AN IMPROVED MICROGRID MODEL INTEGRATING DG DISTRIBUTED GENERATION SOURCES USING THE IEEE 13 BUS SYSTEM

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Abstract
A combination of factors—including a meteoric increase in energy demand and the depletion of traditional energy sources—has resulted in a global shift in emphasis toward renewable energy sources. Using microgrid technology, distributed generation (DG) units powered by renewable energy sources may be seamlessly and reliably included into the system. It is common practice to employ inverters to connect the DGs to the microgrid. Reliable microgrids need to operate in both standalone and grid-connected modes. A fast mode transition would have a negative impact on the functioning of the DG inverter system. An effective microgrid model was created and tested in this work using MATLAB/Simulink. The proposed architecture is meant to efficiently include DGs with inverter interfaces into the microgrid. The IEEE 13 bus test feeder has been converted into a microgrid by adding distributed generation (DG) components such a diesel generator, solar photovoltaic (PV) block, and battery. The MG model is distinguished primarily by its dual-mode optimization, which ensures exceptional dependability. In order to guarantee the planned MG model can connect to the power grid reliably, a control strategy for the DG inverter system based on PI controllers and DQ-PLL (phase-locked loop) has been designed. The suggested approach provides constant voltage in both standalone and grid-connected modes. The power quality has been enhanced by using an LCL filter to regulate the introduction of harmonic currents. The effectiveness of the MG model in the design has been evaluated by MATLAB/Simulink simulation results.

Keywords: Distributed generation (DG), photovoltaics (PV), batteries, and phase-locked loops (PLL)

Introduction
The increasing need for electricity, the depletion of fossil fuels, and the imperative for clean power have all contributed to the rising prominence of renewable energy sources [1]. Distributed generation (DG) has been proposed as a possible remedy for the recent widespread outages [2]. Distributed generation, sometimes known as centralized energy [3], proposes the idea of on-site generating. The best way to incorporate DG into the power grid without completely replacing the distribution infrastructure and spending a fortune is to set up a microgrid [4]. According to the United States Department of Energy, "a set of linked loads and dispersed energy resources within clearly defined electrical borders that function as a single controlled entity with regard to the grid" constitutes a microgrid. A microgrid may connect and disengage from the grid to enable both grid-connected and island modes of operation [5]. The components of MG and the difficulties they face may be easily identified and understood. When all of these components are merged to make a real-time MG, however, the research as a complete system becomes quite complex. [6]. Current research efforts are focusing on MG modelling in an effort to develop a fully-controllable and trustworthy system. Modelling the MG and simulating it are required for fault analysis, stability analysis, dependability operation, design of protection and control system, application of optimization approaches, economic dispatch, and unit commitment [7–14]. Mathematical modelling, real-time modelling, and dynamic modelling are among the modelling strategies used in the design and simulation of MG, as discussed in the literature review [15]. Designing and modelling MG may be done using a variety of different

