The Application of Real-Time Digital Simulator for PV Integration Grid Studies

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1. Introduction

There has been an increase in distributed generators (DG) connected into the electrical networks near consumption points in the last few years. The increasing DG system connections have potential impact on the control and operation of the associated power system network [1]. The decrease of PV system prices and environmental considerations are driving these levels even higher further increasing the impact on the network performance. The main challenge faced by power system controllers and operators is the assessment of these impacts in real time.

There is wide range of literature covering the application of real time simulation in existing systems and some relevant applications. A detailed survey of simulations used for solving power network differential algebraic equations, planning, design testing, and deployment of a new system or post event analysis is presented in [2]. Reference [3] highlights that there is an increasing use of real time simulations in power and energy systems in academic research and industrial applications. Real time applications have included the development of simulation platforms for smart grid [4]. These are characterised by complex smart grid models that consist of large numbers of high-speed switching devices.

Reference [5] details the controller development using real time simulations to optimise the DG system in the microgrid with inner voltage and current loops for regulating the three-phase grid-interfacing inverter. Real time simulation can also be applied to simulate scalable networks [6]; the results demonstrate promising accuracy when compared with non-real time simulation tools. Furthermore, it is acknowledged in literature that large distribution networks can present challenges due to number of components, modules and buses and the accuracy in simulating switching power converters [7].

Advancements in computer technologies have led to the reduction of costs and increased performance of simulation tools that solve complex power system challenges. This has resulted in the paradigm shift in simulation capabilities; real time simulations seek to represent the operation or features of a system through the use or operation of another [8]. The important characteristics of this simulation approach is discrete-time and constant step duration when computation is performed. During discrete-time simulation, time moves forward infinitely in steps of equal duration.

There are essentially two approaches to real time digital simulations, namely: fully digital real-time simulation (e.g., model-in-the-loop, software-in-the-loop, or processor in-the-loop), and hardware-in-the-loop (HIL) real-time simulation [9]. The fully digital real-time simulation requires the entire system to be modelled inside the simulator without interfacing inputs/outputs. This type of simulation allows for the emulation of the dynamics of large power systems and study the behaviour of controllers that will eventually be installed on the grid, by interconnecting an actual controller to a simulated grid without the actual hardware [10]. HIL simulation deals with situations where parts of the fully digital real-time simulation have been replaced with actual physical components. The HIL mode of the simulation proceeds with the device-under test or hardware-under-test (HuT) connected through input/output interfaces.

In practice physical equipment require a variety of large voltages and currents, which limits the direct connection of the real time digital simulator from connecting directly to the equipment under test. Control equipment can however be connected in the case of closing or opening of switches that connect or disconnect the components in the simulated power system. Interface between the input/output and actual hardware connection will require signal amplification. The feedback signals can also be measured at high voltage or current quantities and pass through the amplifier for reduction. For this study the model-in-the-loop approach is used to extract the results based on the model detailed in the next section.

The aim of this investigation is to assess the impact of integrating the inverter based technology generation, specifically the integration of PV systems. The steady state voltage profiles and harmonic distortions from the real-time simulator will be assessed. The next section will describe the real time simulation approach covering the different types. Section 3 describes the reduced grid that is used for the simulations. Section 4 focuses on the simulation results accompanied by the discussion of results and Section 5 covers the conclusion.

2. Description of the grid model

This section outlines the grid model that is used to demonstrate the integration of PV using the real time simulator. The model represents the actual distribution grid of an operating facility. The network is designed using the ring type topology. The facility receives grid power from a local municipality which is supplied at 132 kV level. The facility has its own step down substation that transforms the voltages from 132/11 kV. In addition, power is further stepped down at multiple points within the reticulation system consisting of 11 kV ring feeders and power is supplied to multiple buildings at 400 V. For power factor correction, the system consists of 11 kV shunt capacitors.

The facility has completed the installation of PV generation system. There are three PV plants installed, namely: at low voltage (LV) that is 400 V, there are two plants commissioned, a dual axis tracking system with a power capacity of 203 kWp -, a 250 kWp rooftop installation and a 558 kWp single axis tracking system connected through the 11 kV/400 V step down transformers. Although the reticulation system consists of multiple rings, one of the rings connects two PV generation units. It is therefore decided, for simplicity that the cable ring consisting of the two PV generating units is used as the basis of the study. This reticulation system is illustrated in Figure *1*: Simplified reticulation of the facility under studyFigure 1 where components connected in the ring are shown.

