Control of Grid Frequency under Unscheduled Load Variations: A Two Layer Energy Management Controller in Urban Green Building's

S. N. V. Bramareswara Rao*‡, Kottala Padma**

*Department of Electrical and Electronics Engineering, Sir C. R. R. College of Engineering, Eluru, West Godavari Dist., Andhra Pradesh-534007, India

**Department of Electrical Engineering, Andhra University College of Engineering (A), Visakhapatnam, Andhra Pradesh-530003, India

(snvbrao.eee@sircrrengg.ac.in, padma315@gmail.com)

‡ Corresponding Author: S. N. V. Bramareswara Rao; Department of Electrical and Electronics Engineering, Sir C. R. R. College of Engineering, Eluru, West Godavari Dist., Andhra Pradesh-534007, India, Tel: +91 810 610 8690,

snvbrao.eee@sircrrengg.ac.in

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Abstract- Demand side response (DR) became a major tool to the utility companies with the integration of many smaller grids. DR helps to manage the fluctuations in the grid which leads to cost optimization. However, in undeveloped electricity markets the operation of DR is very limited. In such cases, proper energy management controller helps to operate the interconnected microgrids with proper power sharing and minimum frequency deviations. By keeping this point in view this paper proposes, "A Two Layer Energy Management Controller (TLEMC)" to manage the generations and loads in the system formed by interconnecting four microgrids and is referred as 'Minigrid'. In the minigrid system each microgrid (MG) is associated with locally available renewable energy sources (RES) such as photovoltaic (PV), wind (WP), fuel cell (FC), storage systems and local building loads. The proposed controller effectively incorporates interoperability concept in the system considered for study, i.e., the power is shared in between the interconnected microgrids during excess/deficit power conditions. The robustness of the proposed controller is verified by comparing frequency deviations and the exchange of power in the interconnected system under unscheduled loading conditions and also the performance of the controller is tested in the presence of DR. The system configuration and proposed controller considered in this paper are developed in MATLAB/Simulink© environment, and from the THD analysis effectiveness of the proposed controller is verified.

Keywords: Microgrid, Demand Response, Minigrid, Renewable Energy Sources, Utility grid.

Nomenclature

MG	Microgrid
P_G	Power Generation (kW)
P_D	Demand Power (kW)
t	Time index
i	Index for i^{th} microgrid for $i=1,2,3,......n$;
j	Index for j^{th} microgrid for $j=1,2,3,......n$;
P_{Gi}	Generating power of i^{th} microgrid (kW)
P_{Di}	Demand power of i^{th} microgrid (kW)
P_{Gj}	Generating power of j^{th} microgrid (kW)
P_{Dj}	Generating power of j^{th} microgrid (kW)
P_{sol}	Power extracted from solar cell (kW)
P_{wind}	Power generation from wind generator (kW)
P_{fuel}	Power generated from fuel cell (kW)

P_{bat}	Power produced from battery (kW)
k	Boltzman's constant
q	Unit electric charge
s	Solar irradiation (kW/m^2)
i_{rs}	Reverse saturation constant of solar cell (amp)
I_{scr}	Short circuit current of solar cell (amp)
A	Ideal factor of solar cell
k_v	Temperature coefficient of solar cell
n_p	Solar cells connected in parallel
v_r	Reference cell temperature of solar cell
V_0	Output voltage of solar system (volt)
V_w	Wind velocity (mph)
ω_b	Turbine angular speed (rad/sec)
ρ	Air density (Kg/m^2)
A_1	Area cleared by rotor blades of wind turbine
E	Potential of fuel cell (volts)
T_f	Cell Temperature (^{0}C)
v_f	Simple fuel cell voltage(volt)
v_{ohm}	Ohmic losses of fuel cell
v_{conc}	Concentration losses of fuel cell
v_{act}	Activation losses of fuel cell
E_0	Battery constant voltage (volt)
I_{bat}	Battery current (amp)

1. Introduction

The concept of microgrid was introduced earlier to reduce the stress due to major power outages caused by urbanization around the world. In developed/developing countries people are keep on pursuing high quality of life with increased electricity demand [1-3]. If the demand is keep on increasing causes heavy burden on the utility grid and at the same time the fossil fuels are depleting with heavy consumption [4]. Due to this reason conventional plants are getting overloaded, and also require huge balancing services to meet grid code. So, to have reliable power at consumer premises focus has been moved towards developing microgrids which are associated with local renewable energy sources. Later, microgrids are treated as a solution to penetrate distributed generation for the grid integration. In urban, remote farming and stockbreeding areas these microgrids are connected to the conventional grid to reduce the major burden due to industrialization [5-6]. Further, demand side management is also being implemented in some of the markets to reduce frequency intrusions. Demand response is considered as an operating reserve when there are imbalances between generation and utilization. The important component of DR management is to encourage the smart grid customers to modify their use of electricity temporarily by reducing the load on utility grid. The usage of demand response is discussed in [7, 8]. In conventional VSI based renewable energy system DR management is performed by reducing the voltage level of the system is given in [9]. DR also helps to maintain system stability along with the conventional frequency controller presented in [10]. However, DR is absent in some of the electricity markets by its definition. So alternatively researchers are focusing on microgrids to deliver the local loads in the absence of DR without creating burden on utility grid. Basically microgrids are small power generating stations developed based on locally available energy sources such as 'PV', 'Wind', and FC etc. Initially, these are installed to meet the energy requirements where the power accessibility is low [3]. So, to enhance the reliability of power at the consumer premises without extra burden on the grid the proper control of microgrids is needed. In the present scenario, because of higher energy requirements researches are emerging in the area of microgrids interconnection. The various techniques available to interconnect the microgrids are discussed in [11]. IEEE-1547 is best choice for network protections which are available on the grid side out of all the available standards. Many research works are carried to develop better control algorithms for operation and control of microgrids. Some of the works are discussed in this literature. Initially an attempt was made by interconnecting two DC microgrids with different voltages and frequencies in grid connected mode with a new control strategy and uses bi directional converter and a dc cable for interconnection was proposed in [12]. After that interlinking power converters are used for managing both active and reactive powers of two interconnected AC microgrids without depending on fast communication links was discussed in [13]. AC/DC hybrid microgrid was introduced in [14], to decrease multi conversions such as AC to DC to AC and also multi bi-directional converters are used to connect ac and dc networks along with coordination control algorithm for smooth power transfers between the mentioned networks. Later, optimal power flow in hybrid microgrid was discussed in [15], with smart grid' bus for communications between power grid and various energy sources for balancing power transfer. A two level scheme for DG resource management for multi microgrids using multiple agents was proposed in [16]. In this Auction algorithm was proposed to allow all agents of generation, loads, auction, and also grid are participating in the energy markets. Similarly, in [17], hierarchical control architecture was introduced that combines transactions of market at higher level with inter-area and unit wise control at low level was discussed. Later the analysis has been extended and review of multi microgrid architectures and their interface technologies were discussed in [18]. Later in [19] the minigrid is formed by interconnecting green buildings and integrated in MATLAB/Simulink environment with power sharing. Later in [20], stochastic energy management algorithm was proposed for the management and operation of interconnected MG's. In this reference different uncertain sources were considered in each microgrid for managing the power flow. Later in [21], frame work for energy management in multi microgrid system with high renewable sources was proposed. In this only single microgrid with battery is taken to optimize the model.