software [16]. These include the ubiquitous Simulink and MATLAB, as well as PSCAD, EMTDC, ATPDraw, ETAP Grid, and RAPSim. Because of its adaptability and precision, MATLAB/Simulink was chosen for this project. It comes with its own set of modules, and it also allows users to build their own library, if they so want [17]. MG's categorization (MG for rural, urban, or industrial usage) and structure (MG's component, communication, information, application, and business levels) are all explained in detail in [18]. Installation of DGs into the electric system requires careful monitoring in order to guarantee system dependability, safety, and power quality [19]. Parameters for interconnecting DGs to the grid are outlined in [20]. Even if the grid handles all the control in grid-connected mode, MG still has to deal with certain crucial loads at the Point of Common Coupling PCC. Consequently, it serves as a PQ bus when linked to the mains. When operating in island mode, power is disconnected from the main grid source. In this configuration, the MG operates as the PV bus and is responsible for maintaining a consistent frequency and voltage. Both in grid-connected and isolated modes, MG must keep constant currents to follow the main grid's predetermined signals, and in isolated mode, MG must keep constant voltages to provide load. Voltage source inverters connect microgrid's DGs to the main grid. In grid-connected mode, electricity from DGs is supplied via these inverters. However, due of the non-linear loads and voltage harmonics at PCC, the inverters cause extra harmonic currents to be injected into the grid. Besides increasing power losses, it causes power quality issues. The droop control loops provide a significant problem with harmonic current insertion while operating in islanded mode. Harmonic current sharing between the inverter's output impedance and the line impedance causes voltage aberrations at the power factor correction (PFC) stage. These voltage distortions lead to instability because of MG's resonant nature. The amount of harmonics that can be fed into the grid is finite. Total harmonic current distortion (THD) at the rated output power must be less than 5%, as specified by IEEE Standard 1547. Harmonic insertion by DERs is simulated in an MG model in MATLAB. Researchers have developed a variety of methods for filtering out the harmonic components. Common practice includes connecting active and passive filters in series or in a shunt configuration. The MG model in the literature is intended to supply loads through DGs and makes use of power converters based on the PWM (Pulse Width Modulation) technology. Power electronics interface is modelled in MATLAB/Simulink in an MG model that uses PV (Photo Voltaic) and PEMFC (Proton Exchange Membrane Fuel Cell). The MG model is modelled with data collected in real time. A plan is developed for the realistic incorporation of MG into a power system, and a method for optimizing the use of Energy Storage devices is given. However, these techniques don't help with voltage distortions in MG because they're too expensive to be practical. In addition to reducing harmonics, the technique provided here helps build a voltage management system that maintains a constant voltage supply in the isolated mode and a constant current supply while connected to the grid. The Optimized MG model presented here is unique due to the following aspects: • Detailed modelling instructions for each MATLAB/Simulink module are provided. • The efficiency of the DGs is measured by connecting them to the severely loaded IEEE 13-test distribution feeder. MG functioning in both grid-connected and isolated modes is guaranteed by the control schemes developed for each individual block. • A control strategy for PV arrays that reliably employs the Maximum Power Point Tracking (MPPT) method was developed using the Model Predictive Control (MPC) approach. • A separate control method for inverter-based sources has been devised to guarantee the secure integration of DGs into the main grid. Constant current is provided by the control technique while the system is linked to the grid, and constant voltage is provided when the system is operating in an isolated mode.

Proposed System

The work here involves the development and simulation in MATLAB Simulink of an optimized microgrid model. In order to create the microgrid model, dispersed generating sources are installed in an altered version of the IEEE test bus feeder. This consists of a control system for enhancing MG dependability, a diesel engine generator, a PV module, and a battery module. The DGs are distributed such that they complement one another and facilitate the microgrid's efficient functioning. In order to guarantee the functionality of the microgrid in both grid-connected and islanded mode, the control schemes inside the modules are tailored for each block. Without considering the voltage regulator, a complete model of an IEEE 13 bus test feeder is created in MATLAB. Detailed explanations of the load, line, and other component models are provided. Control plan in diesel generator type with diesel engine governor and hydraulic governor described in depth. To maintain peak power production, PV modules use a model prediction algorithm based on maximum power point tracking (MPPT). In both grid-connected and isolated modes, the battery control relies on bidirectional voltage source converters to power the battery module's charging and discharging functions. For inverter-based sources, distinct voltage and current control systems are developed to keep voltages and currents stable in grid-connected and isolated modes, respectively. Harmonic current sharing is enhanced with the use of LCL filters. These building components are all modeled and simulated in depth using MATLAB (Simulink).

The IEEE 13-bus Test Feeder System
A Model the grid length is relatively modest at 8200 feet, but it is strongly loaded with a voltage of 4.16 kilovolts. One 4.16 kV/480 V in-line transformer connected in a Y-configuration, imbalanced spot, dispersed loads, and a breaker make up the system. The 13 buses are linked together by 10 overhead and subterranean cables.

Modelling Load
Three-phase and single-phase loads with constant PQ, I, or Z coupled in delta or Y-configuration make up the bulk of the IEEE test bus feeder's load. Three-phase balanced loads are represented in Simulink using a special three-phase dynamic load block, whereas single-phase unbalanced loads are modelled with regular single-phase dynamic load blocks. According to equations (1) and (2), the reactive power Q for load may be calculated from the actual power P.

$$P = Po\left(\frac{U}{Uo}\right)^{np} \quad (1)$$

$$Q = Qo\left(\frac{U}{Uo}\right)^{nq} \quad (2)$$

where the starting values of active power, reactive power, and voltages are Po, Qo, and Uo, respectively. Types of loads (PQ, I, and Z) are controlled by the constants np and nq. This model takes into account the finer points of the load models as stated by IEEE [35]. As can be seen in Table I, the total load on all three phases is not balanced.