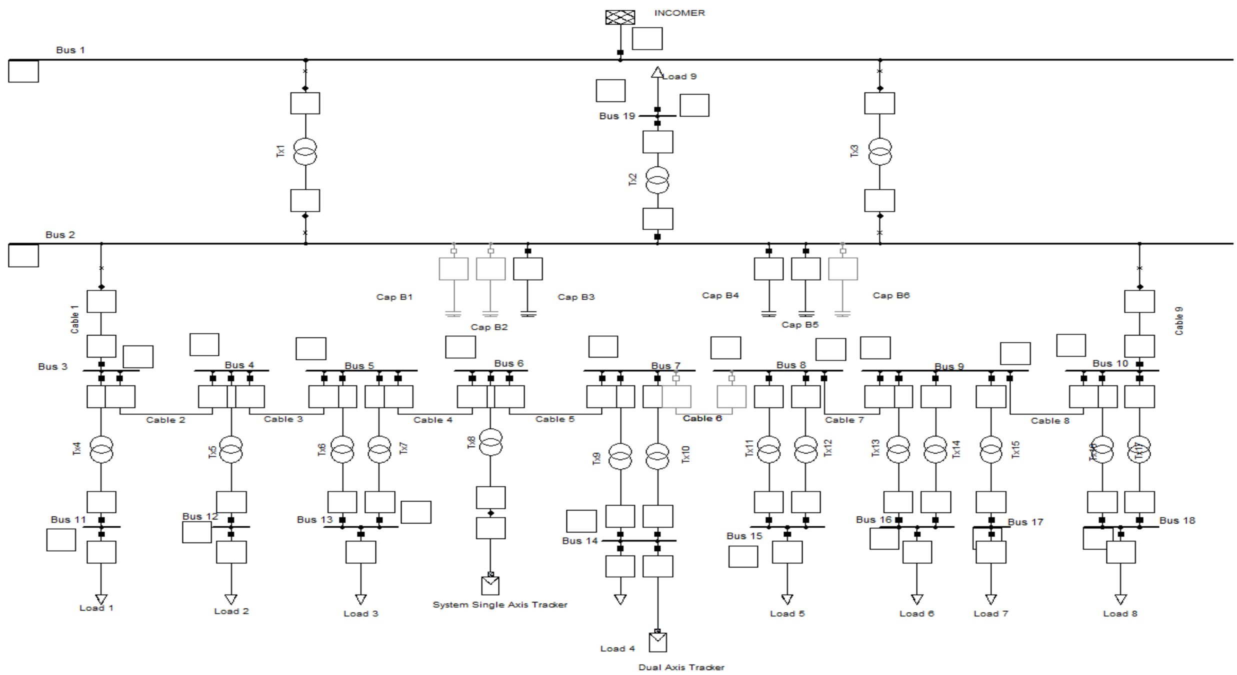

Figure 1: Simplified reticulation of the facility under study

In Figure 1 shows the two PV generation units that are under consideration in this study. In addition, the ring connection points are switched at two instances in the network. The PV generating units are connected on one side of the open ring. The main parameters of the PV generation units are as follows:

Table 1: PV characteristics for the generating units

	Single Axis Tracker	Dual Axis Tracker
Capacity (kWp)	558	203
PV Modules (No.)	1800	630
Module rating (Wp)	310	285
No. Inverters	8	17
Inverter Size (kWp)	60	15
Connecting Voltage (kV)	11	0.4

3. Simulation results

The simulation platform used combines Matlab and RT-Lab (a proprietary software of OPAL-RT). The system topology presented in the preceding section is used to conduct the simulation. To ensure that results are accurately achieved, following the simulation steps is important. These steps include representing the power system using single line diagram (may involve conducting simulations in a different power system design tool for validation later) and record the electrical component parameters. The second process is the representation of the model in Matlab, which should be completed, and have results analysed. The next process is to split the model according to computing and displaying/ console parts. These should be managed in subsystems and named accordingly. Figure 2 depicts this network representation in Matlab. This section further presents the results obtained after accurately representing the system and running it in real time with the simulator connected.