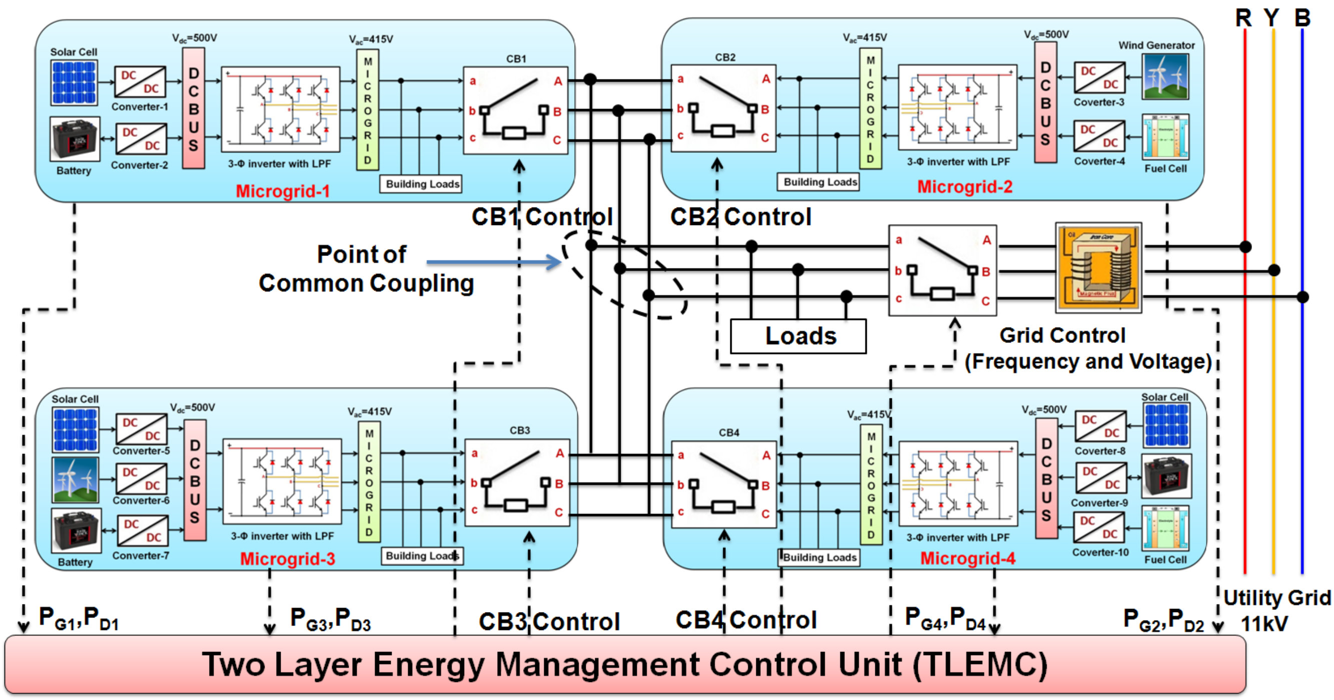

Fig. 1. General architecture of minigrid system

After that in [22], the energy management system was proposed for islanded multi microgrid cluster. In this system frequency security constraints were considered for designing the energy management system. From the above discussed literature many attempts were made to design the energy management control scheme only eighther for two AC/DC or hybrid (AC & DC) microgrids with proper power sharing but not discussed about the proper utilization of energy resources among the microgrids which are interconnected. So, by keeping these aspects in view in this paper a "Two Layer Energy Management Controller (TLEMC)" is proposed to incorporate the interoperability [23] in the minigrid system to exchange the power during excess/deficit power conditions with less frequency deviations in grid connected mode with reduced burden on the utility grid with effective utilization of energy sources in all microgrids. The proposed controller in this work is considered to be a two layer structure, 1) Layer_1: Discusses about the control of generations and loads in individual microgrids and 2) Layer_2: Discusses about the power sharing in between interconnected MG's in the minigrid by controlling grid frequencies. This paper organized as follows: Structure of minigrid system under study is discussed in Section 2. The methodology used in the design is discussed in brief in Section 3. The simulation results were discussed in detail in Section 4 and the conclusion is presented in Section 5.

2. Structure of minigrid under study

The general schematic view of minigrid system considered for study is shown in Fig. 1. Minigrid system is formed by interconnecting four different buildings and each building is referred as single microgrid (MG) which is associated with the locally available renewable sources such as solar, wind, 'fuel cell' and storage systems' and their modelling is given in [24-27]. As the power produced from renewable energy sources is intermittent in nature and the voltage obtained from these sources is not sufficient to meet the required demand connected in the MG. So, the voltage of dc/dc boost converter is boosted up to the required level (500V) to deliver the loads on AC side (415V) by adjusting the duty ratio of the converter. Each microgrid is modelled by considering the combination of free energy source and paid energy source, boost converter and multi level inverter to meet the loads.

