were undertaken.

[12] The period of clearly erroneous behaviour starts around 170ms after fault clearance and ends about 280ms after fault clearance. It is not known if Statcom behaviour at other times is correct – but it is at least not as obviously wrong as it is during the highlighted period.

Figure 2: Comparison of results from PSCAD v4.6 and v5.0.
Pink = MVAr output of GE statcom at Ninfield 400kV
Green = MVAr output of old saturable-reactor-based “SVC” at Ninfield 400kV
Brown = RMS voltage at Ninfield 400kV