TABLE I: TOTAL LOAD OF ALL THREE PHASES

Phases	Active Power P (MW)	Reactive Power Q (kVAR)
Phase A	1.175	416
Phase B	1.039	465
Phase C	1.625	878

Line Model
Lines of distribution feeders may be modeled with the help of the suggested PI-line model, as seen in Fig. 1. There provides access to the IEEE-required information for line setup, impedance, andadmittance. Parameterization of the load model was accomplished via a MATLAB script.

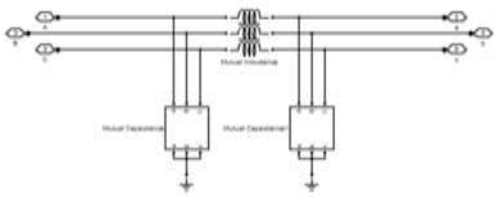


Fig. 1. 3-phase PI line model.

Transformer Model
In Table II [35], the following parameters are utilized for the 3-phase transformer model block:

TRANSFORMER BLOCK SPECIFICATIONS

	kVA	kV-high	kV-low	R-%	X-%
Substation	5000	115-D	4.16-Gr.Y	1	8
XFM-1	500	4.16-Gr.W	0.48-Gr.W	1.1	2

Capacitor Model

Table III contains information about the capacitors used in the series RLC branch model of the capacitor banks.Figure 2 depicts a model of a 3-phase capacitor bank.

CAPACITY INFORMATION TABLE III

Node	Ph-A	Ph-B	Ph-C
	kVAr	kVAr	kVAr
675	200	200	200
611			100
Total	200	200	300

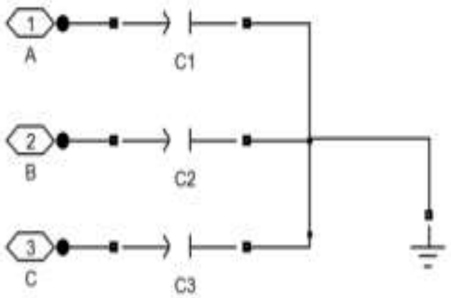


Fig. 2. 3-phase capacitor bank model.

Voltage Regulator

The purpose of this study is to use DGs to create a simplified model of a micro grid without compromising on accuracy. This is accomplished by omitting the voltage regulator from the model of the IEEE-13 Bus system. Given that DGs may affect grid voltage.

IEEE-13 Bus Test System Modelled in Simulink

By modifying these variables, the model presented in may be optimized for specific applications. See Fig. 3 for a representation of the IEEE-13 bus test system's Simulink model.

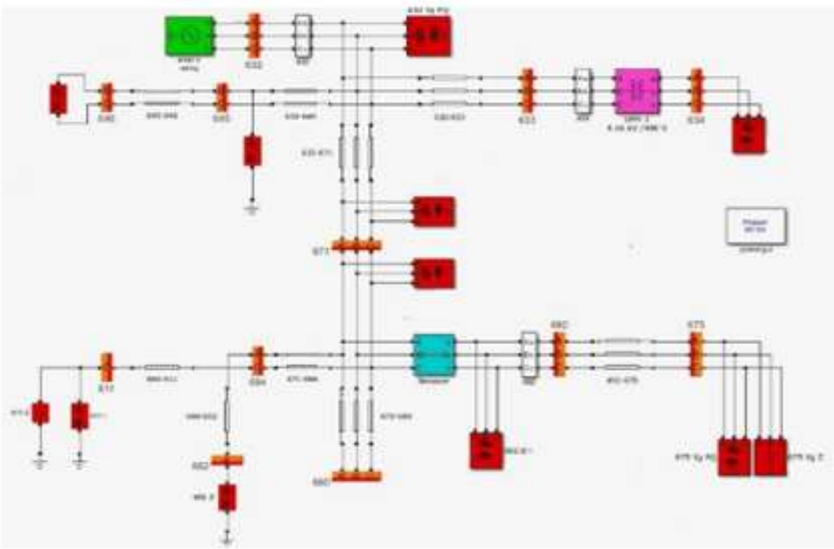


Fig.3. Simulink model of IEEE 13-bus system

Control Scheme in Proposed Micorgrid Model

Both standalone and grid-connected modes of operation are possible with the proposed microgrid paradigm. Power in a microgrid is managed by converter controllers, which vary depending on the distributed generating type. The LCL filter, current controller, and voltage regulator all work together to provide stable power quality in any mode.