The general power balancing equation of minigrid system is given in Eq. (1).

$$\sum_{i=1}^{n} P_{Gi} - P_D = 0 \quad (1)$$

Where $\sum_{i=1}^{n} P_{Gi} = P_{G1} + P_{G2} + ... + P_{Gn}$

Power extracted from each energy source used in the minigrid is calculated using Eq. (2) to Eq. (5).

$$P_{sol} = \left(V_0 * \left(\begin{array}{l} n_p.(I_{scr} + k_v(v - v_r))\frac{s}{100} \\ - n_p.I_{rs}\left[\exp\left(\frac{q}{k.vA}\frac{v_{dc}}{n_s}\right) - 1\right] \end{array} \right) \right) \quad (2)$$

$$P_{wind} = \left(\begin{array}{l} \left(\frac{1}{2}\right)\rho A_1 V_w{}^3 * \left(\left(\frac{V_w}{\omega_b}\right) - 0.022\left(\frac{V_w}{\omega_b}\right)^2 - 5.6\right) \\ \exp^{-0.17\left(\frac{V_w}{\omega_b}\right)} \end{array} \right) \quad (3)$$

$$P_{fuel} = \begin{pmatrix} 1.23 - 0.085 * 10^{-2}(T_f - 298.3) + \\ 0.43 * 10^{-4} T_f \left(\ln(P_{H_2} + 0.5\ln(P_{O_2})\right) \\ - v_{ohm} - v_{act} - v_{conc} \end{pmatrix} * I_{fuel} \quad (4)$$

$$P_{bat} = \left(E_0 - K \frac{Q}{Q - \int idt}.i + A.\exp(-B.\int i.dt) - R.i \right) * I_{bat} \quad (5)$$

2.1. Microgrid 1:

The power generation in 'MG_1' is produced from solar cell and battery system which is considered to be a paid energy source. The sum of solar power and battery power delivers the power to local building loads (AC). So, the total power generation '$P_{G1,T}$' and power difference ($P_{diff,1}$) in 'MG_1'are obtained as given in Eq. (6) and Eq. (7).

$$P_{G1,T} = P_{sol}(Eq.(2)) + P_{bat}(Eq.(5)) \quad (6)$$

$$P_{diff,1} = P_{G1,T} - P_{D1} \quad (7)$$

2.2. Microgrid 2

The power generation in 'MG_2' is obtained from wind source (free source) and fuel cell (paid source). The combination of two sources delivers the power to local building loads (AC). So, the total power generation '$P_{G2,T}$' and power difference ($P_{diff,2}$) in 'MG_2' are calculated by using Eq. (8) and Eq. (9).

$$P_{G2,T} = P_{wind}(Eq.(3)) + P_{fuel}(Eq.(4)) \quad (8)$$

$$P_{diff,2} = P_{G2,T} - P_{D2} \quad (9)$$

2.3. Microgrid 3

The power generation in 'MG_3' is obtained from solar, wind sources (free sources) and battery system. This combination delivers the power to local building loads (AC). Total power generation '$P_{G3,T}$' & power difference ($P_{diff,3}$) in 'MG_3' are calculated by using Eq. (10) and Eq. (11).

$$P_{G3} = P_{sol}(Eq.(2)) + P_{wind}(Eq.(3)) + P_{bat}(Eq.(5)) \quad (10)$$

$$P_{diff,3} = P_{G3,T} - P_{D3} \quad (11)$$

2.4. Microgrid 4

The generation in 'MG_4' is obtained from solar, fuel cell and battery energy sources. This combination delivers the power to local building loads (AC). Total power generation '$P_{G4,T}$' and power difference ($P_{diff,4}$) in 'MG_4'are calculated using Eq. (12) and Eq. (13).

$$P_{G4} = P_{sol}(Eq.(2)) + P_{fuel}(Eq.(4)) + P_{bat}(Eq.(5)) \quad (12)$$

$$P_{diff,4} = P_{G4,T} - P_{D4} \quad (13)$$

2.5. Modelling of DC/DC boost converter

The Renewable Sources are intermittent in nature; the voltage obtained from these sources is not capable to feed the loads connected at the output of inverter. So, the voltage is boosted up to the required level by DC/DC converter before being fed to inverter. The equivalent circuit of DC/DC converter is shown in Fig. 2 and the dynamic equations used to model dc/dc converter is given in Eq. (14) and Eq. (15).

$$\frac{dI_L}{dt} = -\frac{rI_L}{L} - \frac{(1-\delta)U_{dc1}}{L} + \frac{V}{L} \quad (14)$$

$$\frac{dU_{dc1}}{dt} = \frac{(1-\delta)I_L}{C_2} - \frac{I_0}{C_2} \quad (15)$$

Where U_{dc1} – Voltage (average value) across capacitor 'C_2' and V- Voltage applied to the circuit, δ - Duty cycle.

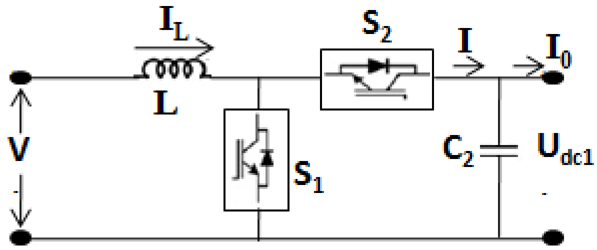

Fig. 2. Equivalent circuit of boost converter

2.6. Modelling of 3-phase 5-level inverter

In renewable energy based power systems, the power electronic inverter plays important role. The conventional 3-phase 5-level inverter is modelled in MATLAB/Simulink is shown in Fig. 3 is used for the analysis of the minigrid system considered. It consists of 4 dc link capacitors and 28 switching devices.

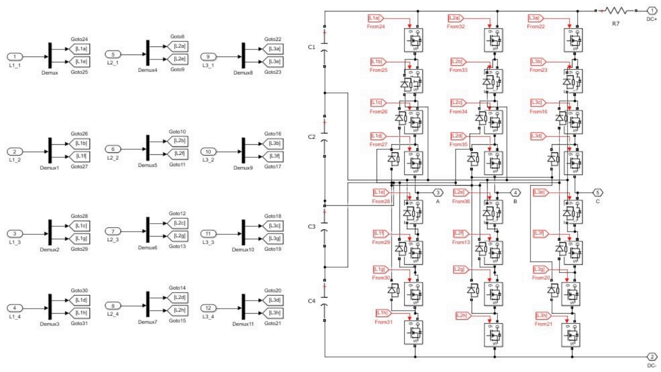

Fig. 3. MATLAB/Simulink implementation of inverter

So, the output voltage of a 5-level inverter is a quarter wave symmetry and the voltage of the inverter is obtained by considering fourier series expansion of the periodic output voltage, which is the sum of dc component and infinite series of sine and cosine terms of frequency '$n_{\omega 0}$' where 'n' is positive integer.

