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Evaluation of Dynamic Stability of Microgrid Energy Storage System and Solar Power Plant

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Abstract: **-** A microgrid is made up of electrical and thermal loads, distributed generation sources (DGs), and energy storage systems (ESS). The low inertia of the analogous system makes it difficult to control and run an autonomous microgrid without the assistance of the power grid. A small signal model of a microgrid, comprising a solar power plant and a battery energy storage system (BESS), has been simulated in the MATLAB simulator environment in order to look at the dynamic stability of the microgrid. In the system simulation section, the microgrid is put through a series of tests that include lowering the power of the solar power plant, managing the active and reactive power, compensating for imbalances, and Gridforming-Gridfollowing operations to synchronize with the grid. Microgrid control ensures that the microgrid operates correctly under a variety of tests in both states where it is connected to the power grid and when it is disconnected from it, based on the outputs.

Keywords: microgrid, energy storage system, photovoltaic system, droop controller and dynamic stability

1. Introduction

Through appropriate regulation of storage systems, microgrids can be viewed as an advanced form of distributed generation systems that have less of an impact than random distributed generations (DGs), such as PV arrays and wind turbines. taken into account transmitted loads and energy (ESS) [1] and [2]. The microgrid is crucial to the efficient use of renewable energy sources, the steady operation of the public power system, and the enormous advancement of renewable energy sources [3] and [4]. Normally, distributed generation sources can be connected to the microgrid through electronic power converters or rotating machines [5] and [6]. The microgrid's functioning is more flexible and the electronic power converter reacts to the controller rapidly. However, in the event of a system disturbance, this kind of link may oscillate [7], On the other hand, synchronous generators with excitation systems are typically included in the second type of connection (spinning machines). and governor, as well as small- to medium-sized asynchronous wind turbines (AWT).

A microgrid typically has two operating modes: off-grid and grid-connected. To ensure a reliable power supply for key loads, proper switching between these two operational modes is vital [8]. and [9]. Controlling and managing the microgrid is more difficult without the support of the main grid, because the microgrid has significantly less physical inertia than the main grid. Some moderate or even minor disruptions, like as changes in the output power of PV arrays or wind turbines, or local load interruptions, can cause problems with power quality and system stability, particularly with voltage and frequency reductions. It is accompanied. Energy storage can now be controlled to release or absorb active/reactive power more flexibly thanks to advancements in power electronics. When energy storage is integrated into the microgrid, it can preserve the system's instantaneous energy balance while also improving dynamic performance through suitable energy management tactics, effectively boosting the system's inertia. As a result, the impact of power fluctuations and other disruptions from distributed production sources on system stability and power quality can be significantly minimized, which is critical for microgrids operating independently.

Many energy storage technologies and their applications in microgrids have been lately investigated, including lithium-ion batteries, Flywheel Energy Storage (FES), supercapacitors, superconducting magnetic energy storage (SMES), vanadium redox batteries (VRB), and so on [10] and [11]. One of the most important concerns in the reliable operation of the microgrid is dynamic stability. In conventional power systems, stability analysis with standard models of synchronous machines, governors, and excitation systems with different orders that modes

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importance for certain classes of problems is well established; however, this is not yet the case for microgrids, which could be due to the wide range of power technologies that may be used. It is difficult to accomplish. Therefore, full models of microgrids with scattered generation sources are required. Small signal models and generations based on inverters and power grids have been developed, and dynamic properties in independent operation mode have been investigated using different models [12] and [13]. The general small-signal model of inverter-based microgrid has been launched to design the controller of inverter-based DGs. Figure 1 shows an example of a microgrid that includes distributed generation sources (electric power plant, wind turbine, etc.), energy storage systems, electrical and thermal loads, combined cycle power plant, and microgrid control system. It can operate in the operating mode, separated from the grid or connected to the power grid [14].