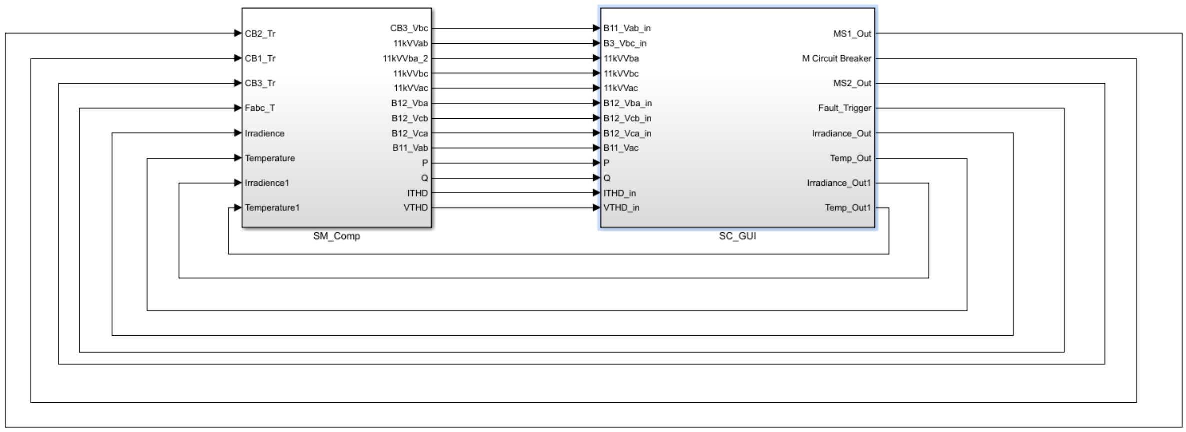

Figure 2: Matlab integrating console and computation systems

The details of the subsystem in Figure 2 are not presented. Rather it shows the multiple input and outputs at high level although the whole network and result visualisations are packaged inside the subsystem. As the study is focused on the integration of PV, it is prudent that the details of modelling this system are outlined. The PV generating model as shown in Figure 3 uses the PV solar Matlab block which requires the number of strings and modules based of the capacity and installation.

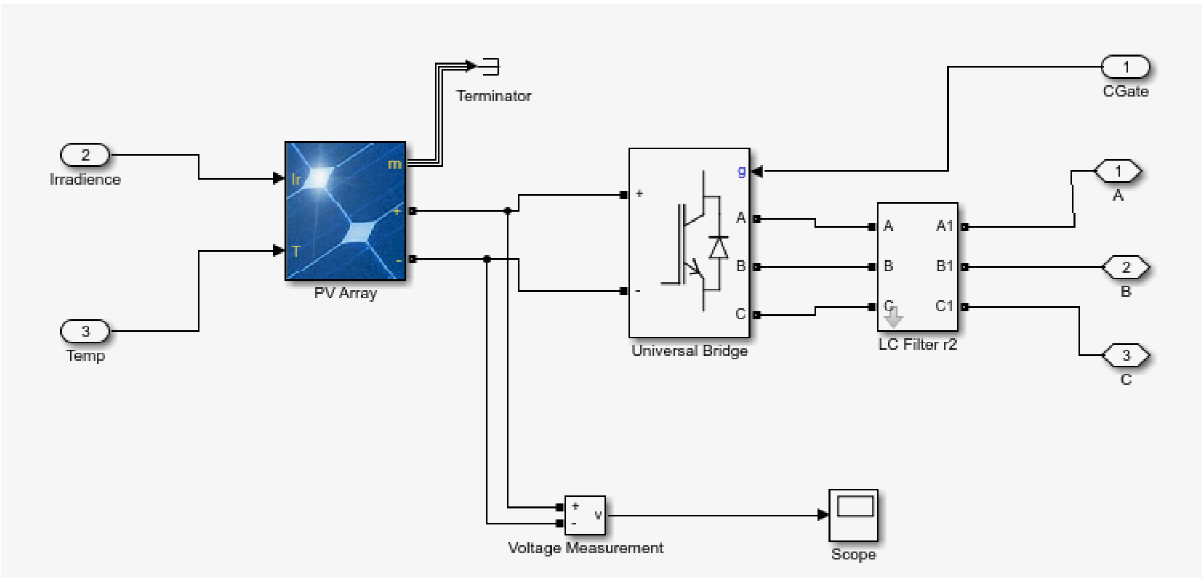

Figure 3: Implementation of PV modules and the inverter in Matlab

Special consideration should be take into account when simulating the inverter as the inverter control scheme depends on the sampling time. It should be noted that the simulations in real time can only be achieved from a discrete simulation configuration. In addition, it is emphasized that before the model could run in RT- Lab special communication blocks are required for all inputs to enable interaction with the real time simulator. The results received after the correct simulation setup are presented.