The output voltage is given by

$$V(\omega_0 t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos\omega_0 t + b_n \sin\omega_0 t) \quad (16)$$

As the output voltage of inverter is quarter wave symmetry the coefficients a_0 and a_n becomes zero. The coefficient b_n can be obtained using Eq. (17).

$$b_n = \frac{8}{T}\int_0^{T/4} V(\omega_0 t).\sin n(\omega_0 t).d(\omega_0 t) \quad (17)$$

Consider the fundamental time period signal $T = 2\pi$ sec and b_n becomes as given in Eq. (18).

$$b_n = \frac{4}{\pi}\int_0^{\pi/2} \frac{V_{dc}}{2}.\sin n(\omega_0 t).d(\omega_0 t) \quad (18)$$

Up on simplification we get $b_n = \frac{2V_{dc}}{n\pi}$ (19)

By substituting values of a_0, a_n and b_n in Eq. (16), we get the phase voltages of the inverter as given in Eq. (20) – Eq. (22).

$$V_{an} = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{n\pi}\sin n\omega_0 t \quad (20)$$

Similarly other two phase voltages can be obtained as follows,

$$V_{bn} = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{n\pi}\sin n(\omega_0 t - 120^0) \quad (21)$$

$$V_{cn} = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{n\pi}\sin n(\omega_0 t - 240^0) \quad (22)$$

3. Modelling of Two Layer Energy Management Controller

The minigrid system consists of 'n' number of interconnected RES based microgrids may be connected to utility grid via the feeder line section shown in Fig. 4. Assume that system considered for study is balanced. The power produced from the MG is proportional to the voltage produced from RES based inverter at its output. The active and reactive powers [10] flowing from 'i^{th}' microgrid to 'j^{th}' microgrid is calculated using Eq. (23) and Eq. (24).

$$P_i = \frac{V_{MG,i} * V_{MG,j} * \sin(\delta_i - \delta_j)}{X_{LT}} \quad (23)$$

$$Q_i = \frac{{V_{MG,i}}^2 - V_{MG,i} * V_{MG,j} * \cos(\delta_i - \delta_j)}{X_{LT}} \quad (24)$$

Where $V_{MG,\,i}$ and $V_{MG,\,j}$ are microgrid i^{th} and j^{th} voltages and δ_i, δ_j are corresponding phase angles and X_{LT} be the total inductance of interconnected microgrids, $I_{inv,1}$ and $I_{inv,2}$ are inverter currents, φ1 and φ2 are phase displacement angles between *MG* voltage and inverter currents.

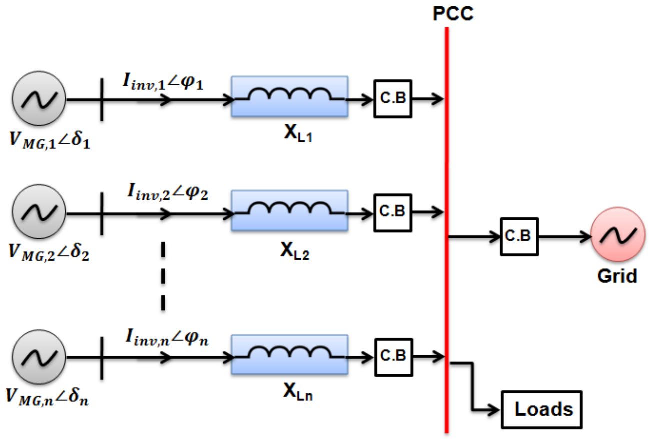

Fig. 4. Single line diagram of interconnected microgrids

Eq. (23) and Eq. (24) indicates the real and reactive powers at PCC of i^{th} microgrid are depends on the converter voltage ($V_{MG,\,i}$) and phase angle (δ_i). The proposed "Two Layer Energy Management Controller (TLEMC)", is used to manage the generations and loads, which are connected in four microgrids and controls the power exchange in between them by operating the switch gear mechanism of respective microgrid to export/import the power to/from adjacent microgrids or utility grid. The controller takes the power differences (P_{diff}=P_G-P_L) of all microgrids as inputs. Each microgrid is modelled with the renewable energy sources, adjustable and non adjustable building loads. The load state changes to ON and OFF continuously connected to the system. The implementation of proposed controller in MATLAB/Simulink is shown in Fig. 5. The sequence of steps for implementing Layer_1 of the proposed algorithm is described as follows,

Step-1: Set the values for i^{th}, j^{th} microgrids.

Step-2: Read the generation and utilization of i^{th} microgrid.

Step-3: Set the initial power difference to zero.

Step-4: Calculate the power difference $P_{diff,i} = P_{G,i} - P_{D,i}$

Step-5: Check the following conditions

- If $P_{diff,i} \geq 0$ which means, the excess power is available at i^{th} microgrid. Verify whether paid energy source is ON/OFF, if it is ON then it must be turned OFF. Check again whether power available at i^{th} microgrid is excess, if power is excess then controller checks, whether adjustable load is ON/OFF. If the load is OFF, then it must be ON and checks the power availability. Still excess power is available at i^{th} microgrid the controller checks the limits of voltage and frequency of the microgrid. If the limits are within the acceptable range then microgrid switch gear mechanism receives a control signal from controller to export the power eighther to adjacent microgrids or to utility grid.
- If $P_{diff,i} < 0$ which means, the power available at i^{th} microgrid is deficit.