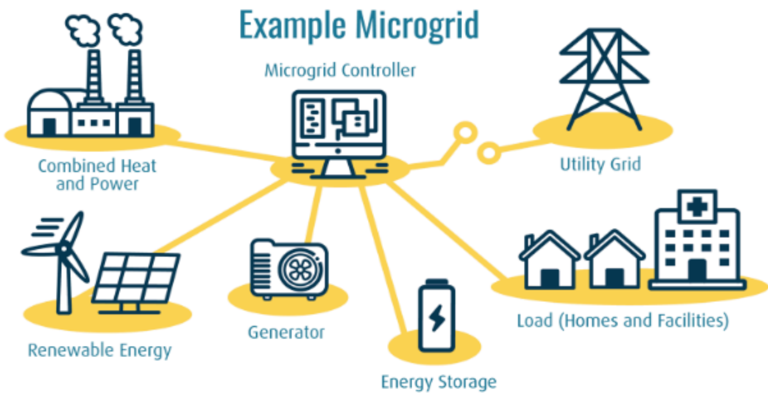

Figure 1- An example of a microgrid

2 .Description of the used microgrid mode

A microgrid model (SPS) consisting of a battery energy storage system (BESS) and a solar power plant has been simulated, demonstrating that the microgrid can operate in both grid-forming and grid-following modes. Several various tests may be run on this model to ensure dynamic stability, including grid-following to grid-forming operation, following synchronization with the grid, lowering the power of the solar power plant, and other tests (P&Q control). and imbalance adjustment), which are described in the simulation section.

The used microgrid model is shown in Figure 2. The various components of the microgrid model used are described below.

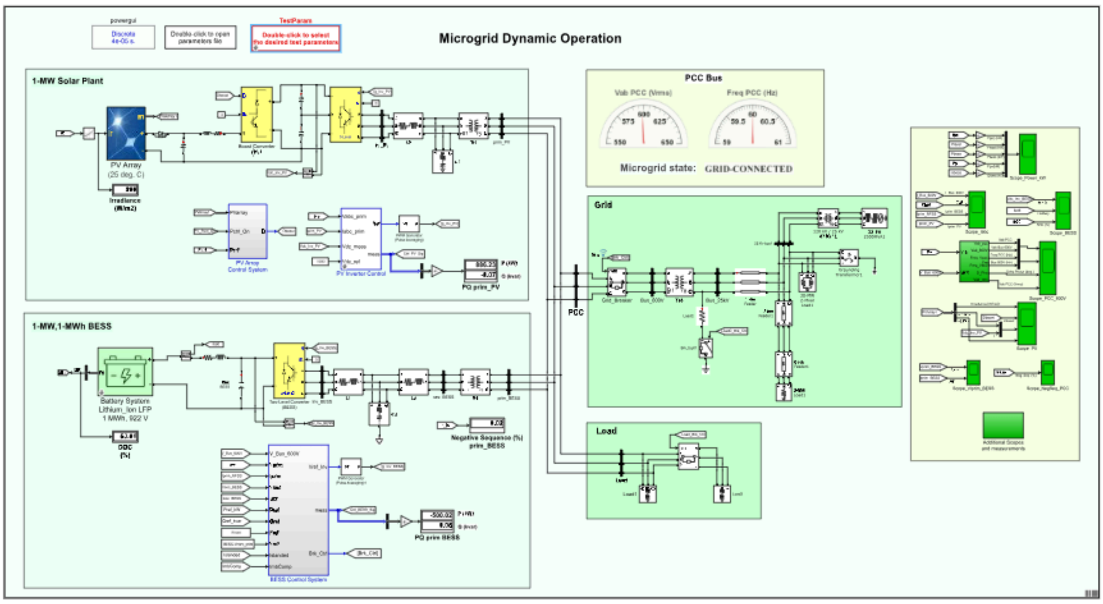

Figure 2- Used microgrid model

1-2 Distribution system

The electrical network is modeled using 120 kV network, transformers and 25 kV feeders. A single-phase load can be connected to unbalance the network. A three-phase breaker and a 25 kV/600 V transformer are used to connect the microgrid to the distribution system.

