Multi-Domain Simulation of IEEE 13 Bus System with Microgrid

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***Abstract*—Despite the significant beneficial aspects that renewable energy sources provide, they pose many challenges to the stability of the power system. Large penetration of renewable energy (RE) sources into the power system not only reduce the quality of the power generated but also compromises the stability of the power system due to a reduction in the system's inertia. This paper presents a co-simulation framework for a transmission system and microgrid, using Power System Simulator for Engineering (PSS/E) power system analysis tool, and electromagnetic transient simulator (PSCAD). Additionally, it investigates the possibility of injecting a large amount of various renewable energies into the electric power grid while maintaining the quality and stability of the power generated. A multi-domain simulation of power systems and power electronics is presented. The simulation results demonstrate the effectiveness of multi-domain simulation between the power electronics system and the electric power network.**

Keywords—Renewable energy integration, instability, co-simulation framework, voltage stability.

I. INTRODUCTION

The dynamics of the electric grid are changing due to the large-scale integration of power electronic converters into the grid for the utilization of renewable energy (RE). Therefore, the stability and power quality of the grid has become a significant concern. Integrating renewable energy sources delivers various benefits such as reducing CO_2 emissions, increasing sustainability in the power sector, and increasing the security of power supply, with the addition of microgrids [1]. It can enhance the reliability, security, and resiliency of the power grid. It also can introduce electricity to new remote locations. Hence large-scale integration of RE into the power grid demands the optimization of the sources involved, to improve and enhance the power distribution capacity of distribution networks [2]. Variable renewable energies such as solar photovoltaic and wind have four characteristics that need to be taken into consideration when being integrated into the power system; variability, uncertainty, location-specific properties, and marginal costs [3]. Due to the increase in penetration level of the renewable energy sources via inverter-based sources, the inertia of the power system is decreased which affects the dynamic stability of the grid [4]. The main challenges and issues associated with grid integration of renewable energy resources in microgrids can be divided into two types: technical and non-technical issues. Technical issues include power quality, power fluctuation, storage, and network protection issues. Non-technical issues include lack of technically skilled manpower, less availability of transmission lines, and their exclusion from the competition. In the last years, several solutions have been proposed to such problems to mitigate the impact on the power networks. These solutions include the use of power electronics technologies [5], installation of storage systems [6], and distribution of renewable energy systems into small units [7]. Due to the intermittent nature and variability of the renewable energy sources, there are always some sudden rises and falls in the generated power which causes problems for the available conventional energy sources. Conventional energy sources have high inertia, so these sources take a long time to adjust to new generation levels, unlike renewable energy sources whose response is very fast. Moreover, inverter-based interconnection of renewable energy sources provides no inertia to the power systems and any disturbance occurring in the electric power system causes stability issues [8].

Modeling and simulation of electrical power systems with large-scale integration of renewable energy sources makes it possible to identify any undesirable conditions that can occur during planning and operation, which assures reliable operation. It also can identify any voltage and frequency instability, and provide information on any unexpected disturbance that occurs in the grid. The challenge that may be faced with such a system is that the system can be oversized due to the maximum load, which can limit the number of appliances running at a certain instant. Other than that, carrying out enough analysis can always be tricky given a large-scale system, loopholes could be missed therefore a lot of scenarios need to be carried out. In addition, there are computational challenges in such complexly engineered systems.

Co-simulation framework has become an essential tool for the design and evaluation of power grid solutions. It has significant importance in power electronics simulations, that allows relying on the merits of two powerful environments in a complementary way to improve the simulation accuracy of the application of power electronics in power system simulation; PSCAD is a powerful tool for power electronics system simulation and PSSE software used extensively for the power systems, modeling and it is widely used for power grid planning and operations.

In recent years, several attempts have been considered in the literature to build a co-simulation architecture for power systems, communication, and power electronics in the smart grid [9]-[13]. In [9], the authors attempt to take a holistic approach to the optimal operation of smart integrated energy systems under consideration of resilience, economics, and sustainability. Also, efforts require software programs written in various programming languages that do not have shared data interchange interfaces. A typical approach for the interface schedulers is to process events using a firstin, first out (FIFO) approach in both power and communication networks. Preliminary versions of such event-driven co-simulations use the predefined temporal steps to progress both simulators and run all buffers events at once [10]. Some efforts include EPOCHS [11], VPNET [12], and PowerNet [13].