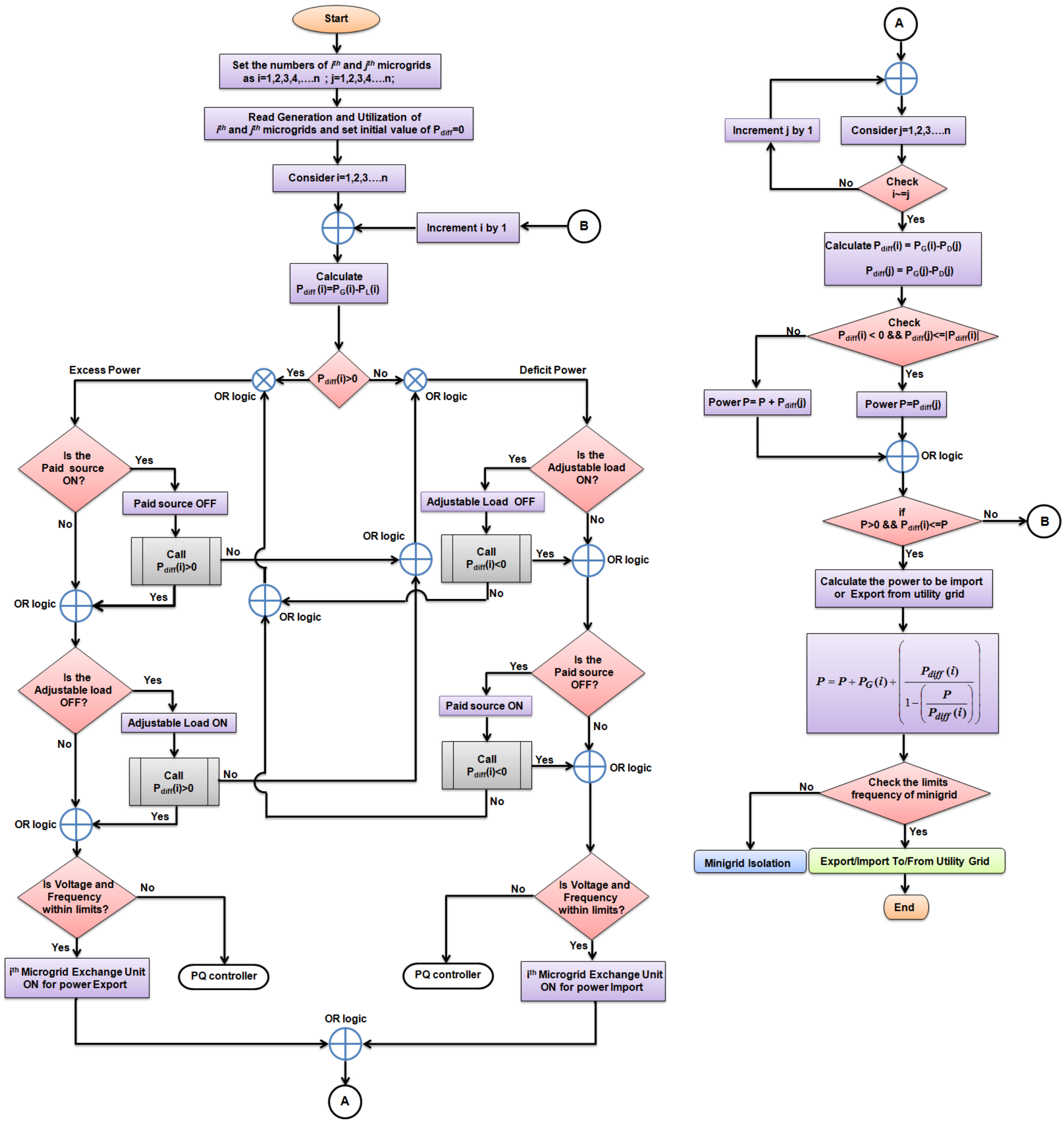

Fig. 5. Flow chart of proposed controller modelled in MATLAB/Simulink

Verify whether adjustable load is ON/OFF, if it is ON then it must be turned OFF. Check again whether power available at i^{th} microgrid is still deficit, if it is deficit then controller checks whether paid energy source is ON/OFF. If the paid source is OFF, then it must be turned ON and checks the power availability again. Still power is deficit then the controller checks the voltage and frequency of ith microgrid are within acceptable limits or not. If the limits are in acceptable range then microgrid switch gear mechanism receives a control signal to import the same amount power eighther from adjacent microgrids or to grid.

The sequence of steps for implementing Layer_2 of the proposed algorithm is as follows,

Step-6: Set the value of j^{th} microgrid.

Step-7: If both the indexes i, j are equal, go to step-8 else increment j by 1.

Step-8: Check whether $P_{diff}(i) < 0 \,\&\&\, P_{diff}(j) \le \left|P_{diff}(i)\right|$ is satisfied or not.