Filter using a Least-Common-Superset (LC)

An LCL filter compensation is employed on the grid side to filter the harmonics introduced by the voltage source converters, which improves the harmonic current sharing. In Fig. 4 we see the LCL filter in action.

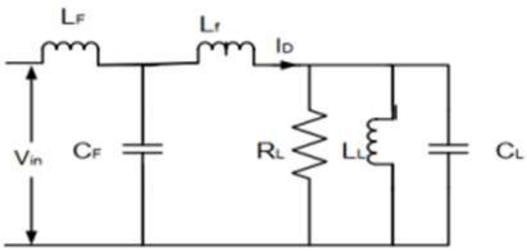


Fig.4. LCL filter and parallel RLC load circuit.

Islanded Mode

Isolating the MG means that its main supply is turned off. When operating in isolation, the grid stops sending voltage and frequency reference signals to the MG. In such a circumstance, MG must adopt a new standard to ensure consistent power quality. The droop control, phase locked loop DQ-PLL, and PI controller are used to produce this new standard. In both grid-connected and isolated modes, the battery and PV module are run in PQ (active power-reactive power). As can be seen in Fig. 5, a control strategy is developed using the suggested control scheme, which is based on dq reference. Both a power control loop and a current control loop make up the suggested controller. Power control loop current setpoints are provided by the power control loop. To do this, d-axis alignment with the grid voltage is required. When implementing a control plan, it is common practice to rotate the dq reference at the fundamental frequency. The fundamental frequency is determined by the PLL block. The converter's output voltage and current are extracted by the PLL blocks using park's transformation. Sinusoidal commands are transformed into DC commands using dq reference, and PI compensators are included into control design blocks.

Modulator of Voltage

The purpose of the voltage controller in the islanded mode is to maintain a consistent voltage supply to the load through the inverters. Voltage control is accomplished by current compensation[50]. The two loops that make up the planned control system. 1.closed circuit of the internal current. The second loop, the external current loop. Figure 6 depicts the block diagram of the LCL filter, RCL filter, and PI controllers. The PI controller transfer function is defined in (3).

$$C(S) = K_p + \frac{K_1}{S} \tag{3}$$

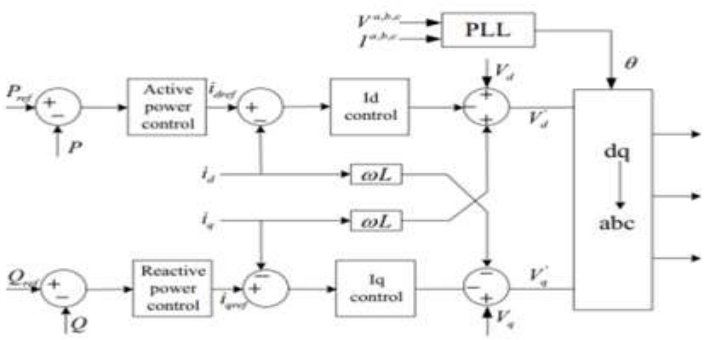


Fig. 5. PQ (active power-reactive power) control strategy

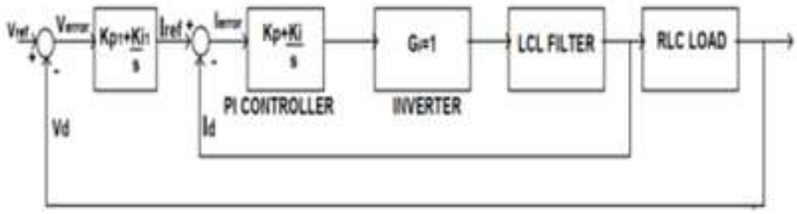


Fig.6 Block diagram of voltage control inverter

Grid Connected Mode

Voltage and frequency are tracked by the grid while in Grid linked mode. In this configuration, the grid is in charge of meeting demand, while MG continues to manage a subset of important loads at the point of common coupling (PCC). The MG reference signals are being generated by the hydraulic turbine governor, which is tracking the grid's frequency and voltage. This signal, produced by a hydraulic turbine governor, is being used as a reference by all the dispersed generators.