Such an approach is undesirable for simulations involving real-time systems such as smart grids.

The main objective of this paper is to design a co-simulation framework based on PSCAD and PSS/E software tools. The power electronics domain model consists of the large-scale grid-connected PV plant, large-scale wind farm, diesel generator, and a detailed model of a Li-ion battery with its electronic circuits. The power system domain model consists of the electric power utility IEEE 13 bus system. Detailed modeling of each module within the microgrid is addressed. The performance of integrating the microgrid into the IEEE 13-test feeder is analyzed, which is a highly loaded, unbalanced distribution feeder. Moreover, the control scheme for each distributed energy resource in the microgrid is designed for a reliable operation in both grid-connected and isolated modes. The impact of integrating the integration of renewable energy resources in the microgrid to the grid has been investigated for the future development of robust control algorithms for the power grid. The motivation is to do extensive analysis on any impact renewable energy can have on the stability and the efficiency of the grid through power flow and contingency analysis.

This paper focuses on the power system's dynamic stability during high levels of renewable penetration. The power system domain is modeled using the PSS/E Simulator software tool and the renewable sources along with the controllers are modeled in PSCAD. Both these software tools are used to evaluate the dynamic stability of fault conditions in the power grid. The stability of electrical power networks is assessed with and without the microgrid. The effect of the renewable energy sources on the power system is analyzed through the co-simulation between PSCAD and PSS/E Simulator. The paper is structured as follows. Section II states the modeling details for both systems, microgrid and distribution system. Section III presents the complete model of the co-simulation of the power grid and microgrid. Section IV covers the simulation of all operating scenarios. Finally, Section V concludes the paper.

II. LARGE-SCALE CO-SIMULATION OF POWER GRID AND MICROGRID

The simulation could be run on three levels, namely conceptual level, functional level, and physical level. The conceptual level is referred to as relating a requirement with the components which fulfill it; the functional level referred to as the system is seen as a set of functions realized by a proposed architecture; and the physical level is referred to as the hardware in the loop simulation (HIL), in which the real controller is connected to a simulated physical model of the machine [14]. Functional modeling of a system is subject to all the functions involved within the modeled system areas such as action, activities, processes, and operations, including a structured representation of all the functions that are involved within the model [15]. It clearly defines the flow of process control from the input side to the output side. It also describes the sequence of activities to be performed by the modeled system within its designed limits or other constraints. The above method is quite helpful for understanding the modeled system and how it will behave and perform with other systems. It also informs about what actions will be taken on the input parameters by the modeled system to fetch the results. Through it, a better analysis of the behavior of the modeled system and the necessary modification keeping in view the desired output/results are conducted. Therefore, in this paper, functional modeling is the most convenient approach for the proposed framework to better analyze. The proposed simulation deals with a variety of complex and heterogeneous sub-systems, such as mixed-signal systems and real-time controllers. The distribution system is modeled in Power System Simulator for Engineering (PSS/E) and the microgrid with its control is modeled in the electromagnetic transient simulator (PSCAD) to simulate the fast transient behavior of the inverter-based technology that is used in the microgrid system [16]. During the simulation, the PSCAD system equivalent, which simulates the detailed distributed generating units and their control gets updated from the PSS/E voltage, current, active/ reactive power, and frequency for the distribution system model (IEEE-13 bus test system). Then the PSS®E system gets updated on what happens in PSCAD. Once the hybrid simulation is set up, both programs run in parallel, communicating and updating each other to perform steady-state, and dynamic behavior of large power systems. The next parts cover the detailed large-scale modeling and simulation of the power grid and microgrid.

A. Modeling of IEEE 13-bus system

The IEEE 13 bus system is modeled in the PSS/E simulator as per standard parameters. The detailed model of the IEEE 13 bus test feeder is shown in Fig. 1. It clearly shows it is a radial distribution feeder, consisting of 13 buses which are connected by 10 overhead and underground lines, capacitor banks of 200 kVAr capacity, one voltage regulator, one 3-Phase generating unit 1.5 MW, one transformer Y configuration, unbalanced spot, distributed loads, and breaker. This network is used to integrate the modeled microgrid.