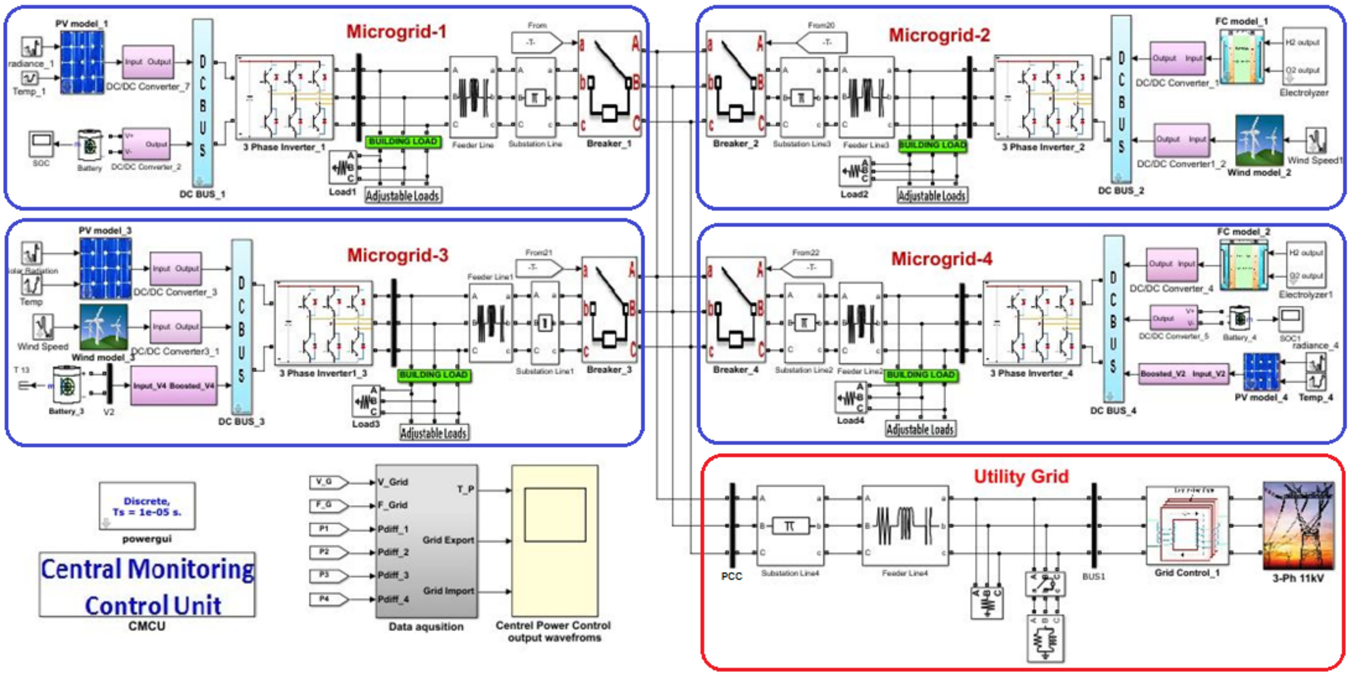

Fig. 6. MATLAB/Simulink implementation of minigrid system with proposed controller

Step-9: if step 8 is satisfied then update power $P = P_{diff}(j)$, else $P = P + P_{diff}(j)$.

Step-10: Check whether power updated in step 9 satisfies the condition that $P > 0 \,\&\&\, P_{diff}(i) \le P$

Step-11: If the condition in step 10 is satisfied then calculate the power as given and go to next step else increment '*i*' by 1 and repeat the above process

$$P = P + P_G(i) + \left(\frac{P_{diff}(i)}{1 - \left(\frac{P}{P_{diff}(i)} \right)} \right)$$

Step-12: Check the frequency limits; if limits violate, isolate the minigrid from the utility grid, else connect the system to the grid for power exchange.

Step-13: End the Process.

4. Results and Discussion

The Simulink implementation of the minigrid system under study with the proposed controller is shown in Fig. 6. The output of each microgrid is connected to adjacent microgrids via the switch gear mechanism controlled by TLEMC. The effectiveness of the proposed algorithm is tested by considering following test cases.

4.1. Analysis of minigrid system in the presence of demand response.

We have simulated the minigrid system, which is operated in islanded/autonomous mode. In the absence of utility grid the total demand is shared among MG_1, MG_2, MG_3, and MG_4 along with their local loads due to interoperability introduced by proposed controller. From Fig. 7(a), it is observed that from 0.15sec to 0.2sec the load is balanced in minigrid system. A base load of 2.5kW is connected and a test load of 10kW is incorporated in the system at time t=0.25sec to 0.3sec to observe the performance of the proposed controller in the presence of DR. It is observed from the results that at time 0.25sec to 0.3sec the additional load is taken by battery which acts as a storage system in the minigrid by shifting/adjusted the demand. The frequency response of the system at Point of Common Coupling (PCC) in islanded mode is shown in Fig. 7(b).

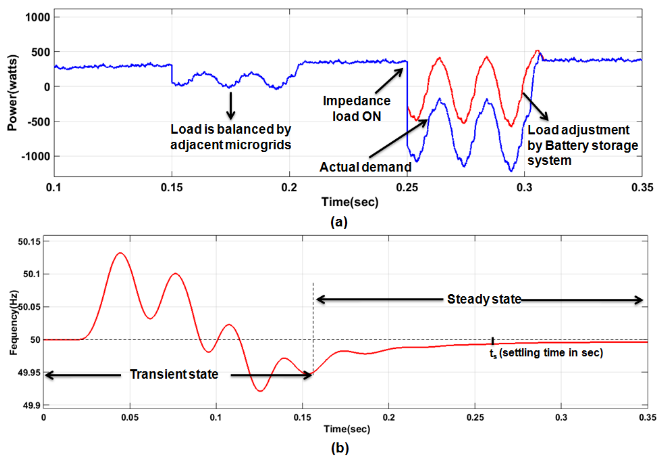

Fig. 7. a) Demand response of minigrid b) Frequency response of minigrid in islanded mode.

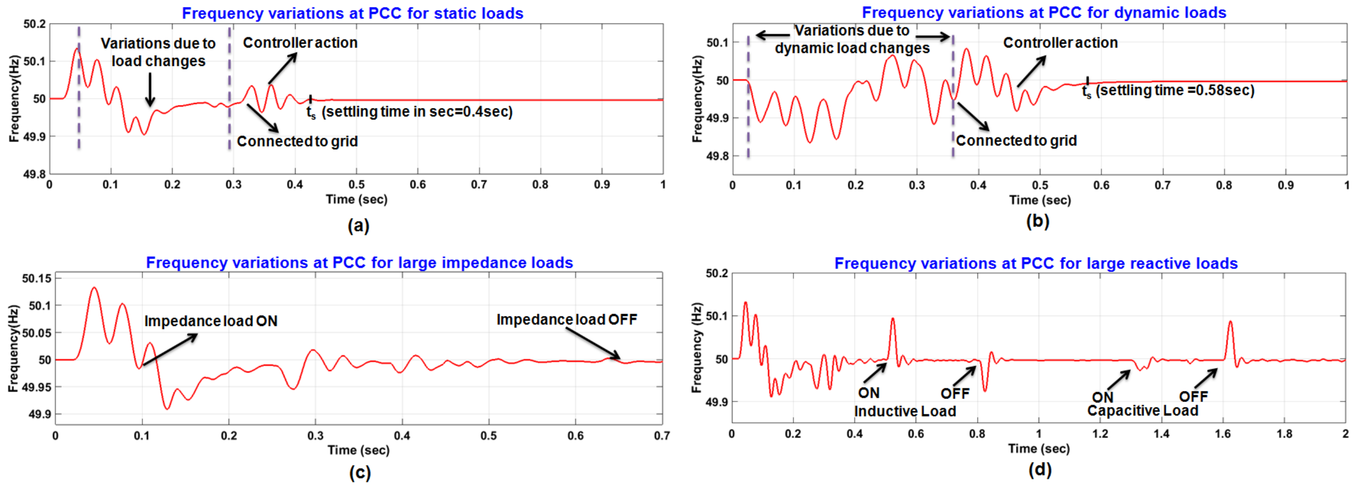

Fig. 8. Frequency response of minigrid system under grid connected mode for a) Static loads b) Dynamic loads c) Large impedance loads d) Large reactive loads.