Current Controller

The MG operates in constant current mode when connected to the grid, and it must closely adhere to the specified power. The current controller's goal is to keep the current flowing steadily. The LCL filter and RLC load circuit blocks are used to determine the transfer function for the current controller. Assume that the gain is 1. Figure 7 depicts the ensuing block diagram.

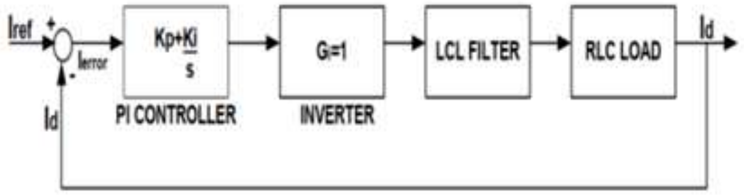


Fig 7. Block diagram of current control inverter

Simulation Results

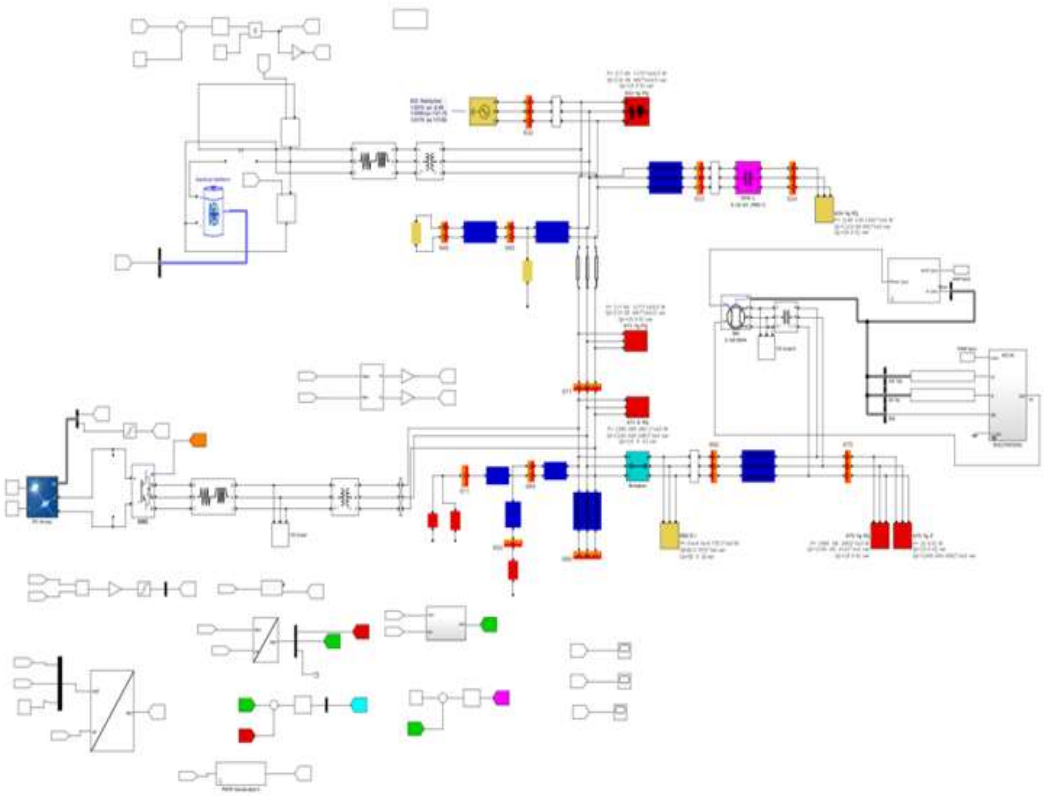


Fig.8. MATLAB/SIMULINK circuit diagram of the Microgrid Model