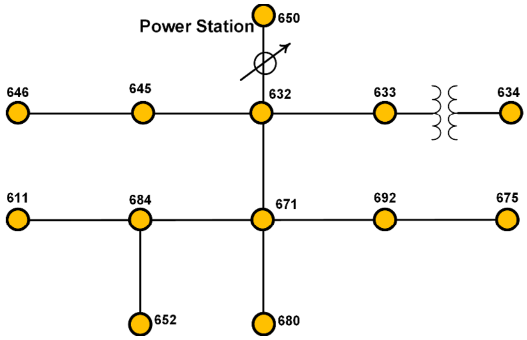


Fig. 1. IEEE 13 Bus System

B. Modeling of Microgrid

The microgrid model has been built in PSCAD, where two hybrid renewable energy sources are used. Fig. 2 shows the schematic configuration of the microgrid under study. Since the operation of the battery energy storage system is one of the most important issues to include in the operation of the microgrid, a detailed model of a Li-ion battery is considered which is connected to a low voltage network. The complete specifications of the grid-connected system are illustrated in Table 1. In this work, a detailed microgrid model and its control has been designed and simulated. Renewable energy sources are modeled with their power electronics interface in PSCAD using its power electronics library. Control actions for distributed energy sources are simulated and validated.

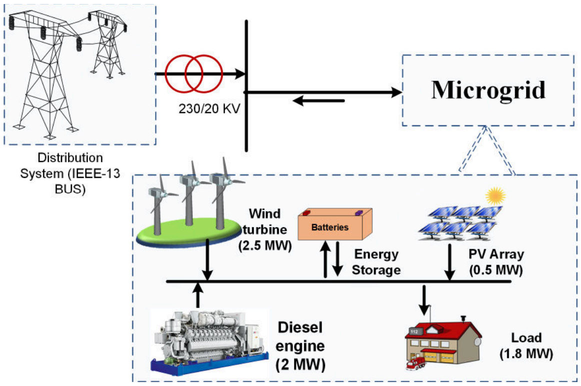


Fig. 2. Schematic configuration of Microgrid

TABLE I
MAIN PARAMETERS OF MICROGRID

Distribution Unit	Active Power (MW)	Reactive Power (MVAR)
Diesel Engine	2.00	*0.8*
Wind Turbine	2.50	*0.3*
Solar PV	0.25	*0.1*
Solar PV+ Battery system	0.25	*0.1*

III. CO-SIMULATION MODEL

A co-simulation framework between PSCAD and PSS/E enables the study of the behavior of power electronics for large renewable penetration with the distribution network.

During the simulation, the PSCAD system equivalent, which simulates the detailed distributed generating units gets updated from the PSS/E voltage, angle, and frequency for the distribution system model (IEEE-13 Node Test Feeder), and the PSS®E system gets updated from what happens in PSCAD through the ETRAN- PLUS for PSSE hybrid co-simulation. Once the hybrid simulation is set up, both programs run in parallel, communicating and updating each other as shown in Fig.3.

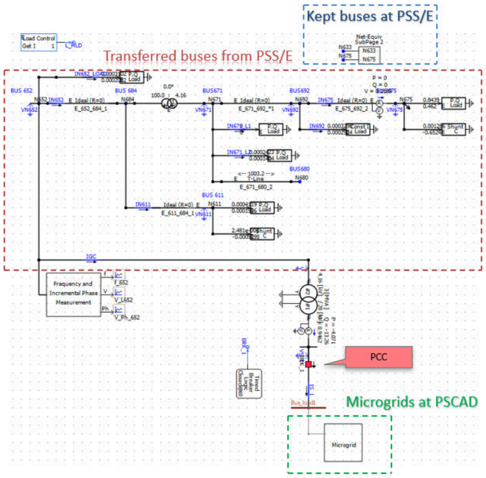


Fig. 3. Complete co-simulation system model

IV. SIMULATION RESULTS

The proposed approach has been tested based on two modes (grid connection and island modes). Through a series of simulations, the basic characteristics of the microgrid in both grid-connected and islanded modes have been obtained. Fig 4 shows simulation results in normal scenarios: (a) voltage terminal at the point of common coupling (PCC); (b) currents at the PCC; (c) active powers, (d) reactive powers at the PCC in grid support and islanding modes.