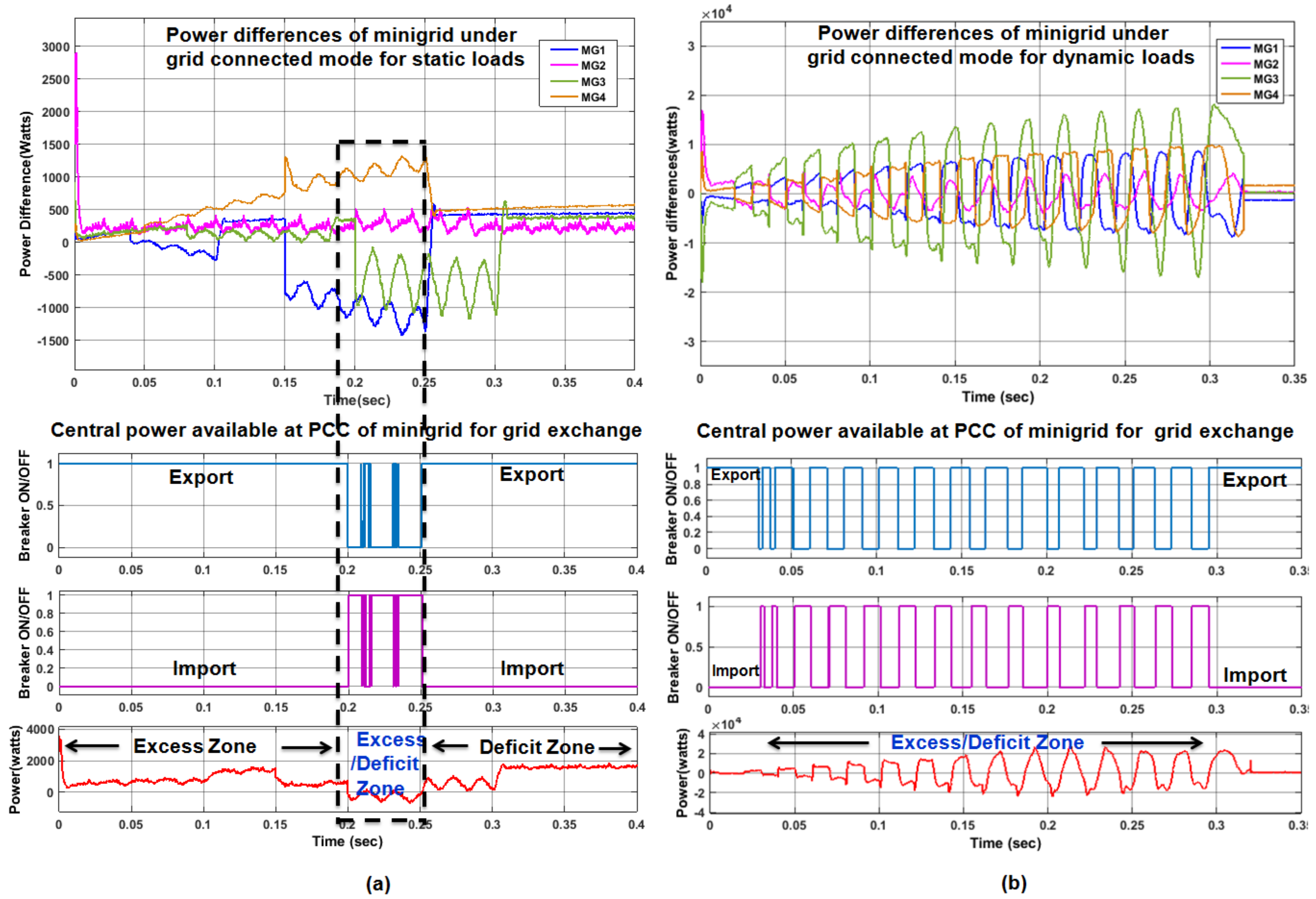

Fig. 9. Minigrid power differences and total power available at PCC for exchange for a) Static loads b) Dynamic loads.

4.2. Frequency response of minigrid system under unscheduled loads

The minigrid system, which is now operated in grid connected mode in the absence of DR. Static loads are incorporated in MG_1, MG_2, MG_3, MG_4 at different instants of time from t=0sec to 0.3sec. Figure 8(a) shows variations in frequency response at PCC and the system is connected to grid at 0.32 sec. The grid frequency retains the nominal frequency range, i.e. as per IEEE standard 1159-2009 [28] with a settling time of 0.4sec and minimum frequency deviation of 0.1% due to the presence of the proposed controller. Figure 8(b) shows the dynamic loads are applied in MG_1, MG_2, MG_3, MG_4 from t=0sec to 0.3sec and large variations in the frequency response is observed. But in the presence of controller the system is connected to grid with in short period of time i.e., at 0.35sec and also maintains system frequency to a nominal value with a settling time of 0.58sec.

Table 1. Minigrid system power exchange (Export/Import) to/from utility grid

Time (sec)	MG-1 (Watts)	MG-2 (Watts)	MG-3 (Watts)	MG-4 (Watts)	Power available at minigrid level (Watts)		Utility Grid	
							Export	Import
0.1	-8073	2865	-19535	9016	-15727	Deficit	×	✓
0.15	11615	2689	23842	-11935	25851	Excess	✓	×
0.2	-13556	-4580	-21291	13060	-26367	Deficit	×	✓
0.25	15463	-6278	-21394	-14419	-26628	Deficit	×	✓
0.3	-11095	339	23211	17097	29552	Excess	✓	×

Figure 8(c) shows the system frequency response for large impedance loads are applied in the system. The test load of (150kW-250kW) is applied at 0.1sec and the load is off at 0.65sec. Figure 8(d) shows that the frequency response variations for large reactive loads. The large inductive load of j50kVAR is injected into the system at time t=0.5sec to 0.8sec and switch off already connected capacitive load. Capacitive load of j50kVAR is applied at time t=1.3sec to t=1.6sec by disconnecting already connected inductive load.