2-2 **BESS**

The battery energy storage system model consists of a battery system, a two-level converter, an LCL filter and a 480v/600v transformer. BESS also includes a control system that provides a reference voltage (Vref) to the PWM that controls the converter and also produces a control signal (open/close) for the network breaker. The battery system model is made of 3.2 V, 14 (amp/h) lithium iron phosphate (LFP) cells. They are arranged in several cell modules (72 4 cell modules) which are connected in series to form a 922V battery string. The battery system of the used model has 80 battery strings in parallel to form a system with a capacity of 1 megawatt hour. The specifications of the battery discharge system are shown in Figure 3. The three-phase, two-level converter model used is of the switching function type, along with the average pulse PWM generator, which has a switching frequency of 2.7 kHz, the system can be accurately simulated with a time step of 40 µs.

The main components of the BESS control system are:

•Synchronization unit

If the microgrid is linked to the distribution system without synchronization, out-of-phase reclosing occurs, resulting in extremely high inrush currents. To avoid this, the synchronizing device aligns the microgrid's voltage with the voltage of the distribution system before resetting the network breaker. This guarantees a steady link to the distribution system. The synchronization procedure takes three seconds. During such time, the PI regulators gradually equalize the voltage and frequency of the microgrid with the main grid.

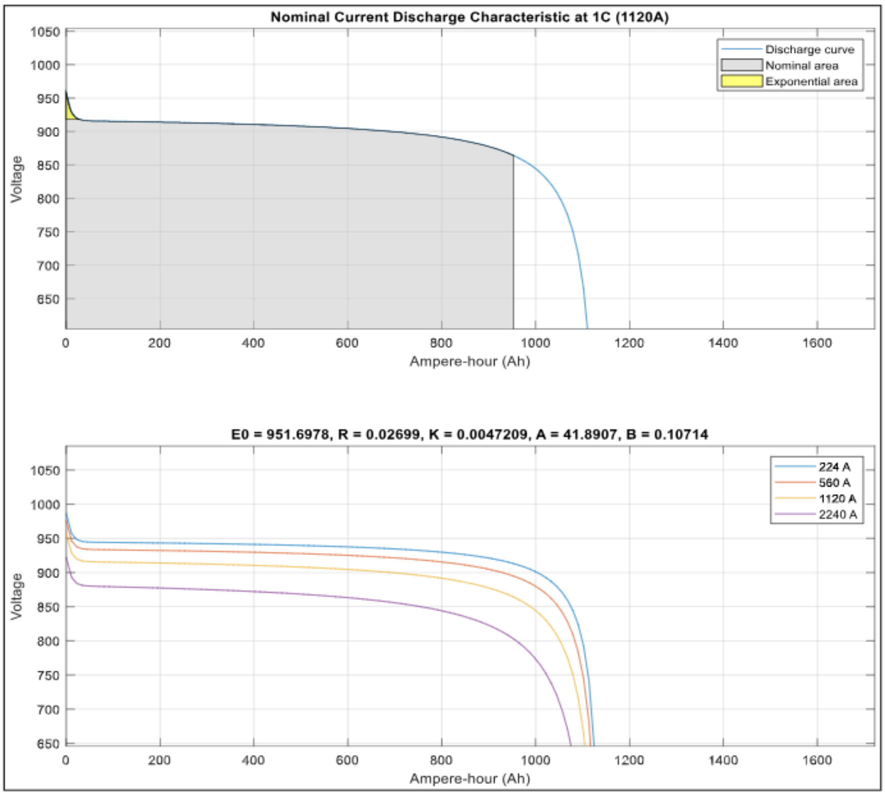

Figure 3- Characteristics of the battery discharge system

•Droop controller

In grid-forming mode, BESS must control the frequency and voltage of the microgrid. The BESS has a P/F control droop set to 0.5%, which means that the microgrid frequency is allowed from 60.3 Hz (the inverter draws its nominal active power) to 59.7 Hz (the inverter draws its nominal active power). produces) to change. The Q/V control droop is set to 3%, which means that the microgrid voltage at the PCC bus is allowed to vary from 609 Vrms (the inverter draws its full inductive power) to 582 Vrms (the inverter produces its full capacitive power). can) change

•Measurement

The measurement subsystem calculates the active and reactive power produced by the inverter. It also calculates the d-q components of three-phase voltages and currents in the microgrid PCC bus (common connection point).