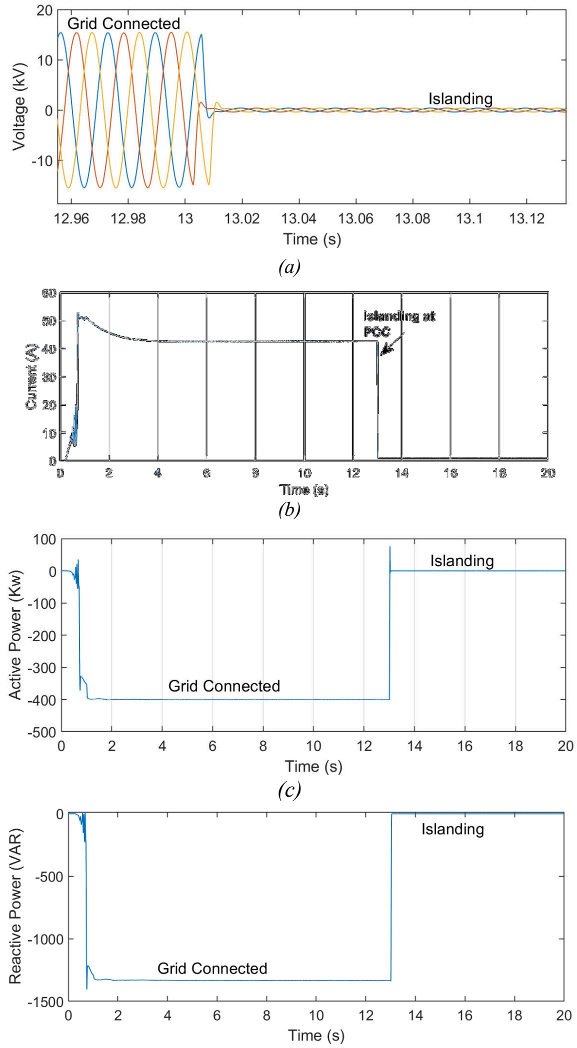
A single line to ground fault is introduced at a time of 7 sec on the PCC Bus to test the behavior of the system during a fault condition. The measurements for the current, voltage, and active and reactive power are presented in Fig. 5. This study is based on a hybrid simulation approach which can have the ability to simulate extended operational scenarios within a short time span and more accurate results compared to the traditional approaches.

A. Case 1: Grid-Connected and Islanded modes of the Microgrid

A microgrid operates mainly in two modes of operation; islanded mode or grid-connected [17]. In general, the interconnection between the distribution network and the micro-grid is carried out by PCC, and both active power (P) and reactive power (Q), flow through the PCC only, it is the link for power exchange between the distribution network and microgrid .

Fig. 4 presents the first case study of the simulated microgrid including two scenarios that correspond to the microgrid operating mode, from t=0 sec to t=13 sec the microgrid is working in a grid-connected mode, consequently switching to the islanded mode by disconnecting from the distribution system at the time t=13 sec. Once the co-simulation was carried out, the data for the whole simulation were exported from the PSCAD. All measurements were conducted at the PCC to investigate the changes in the terminal voltage, currents, and active and reactive power for the distribution system to investigate the behavior of the system during the transfer between the connection and disconnection from the microgrid. The terminal voltages show the stability of the voltage when connecting the microgrid to the distribution system from t=0 where the simulation starts. Then the voltage at the PCC bus drop to zero when the microgrid is disconnected, as shown in Fig.4 (a) where the three-phase voltage drops to zero at t=13 sec when the microgrid turns to islanded mode after being constant from 0-13 sec.

Fig.3 (b) shows a constant current after the transient period where the distributed generation units in the microgrid start to work at their rated capacity at t=0.7 sec. Then the current drop to zero at t=13 sec (islanded scenario). Fig. 4 (c) and Fig.4 (d) show the active and reactive power at the PCC point where the values are P= -400 KW, and Q= -1357 VAR respectively. These negative values indicate the direction of the power flow where the microgrid injects its generated active and reactive power and exceed its loads to the distribution system while it is grid-connected then this power dropped to zero when the system moved to the islanded scenario.