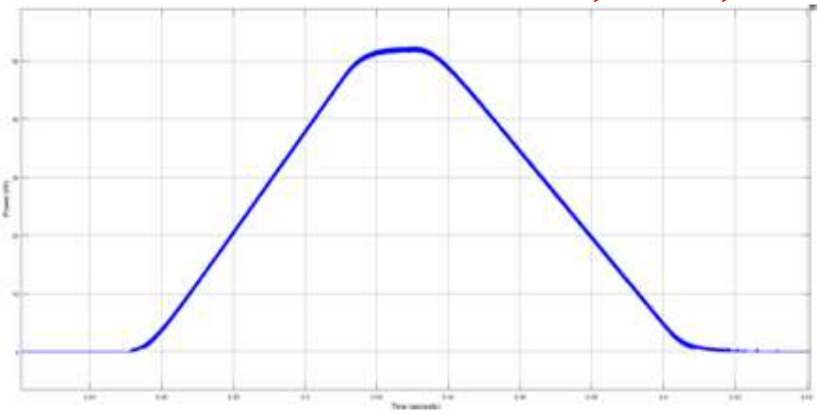
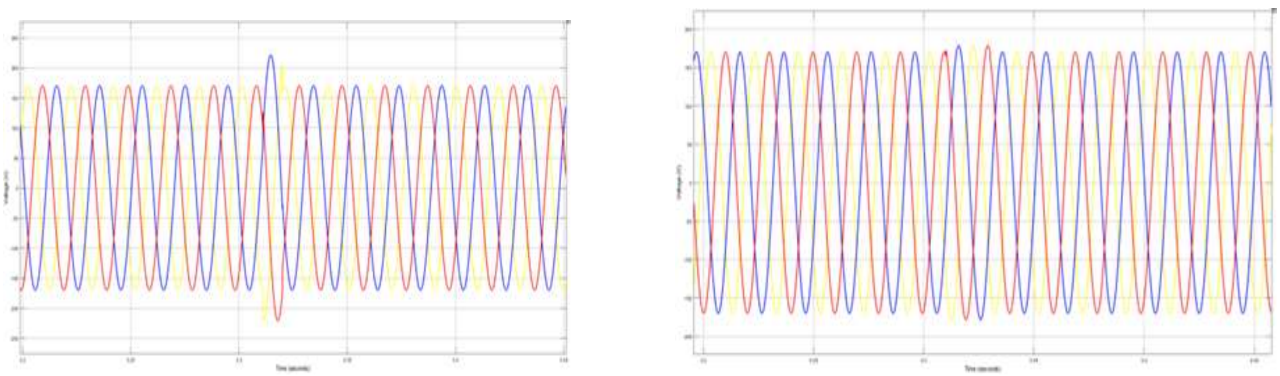


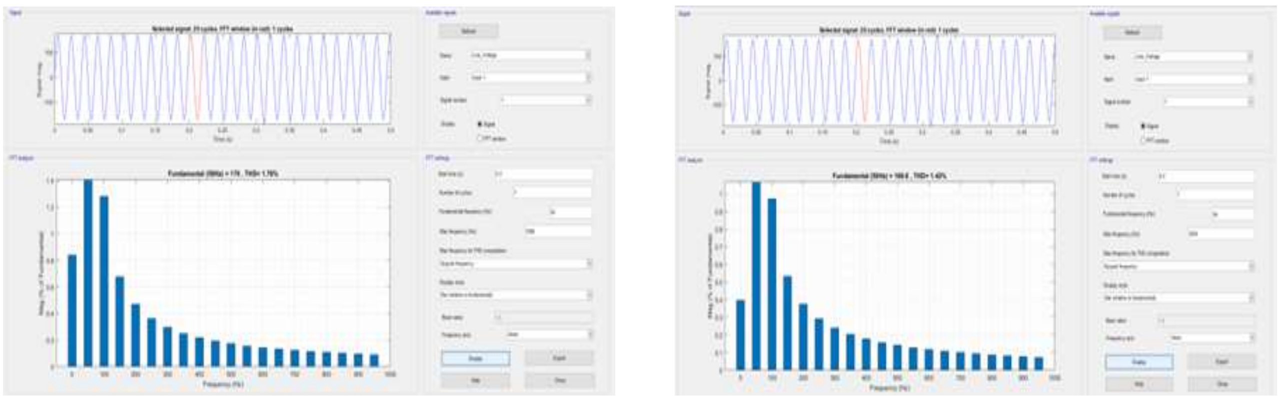
Fig.9 PV Array power

The Microgrid model that was built is cut off from the main power source. We first examine the results without the voltage controller included. Fig.10 depicts the voltage profile during this situation, which exhibits variations (a). A voltage controller is included in to alter the current's output for the better. In Fig. 10 we can see the effective operation of the developed controller system for voltage regulation (b).