•Voltage regulators and power regulators

In grid-forming mode, d-q voltage regulators are active. They process the measured voltages d-q and the reference voltage Vref to produce the reference currents Id-ref and Iq-ref. In grid-following mode, active and reactive power regulators are active. They process the measured power (Pprim & Qprim) in the BESS primary bus and the power reference signals Pref and Qref to produce the reference currents Id-ref and Iq-ref.

•Flow regulators

The reference currents Id-ref and Iq-ref are sent to the current regulators. The regulators process the measured and reference currents to produce the required d-q voltages (VdVq-conv) for the inverter. It should be noted that the regulators use feedforward calculation to achieve high dynamic response.

•Vref Generation

The scaled VdVq-conv is converted into a three-phase signal Vref, which the PWM modulator gives the generated pulses to the inverter.

•Imbalance

Imbalance compensator

When enabled, the Imbalance Compensator reduces the negative sequence voltage on the PCC bus due to load imbalance in the network. It uses a d-q outer-loop voltage regulator and an inner-loop d-q current regulator.

3-2 load

The simple load display includes a fixed three-phase (PQ) load model and a second PQ load model that can be switched on/off.

4-2 Solar power plant

The solar power plant consists of a PV array that can produce 1 megawatt at 21000 W/m of solar radiation and a cell temperature of 25 degrees Celsius. The specifications of the PV array are shown in Figure 5. The array is connected to a boost converter. The boost converter is controlled by a maximum power tracking (MPPT) system. MPPT uses Perturb and Observe techniques to change the voltage at the terminals of the PV array to extract the maximum possible power. However, when limiting operation is required, the boost converter is controlled by an active power regulator. The output of the amplifier converters is connected to a 1000 volt DC bus. A three-level NPC converter (switching frequency 2340 Hz) converts 1000 V DC to about 500 V AC. The NPC converter is controlled by a DC voltage regulator whose task is to maintain the DC link voltage up to 1000 V, regardless of the amount of active power provided by the PV arrays, an LC filter and a 1 MVA (480 V) three-phase coupling transformer. /600V) is used to connect the converter to the microgrid.