(a)

(b)

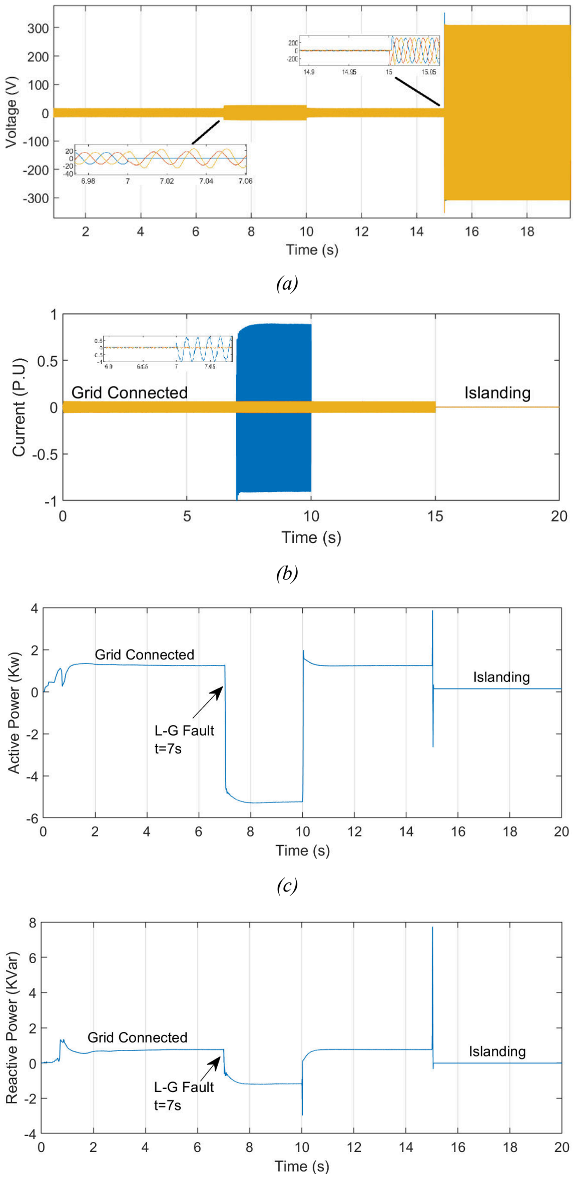
(c)

(d)

Fig. 4 (a) The voltages; (b) The currents; (c) Active powers; (d)Reactive powers at the Point of Common Coupling (PCC) in grid support and islanding modes

B. Case 2 Single line to ground Fault at PCC point

Using the transient stability analysis tool different fault durations have been used to check the stability of the network by analyzing the active power, and reactive power at the Point of Common Coupling (PCC) during the L-G fault. A single line to ground fault is introduced at a time of 7 sec on PCC Bus in the modified IEEE 13-bus test system. Initially, the fault duration is increased in steps of 0.1 second up to 3 seconds. Subsequently, the fault has been cleared, and it has been observed that no instability occurs in the network. The voltages at the PCC under faulted conditions were plotted using the clearing times 7 Sec as shown in Fig. 5 (a). Fig. 5 (b) shows the bus's current angle. Fig.5 (c) and Fig. 5 (d) show the active and reactive power at the PCC point values. The simulation results show that IEEE 13 bus with microgrid improves power systems operation, the system remains stable and reduces rotor angle and voltage instability, which results in reduced generator outages.



(a)

(b)

(c)

(d)

Fig. 5. (a) The voltages; (b) The currents; (c) Active powers; Reactive powers at the Point of Common Coupling (PCC) in grid support and islanding modes during L-G fault

V. CONCLUSION

This paper proposes a co-simulation model driven by an embedded detailed power electronics domain model. The power grid is to be simulated using PSS/E and the microgrid model has been built in PSCAD, where two hybrid renewable energy sources are used. The proposed approach achieves minimum synchronization error and provides the ability to simulate extended operational scenarios. The factors that affect grid stability and efficiency are analyzed by studying the impact of integrating large amounts of photovoltaic and wind renewable energies into the grid. Extensive analysis of any impact renewable energy can have on the stability and the efficiency of the grid is performed through the power flow and contingency analysis. Finally, the numerical results illustrate the effectiveness of multi-domain simulation between the power electronics system and the electric power network. These results show how the co-simulation model can achieve a higher level of understanding of what capability the microgrid integration has in terms of stability and system reliability. The future direction that requires further investigation in the context of microgrid penetration is to investigate the impact of the transition between grid-connected and islanded modes of interaction between distributed systems with a high penetration of distributed generation.

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