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Real-Time Simulation of Distributed Energy Systems and Microgrids

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Abstract: This paper describes the challenges met in real-time simulation of modern power systems, explains various methods to address these challenges and solve the problems they impose. This is detailed and demonstrated through a case study - real time simulation of a micro-grid connected to a large distribution network containing 615 single-phases nodes. The contribution of this work relies in solving two major challenges in real-time simulation of micro-grids and distribution networks: the distribution of large grids over several processors, and the accuracy in simulating fast switching power converters applied to and demonstrated by a case study of a micro-grid connected to a distribution network.

Keywords**:** Micro-grids, Distributed Energy Systems, Power Distribution Networks, Power Electronics, Simulation, Real-Time, Electromagnetic transients.

1. INTRODUCTION

Simulation has been used for decades for power system analysis. And with the increased complexity of modern power grids, and the integration of renewable energy systems, distributed generation, and smart metering and control, the industry is increasingly relying on simulation tools. And digital real-time simulators are becoming essential ([1] - [5]) to design smart grids, distributed energy systems, and test their controls and protection schemes and devices, as they enable the researcher and designer to conduct a vast bank of tests earlier at the design phase and in a safe environment, to ensure that the design requirements are met and the designed system behaves correctly and the controls are reliable, free of software bugs, and robust.

But as these modern distribution systems are becoming to be heavily reliant on complex power electronics and as the complexity of this active grid is increased by the connection of a large number of active distributed generation systems to the power system, real-time simulation of these distribution systems faces two major challenges that need to be addressed by any real-time simulator:

- The ability of the Simulator to simulate large power distributed systems with a large number of components, modules and buses,
- The accuracy in simulating switching power converters especially with the tendency of using an increasing switching frequency.

These two challenges are detailed in the following section.

2. KEY CHALLENGES OF REAL-TIME SIMULATION

2.1 Real-Time Simulation of Large Power Systems

Power grids are complex systems and their electromagnetic transient (EMT) simulation requires the computation of large matrices. The only way for real-time simulators to be able to simulate them in real-time – to solve all the grid equations/matrices within the finite simulation cycle – is to split the grid model and distribute it on several processors included in the simulator.

However, and here lies the main difficulty, the separation of a power grid model on several processors is a tricky issue because of the inherent added delay between the processors (communication and send/receive overheads). A necessary requirement in any real-time simulator is therefore to split the grid model at the network elements with a natural delays (inductors, capacitors, transmission lines, etc.). [6]

However, distribution grids are lumped by nature. They don't have 'long' transmission lines, but only short ones (typically 2-5 km). In addition, distribution grids consist of several hundreds and thousands of nodes, resulting in large set of equations that need to be solved within a fixed time step - a big challenge for digital real-time simulators.

Another method [7] is to use a state-space-nodal (SSN) method. SSN automatically computes the branch equations of the network, and reduces the number of nodes. Reducing the number of nodes is critical because the LU factorization of Y matrix time is proportional to the cube of the size of matrix. SSN allows the parallelization of the network equations without delay.

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2.2 Accuracy of power electronics simulation

In traditional software used for offline simulation of switching power converters, the solver used is either a variable step-solver with time step constraint or a fixed-step using a sub-microsecond step size. For both cases, the switching (rising and falling) is detected with sufficient accuracy so that these solvers do not need nor use an interpolation mechanism. The simulation results are accurate enough because the simulation time-step is very small (usually less than 1 us), or because the variable step solver iterates around the switching events without any simulation time constraint to detect the switching times with a good accuracy.

A real-time simulator (RTS) uses only a fixed-step solver; no iterations or variable step solvers are allowed.

A key parameter in RTS is therefore the selection of the time-step (also called step size): the simulation step size should be small enough to give accurate results, but not too small so that the real-time processor can solve all the equations describing the system within the time step. The RTS should detect the switching events (closing and opening of the switches) that occur asynchronously within the simulation step and apply interpolation on the current equations in real-time.

In EMT simulation, the step size is traditionally in the range of 20-100 us (microsecond). And with the advent of more power electronics, especially to connect the traditional power system to renewable energy sources and active loads, and with the switching frequency of these electronic converters being pushed ever higher, and with it the harmonic frequencies, the step size needed could be as low as 1 us or below, usually achieved only by dedicate chips (FPGAs).

These two challenges are studied over a typical modern network, and the solving methods are applied and implemented in the model as shown in the following section.

3. CASE STUDY

The application consists of a micro-grid connected to a large distribution network with 615 nodes (Figure 1). The micro-grid includes:

- A wind turbine delivering a maximum power of 10 kW at a wind speed of 15 m/s.
- A solar panel of type SunPower delivering a maximum power of 5 kW at 1000 w/m2 irradiance. The PV is connected to the grid through a 2-level IGBT inverter.
- A lead-acid battery connected to the grid via a 2-level IGBT inverter. The role of the battery is to absorb or deliver the difference between power generated by the renewable sources and the total load power.
- Three R-L loads representing a neighborhood.

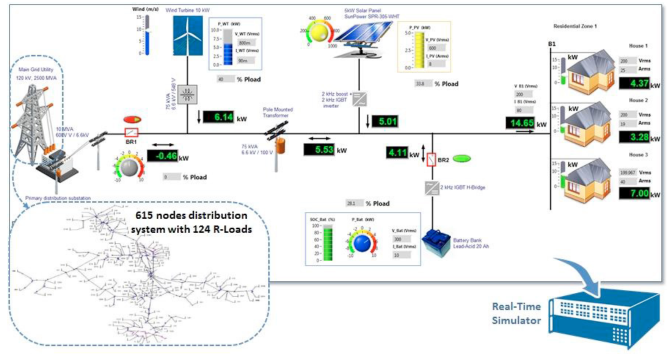

Fig.1. Micro-grid connected to a 615 nodes power distribution network

3.1 RT simulation of large distribution grids

The size of distribution networks is one of the major obstructions to perform an accurate and stable EMT real time simulation. A large distribution network such as the one used in this case study, requires a time step over 300 micro-seconds for EMT simulation using one processor (or core). To reduce the simulation time step to typically 50 micro-seconds, the distribution network needs to be decoupled into smaller sub-networks simulated in parallel using multiple processors or cores.

To simulate the network model on several cores, it should be separated in different subsystems, in order to reduce the complexity of each subsystem and therefore to reduce the simulation sample time.

However, unlike transmission power systems, the decoupling of distribution networks is a very complicated process. Transmission power systems use Bergeron-type line models, with a natural propagation delay [6]. In real time simulation, these delays serve to decouple the transmission power system at the different locations where the transmission lines are placed. The distribution networks contain only short lines (usually 1-10 km), modelled as simple series R-L connections. Which do not allow the Bergeron's line-type logic for power systems decoupling. Therefore the decoupling must be made by other means, such as by adding artificial delays or a short one-time-step delay transmission line (i.e. stublines), that will add a one-step delay and an artificial capacitor to the original system [8]. These delay-based approximations can induce significant accuracy and numerical stability problems.

Distribution networks decoupling: State Space Nodal Solver

In this case study, the 615 nodes distribution network (seen in the lower left corner of figure 1) is decoupled using a real-time solver called State-Space-Nodal (SSN) developed by OPAL-RT Technologies. The SSN (State-Space Nodal) algorithm [7] creates virtual state-space partitions of the network that are solved simultaneously using a nodal method at the partition points of connection. The partitions can be solved in parallel on different cores of a PC without delays in the algorithms.