Figure 4: Hardware configuration of modelling in the loop

Once the whole setup was completed the simulations were run in the real time simulator. Figure 4 shows the OPAL-RT real-time digital simulator setup Due to the complexity of the model, running the model to reach 1s became slow. Thus events were triggered before completing a few seconds to modify the state of the system. The first system change was to switch on the 203 kWp plant and after a few milliseconds to switch on the 558 kWp plants. The simulation was let to run so as to capture the rest of the results. In Figure 5, the bus voltages for all phases are presented. The disturbance introduced between seconds indicates the ripples seen by the network at the time of switching. Another disturbance was introduced at 0.4 µs, the ripple effect became more pronounced after the instance of switching.

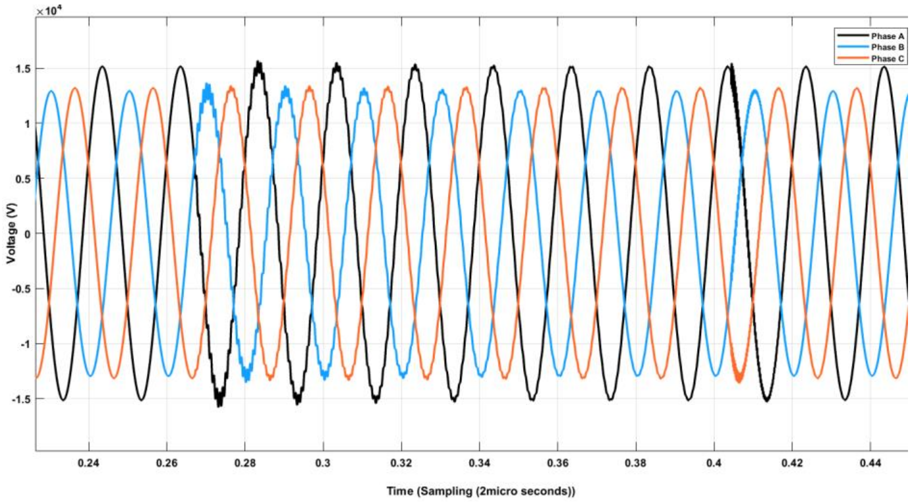

Figure 5: 11kV bus voltages after switching on the PV system

On the 400V bus which connects to the PV system the voltage was sampled and results are presented in Figure 6. The pattern of disturbances are similar to the 11kV bus voltages. It is also clear that the ripples are seen more close to or at peak voltages and in practice this represents an overvoltage concern. It should be highlighted also that the ripples subside after a few peaks.

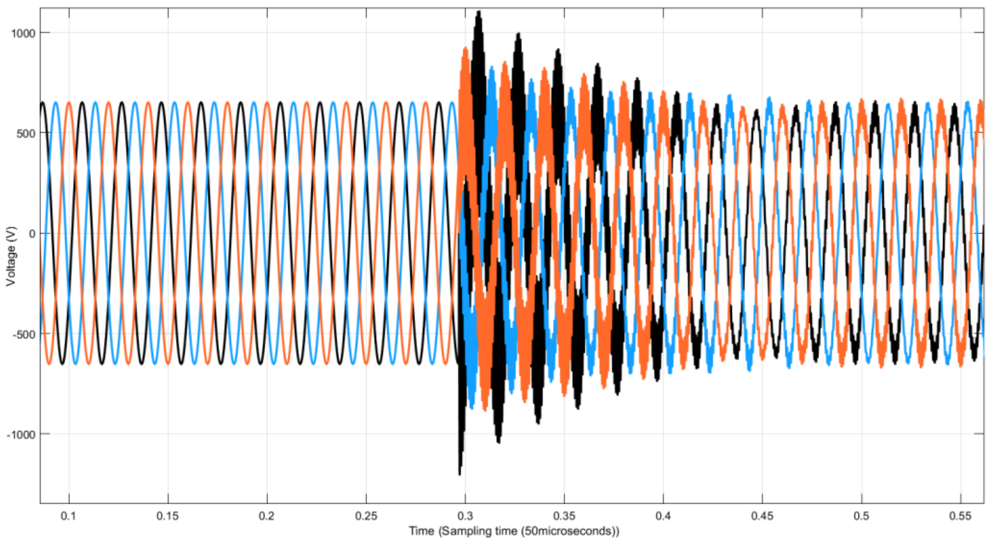

Figure 6: 400V bus voltages after switching on the PV system

To understand the harmonic impact, the measuring block was prepared at pre-simulation stage. The total harmonic measuring block gives the percentage distortion levels of the signal. The results obtained are illustrated in Figure 7 and Figure 8.