4.3. Power sharing in minigrid

The important aspect to be considered in this case is verification of interoperability. The demands in microgrid buildings are not constant at all the times throughout the day because, of their different load profiles. So, it is very essential to exchange the power from one microgrid to adjacent MG's, during power deficit conditions without overloading utility grid. Figure 9 shows the difference of powers ($P_{diff}=P_G - P_L$) in each microgrid building and total power of minigrid (central power) is available at PCC. Static loads are applied at different instants of time from 0sec to 0.3sec and it is observed from Fig. 9(a) that, from 0sec to 0.2sec the power available at PCC is excess and CB of minigrid is ON to export the same power to utility grid. From time t=0.2sec to 0.25sec large impedance loads are applied in MG_1, MG_3 and the total power available at PCC is varying in this period so, grid CB is ON/OFF accordingly. Dynamic loads are injected into the system and control signals and total power available at PCC is shown in Fig 9(b). From the results it is observed that the load is continuously varying and the CB of minigrid and utility grid also ON/OFF accordingly. The active power available at MG_1, MG_2, MG_3, and MG_4 at different instants of time is shown in Fig. 10. Table 1 gives the information about the powers in kW available to export/import the power to/from utility grid at different instants of times.

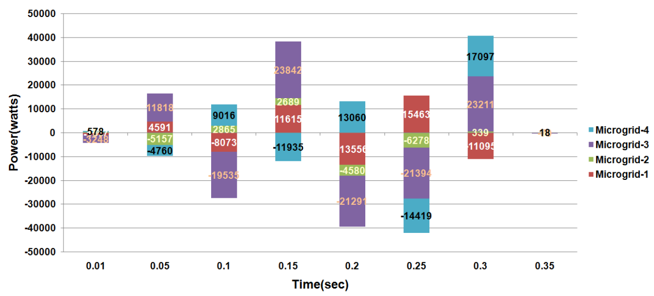

Fig. 10. Power availability in minigrid

4.4. THD analysis of minigrid system

The very important power quality parameter of any power system is total harmonic distortion (THD). Basically it is a sign of measuring harmonic distortion present in the signal. The signal for measuring THD may be eighther voltage or current. It is defined as the ratio of the amplitudes (RMS value) of a set of higher harmonic frequency components to the fundamental frequency component. Considered large nonlinear impedance loads are injected into the system from time t=0.1 sec. The THD is calculated as given in Eq. (25) or Eq. (26).

$$THD_{voltage} = \frac{\sqrt{\sum_{i=2}^{\infty} (V_{i,rms})^2}}{V_{fund,rms}} \tag{25}$$

$$THD_{current} = \frac{\sqrt{\sum_{i=2}^{\infty} (I_{i,rms})^2}}{I_{fund,rms}} \tag{26}$$

Where $V_{i,rms}$ and $I_{i,rms}$ are the voltage and current corresponding to n^{th} harmonic and $V_{fund,rms}$ and $I_{fund,rms}$ are the voltage and current components with respect to fundamental frequency. The THD analysis for the system under study is shown in Fig. 11 and from the result it is observed that the THD for the system is 1.53%, which is in the acceptable range (5%) given by IEEE standard 519-2004 [28]. This verifies the effectiveness of the proposed system.

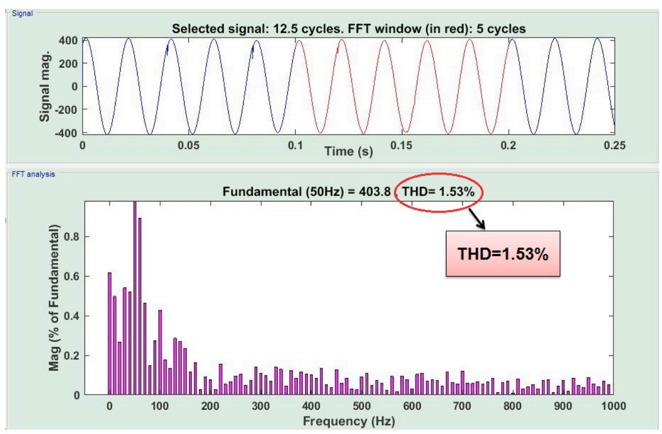

Fig. 11. FFT analysis for harmonic distortion in the minigrid

5. Conclusion

This paper discusses about the architecture of minigrid system and a Two Layer Energy Management Controller (TLEMC) is proposed for the interoperability of microgrids. This scheme effectively manages the generations and loads in all MG's along with the aid of main grid by eliminating need of DR. The minigrid system considered for study eliminates the overall burden on the conventional grid due to regular changes in the system by considering interoperability of microgrids and progressive resources sharing are the major advantages of this work. The applications of this type of minigrids are formed by integration of urban buildings such as academic institutes, industries, IT buildings, residential buildings etc. The usefulness of the proposed controller is tested by considering various loads and tested at different instants of time. From the results it is observed that the frequency response is oscillatory and also settling time is quite high. By keeping this point in view, future research works must be focused to improve the transient stability of the system. Hence it is concluded that the proposed algorithm effectively works for the integrated and interconnected microgrids by sharing the resources and infrastructure facility.

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Appendix

Table 2. Modelling parameters of renewable energy sources

Energy Source	**Parameter**	**Value**
Solar	Open Circuit Voltage	41Volts
	Short Circuit Current	3.16Amp
	Irradiance	[150-1000] kW/m^2
	Temperature	$[20\text{-}45]^0C$
Wind	Speed	10m/s
	Rotational Speed	1.2PU
	Rotor efficiency	0.45(high speed with 2 blades)
Ni-cadmium battery	Nominal voltage	88Volts
	Rated capacity	6.5Ah
	Initial SOC	100%
Fuel cell	Stack Temperature	343K
	Gas constant	8314.7
	No load voltage	0.8Volts
	No of cells in stack	80

Table 3. Modelling parameters of devices used in minigrid

Device	Parameter	Value
Boost converter	Duty cycle	0.76
	Inductance	200μH
	Capacitance	10μF
Inverter	Load resistance	20Ω
	Switching frequency	100kHz
	Snubber resistance	$1e^{-5}\Omega$
Distribution Transformer	Voltage	415V/11kV
	Frequency	50Hz
	Power	500kVA

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