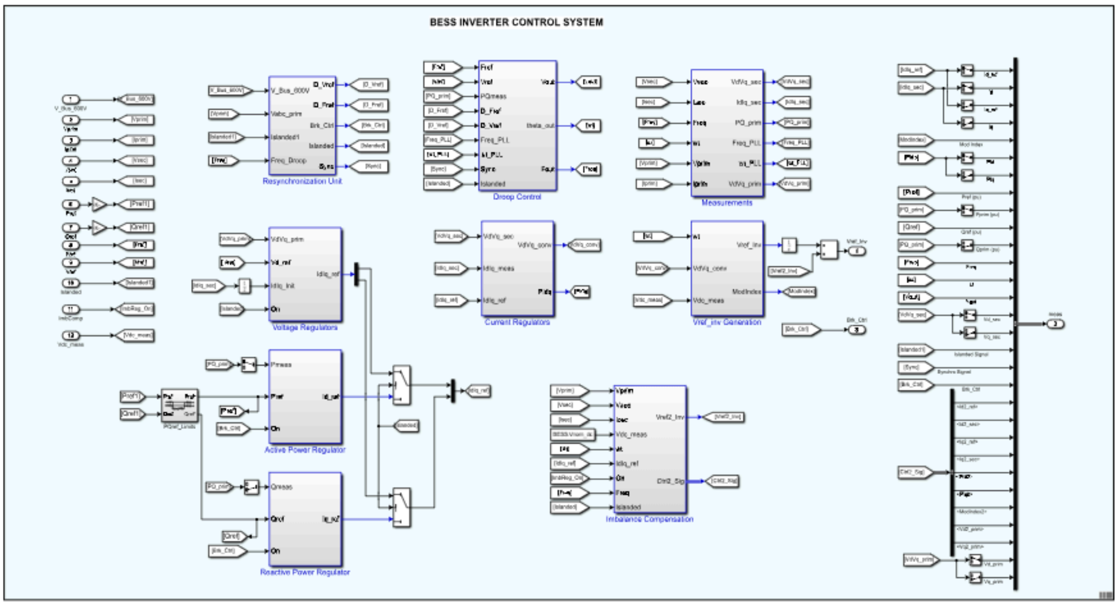

Figure 4- Microgrid controller system

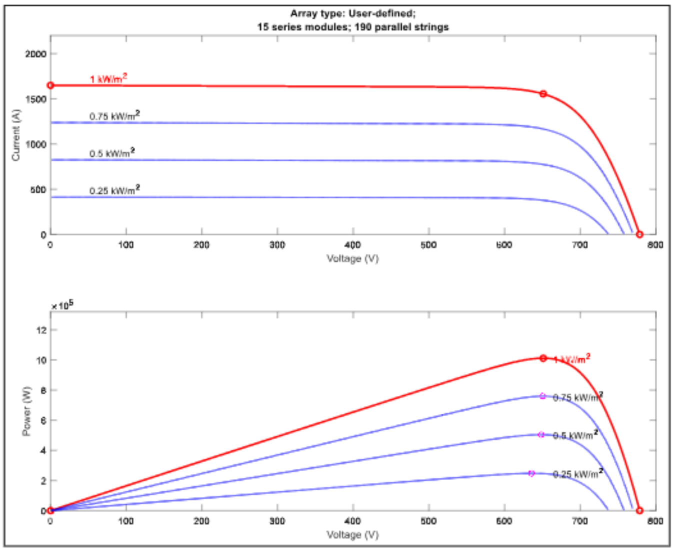

Figure 5- Characteristics of PV array

3. Simulation and interpretation of results

Four tests are performed to check the dynamic stability of the model, which are:

Test 1: BESS in Grid-Following Mode, PQ Control, and Variable Irradiance

Test 2: BESS from Grid-following to Grid-Forming, followed by grid synchronization

Test 3: BESS in Grid-Forming Mode and Solar Power Reduction

Test 4: BESS in Grid-Following mode, imbalance compensation (negative sequence).

Test 1 shows the performance of BESS in grid-following mode (PQ control) and the effect of a change in radiation on the solar power plant and BESS systems.