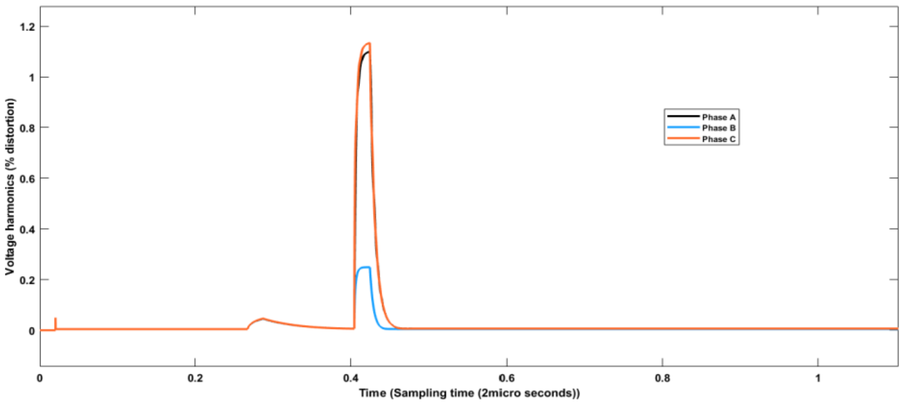

Figure 7: Voltage harmonic distortion during the real time simulations

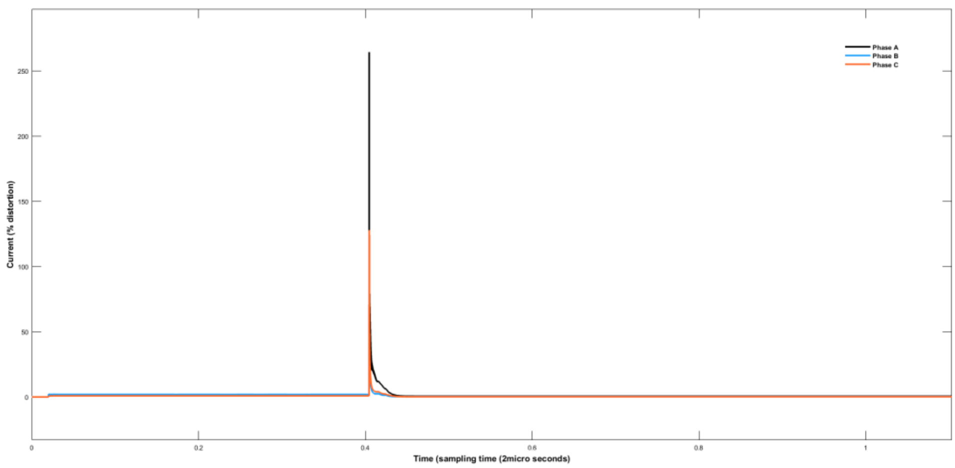

Figure 8: Current harmonic distortion during the real time simulations

In Figure 7 it is clear that during switching of both generating units the voltage distortion (50Hz fundamental frequency) does not rise above 1.2%, which indicates that voltage harmonics will not pose a problem to the downstream equipment. However, in Figure 8, the current harmonic distortion increases significantly even exceeding 250%, this is against the overall total harmonic distortion of 5% as specified by the grid code. This can result in disturbances in electrical equipment, however, the disturbance does not last long; the possibility of the DG plant to absorb harmonics is permitted up 300% as long as the voltage harmonics are significantly low. To fully understand the possible mitigation of the spike in current harmonics, the inverter control scheme should be revisited as this is outside the scope of this publication.

4. Conclusion

The simulation of distribution reticulation of a facility with PV generation integrated has been accomplished using the real time digital platform. The results of the simulation demonstrate that the small disturbances and events that the system will see can be accurately captured in real time interactively. Undertaking this simulation is important from the quality of supply point of view to ensure that the voltage magnitudes and harmonics are kept within acceptable limits. Future work will include hardware in the loop and simulation of the inverter control operation.

5. References

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