(a) (b)

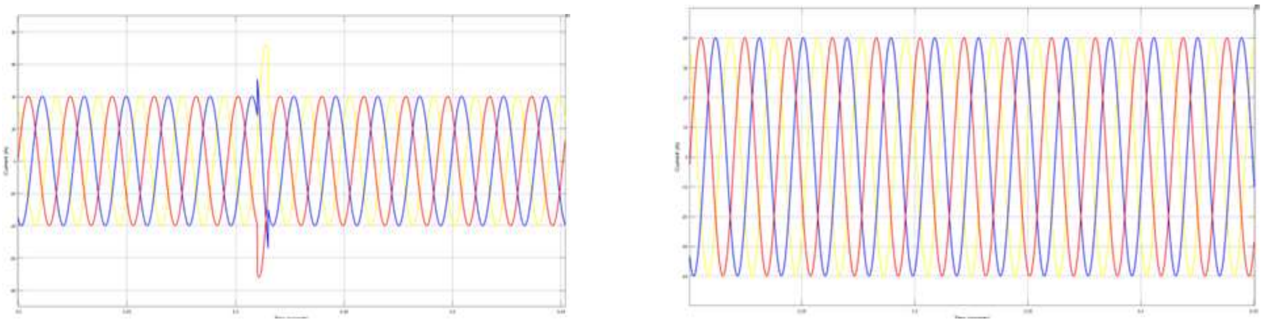
Fig.10 Line voltage without voltage controller (a) and with voltage controller (b).



(a) (b)

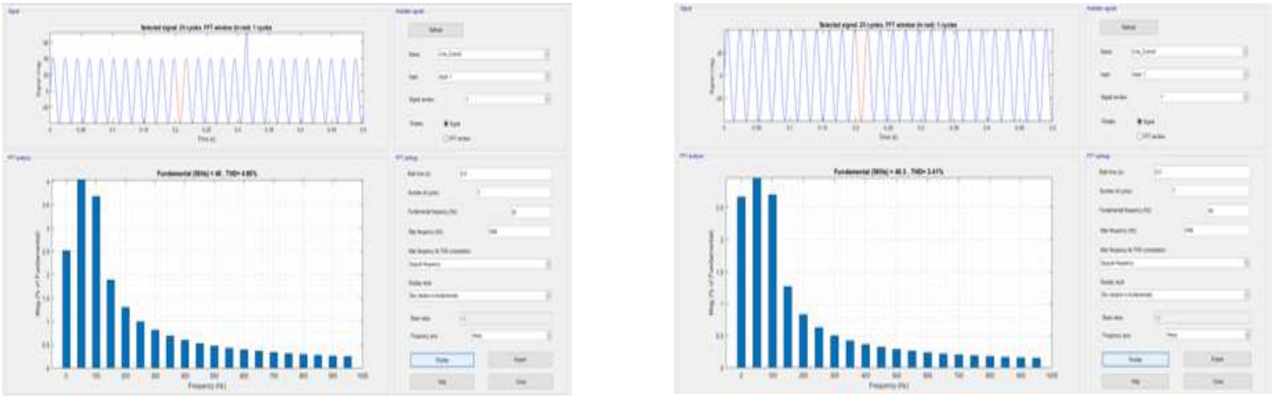
Fig.11 (a) voltage regulator Line Voltage THD Percentage No Current Regulator (b) Line Voltage Total Harmonic Distortion (THD) with

The grid-connected mode is examined after the isolated mode has been put into action. In Fig.12 (a) and (b), we see a comparison of the current profile with and without an integrating current controller (b). Currents at the point of common coupling (PCC; bus 650) are measured in both conventional mode and grid-connected mode, with and without compensating integrating LCL filters. The current and voltage THD% lm without and with a current regulator are shown in Figs. 11 and 13, respectively.



(a) (b)

Fig.12 Line current without current regulator (a) and with current regulator (b)



(a) (b)

Fig.13(a) Line Current THD Percentage No Current Regulator (b) THD of current regulator on the line

Conclusion

Successful integration of DGs into an IEEE 13-bus distribution network has been modeled in detail for this study, along with the microgrid and its components. Both grid-connected and isolated modes of operation for the specified microgrid model function smoothly. Following extensive investigation, the task was completed. Using MATLAB simulations, we select control strategies for each module whose performance we then analyze in order to reach optimal outcomes. In this study, we have succeeded in optimizing the design of the MG model, which allows us to provide higher-quality electrical output.

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