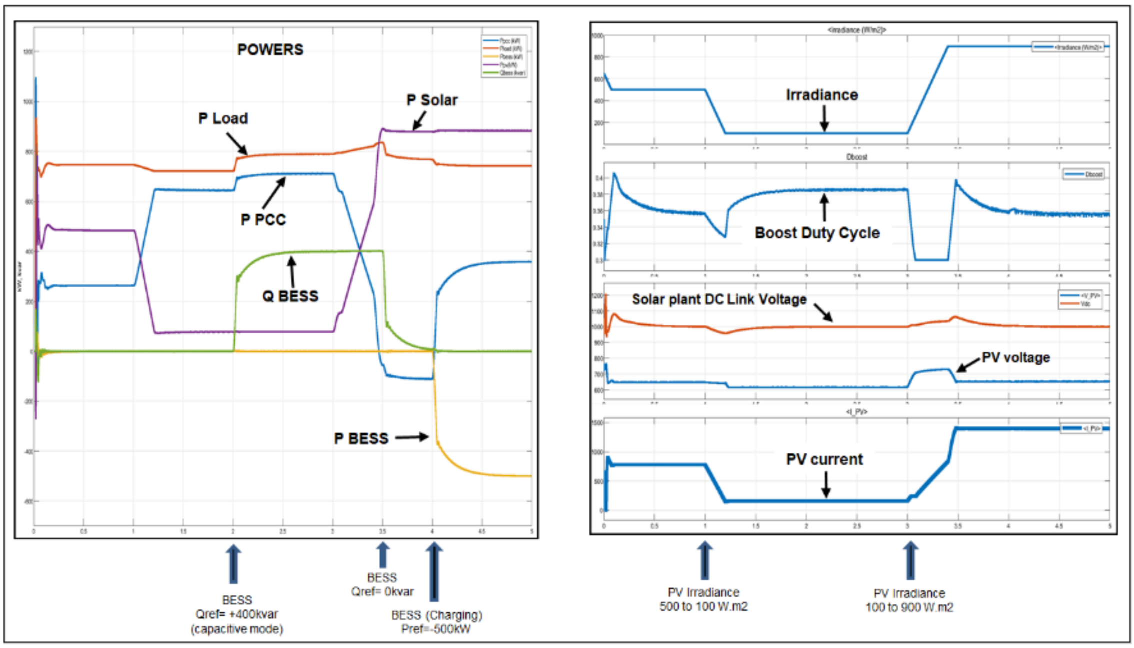

Figure 6- Test 1 results on the used microgrid

Test 2 shows two modes of BESS operation: Grid-following and Grid-forming. A synchronization with the grid is also done to connect the microgrid to the distribution system.

Test 3 shows the reduction of renewable energy. Derating means that the output of the PV array is less than what it could produce, taking into account the actual solar radiation. In the experiment of the paper, a large load shedding is simulated, creating a condition where the generated power exceeds the load demand of the microgrid. Then the BESS temporarily absorbs the excess power and sends a signal to the PV array control system to change from an MPPT control to a PQ control mode to reduce the output power of the solar power plant.

Test 4 shows the performance of BESS imbalance compensation system. In this test, BESS is in grid-following mode and produces 300 kvar power. In 0.5 seconds, a large single-phase load is connected, which causes an imbalance in the microgrid (1.5% negative sequence voltage). Half a second after this event, the imbalance compensation system is activated.

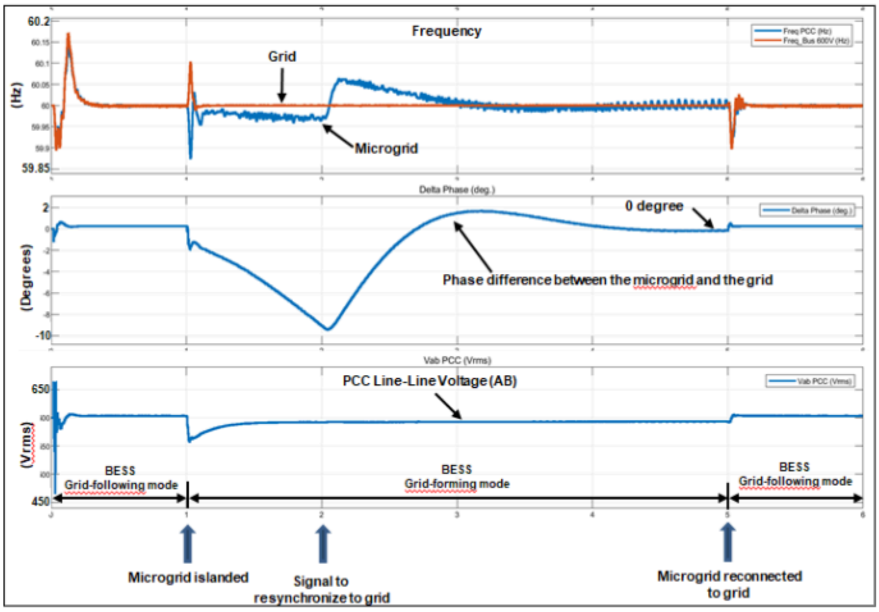

Figure 7- Test 2 results on the used microgrid model

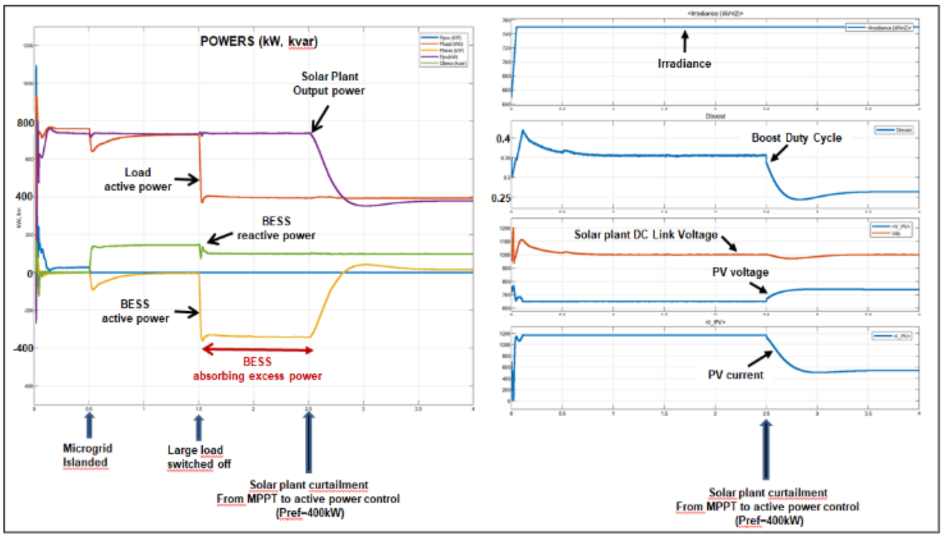

Figure 8- Test 3 results on the used microgrid model

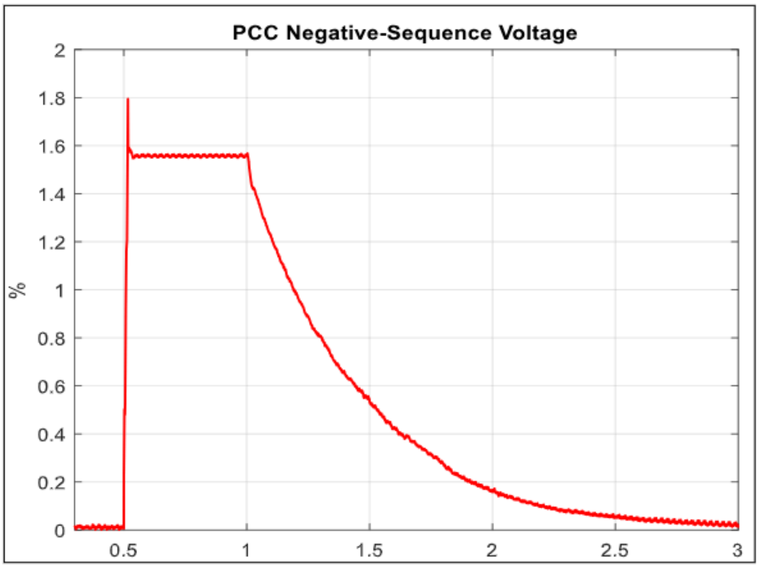

Figure 9- Negative sequence voltage in test 4

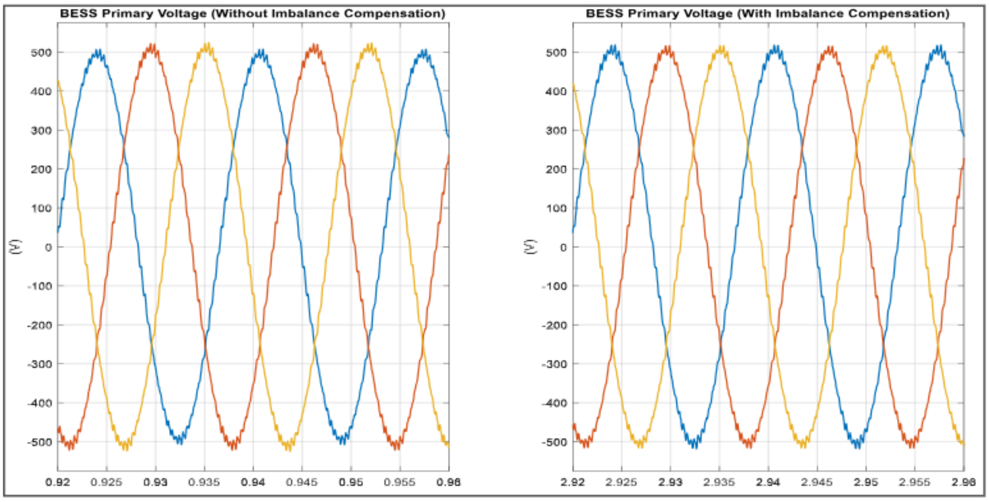

Figure 10 - Initial voltages and currents of BESS in test 4

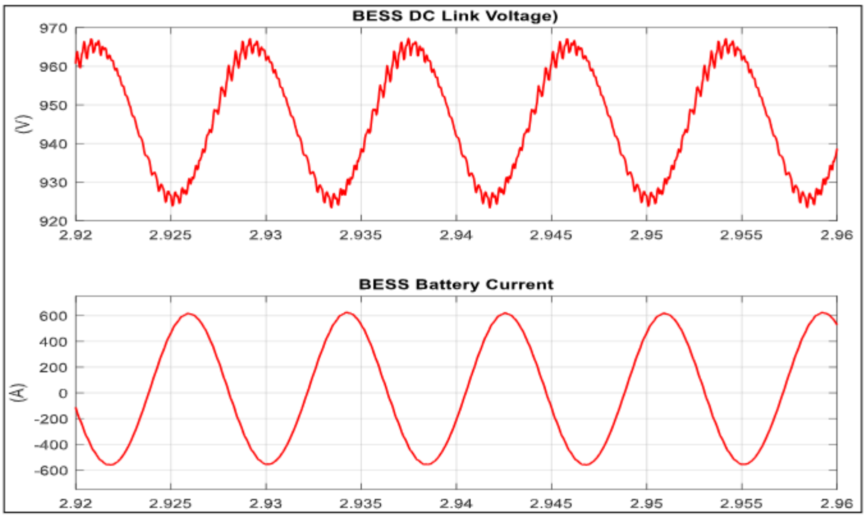

Figure 11- DC link voltage and battery current during compensation in test 4

4.Conclusion

In this article, in order to investigate the dynamic stability of the microgrid, a microgrid consisting of an energy storage system along with a solar power plant has been used. The used microgrid uses Droop controller and can work in two functional modes independent of the power grid and connected to the grid. be In the state connected to the grid, the microgrid can work in Grid-forming and Grid-following mode, and the synchronization with the main grid is done well with the PI regulator. In the following, in order to check the dynamic stability of the used microgrid, four different tests are performed. In the first test, the microgrid is in grid following mode and in PQ control mode, and the radiation is variable. In the second test, the microgrid with Paying attention to the frequency difference and phase difference with the main grid, it is placed in the functional modes of following the grid or following the grid and synchronization with the grid is done. In the third test, the performance of the microgrid is measured by reducing the power of the solar power plant. and in the fourth test, the performance of the microgrid has been measured in the state of connecting a large load and creating imbalance conditions, finally, according to the output of the simulations, it is clear that the used microgrid and the designed control structure have a suitable performance. will have

Resources

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