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POWER QUALITY ASSESSMENT IN GRID CONNECTED MODE HYBRID MICROGRID WITH VARIOUS LOADS

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ABSTRACT

Microgrid plays a vital role to meet reliable and secure energy demands for consumers at various locations. As renewable energy sources are intermittent in nature, the integration of these with power electronic converters leads to various power quality issues. Well-functioning of a microgrid is decided by four key limitation variables voltage, frequency, active and reactive power. Voltage and frequency regulation are the premier control parameters under any operating condition. In Grid connected mode of microgrid, active and reactive power control is required. Various types of loads connected to the power distribution network also affect power quality. In this paper 14-bus, IEEE distribution system is proposed and related power quality issues are analyzed with various loads. The proposed hybrid microgrid is developed using Matlab/Simulink environment.

Keywords: *Power Quality, Renewable energy, energy demand, hybrid Microgrid, and reliability*

1. INTRODUCTION

In Remote Areas where there is no access or Provision for Main Grid Power Supply, Microgrid Provides a Feasible and Competent Energy Supply to Various Communities. Various DG Sources Such as Renewable Energy, Conventional Power Supply, and Various types of Energy Storage options are available In Microgrid. Less Energy Losses,Less Construction and Investment Time in transmission and distribution are major benefits by integration of DG with MG [1-3].Microgrids not only integrate DG but also enhance reliability in its capacity to operate under various phenomena. A Microgrid is basically a collection of loads and micro-sources such as wind turbines, micro-turbines, solar Photovoltaic (PV) and fuel cells which operates as a single controllable system for supplying needed power to different communities [2]. Microgrid can be connected to utility grid using a harmonic reduction pulse width modulated voltage source converters (PWM-VSI) or the converters.

Microgrids are emerging as a reliable and cleaner source of energy. In order to integrate distributed energy resources power electronic device is used. By this integration, power flow between microgrid and utility grid is controlled [3]. Power quality of the system gets distorted as the power electronic devices introduce harmonics due to non-linearity between voltage and current [4].When integrating large number of DGs into the power system, microgrid experiences various power quality and security problems[5]. Efficient and robust control strategy, precise selection of parameters of the selected controller is needed during and after the grid connection for smooth operation of the power system. Power quality standards can be met by the system with smooth operation. MATLAB/Simulink is one of the prominent simulation tools to analyze the

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behaviour of microgrid. By simpower system toolbox power quality disturbances can be simulated in real-time distribution system. Due to high-speed operation of inverter switches, the output waveforms get distorted which is another critical issue. Regulating the flows of both active and reactive power are essential objectives for governing the microgrid output power [6] to meet secure power system operation the power supply also need to be monitored and maintained within the set bounds[9-10].

In order to achieve the stated aims of this study, Section 2 describes the details of microgrid model. Section 3 of this paper is dedicated to Basic Block diagram of Hybrid microgrid showing components and their interconnections. Power quality issues affecting modern MG and their impact presented in section 4. As a part of conclusion, comparison of Total harmonic distortion at various buses is tabulated in section 5

2. DETAILS OF MICROGRID MODEL

Detailed description of proposed three phase model is presented in this section. Designed model was simulated using MATLAB/Simulink R2019a environment. For better understanding of MG dynamics under various operating conditions, detailed model is designed.MG model development and specifications of various elements considered are:

Table 2: Battery Energy Storage system (BESS)

Battery type	Nominal Voltage (V)	Rated capacity(Ah)
Lithium–ion Battery	120	800
Nickel-metal-hydride(3 number)	650	1.5*3

Grid source (4MVA/69 KV) Solar PV (5 KW each), Diesel generator unit (50 MVA/2.4 KV), three phase linear and non-linear load groups, single phase distributed loads with single phase solar PV (10 KW each), 11KV feeders, main transformer (8 MVA, 66 KV/11 KV), and 4 numbers of distribution transformers (1 MVA, 11 KV/415 V). The details of PV arrays for the MG system, Battery Energy Storage system details, line parameters, Transformer ratings for the MG system, and details of each load groups are shown in **Table 1, Table 2, and Table 3** respectively. Diesel Generator considered is another source rated 2.4 kV, 50 MVA.Battery source selected details are given in Table 2.

2.1 Microgrid Power System Model

Main Grid source is considered as thevenin's equivalent rated 69KV and 4 MVA transformer is used to stepdown to required bus level voltage of 13.8KV.

Table 3: Load data for Microgrid system

Load Name	Load Type	Rating of the load(kVA)	Power factor
Load12	Linear Load	800	0.8
Load 14	Linear Load	1600	0.8
Load3	Non-Linear Load	320	1
Load4	Unbalanced load	30	0.85
Load5	Unbalanced load	40	0.9

Table 1: PV arrays for the MG system

Array Number	Module	Series -connected modules per string	Open Circuit voltage Voc(V)	Voltage at maximum power point Vmp(V)	Maxi mum Power (W)
PV array 1	Sun Power T5- SPR-327	7	85.3	72.0	414.801
PV array 2	1Soltech 1STH-215-P	7	37.4	30.7	250.205

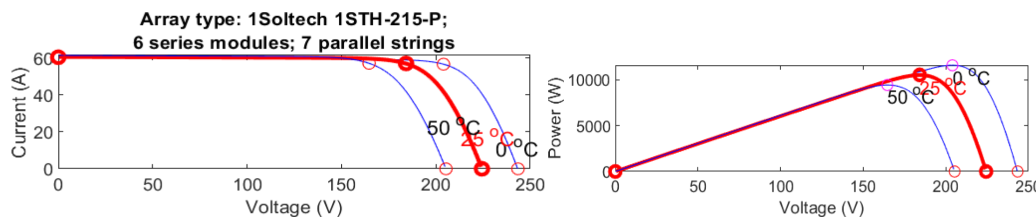

Figure 1: Current vs voltage, power vs voltage characteristics of PV array1

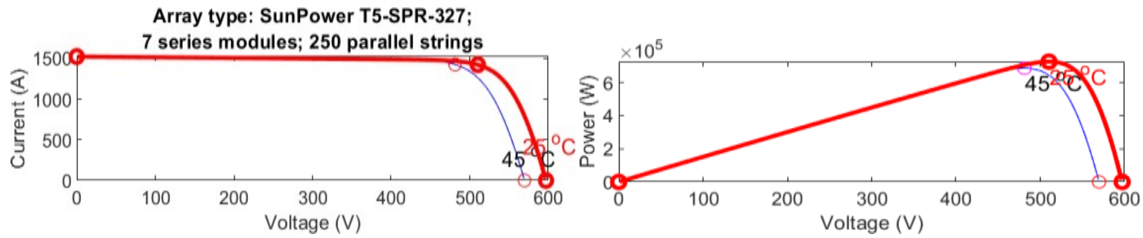

Figure 2: Current vs voltage, power vs voltage characteristics of PV array2

Table 4: Transformer Ratings for the MG system

Transformer Number	kV A Rating	Primary/Secondary Voltage
Tf1	1500	13.8Kv/220
Tf2	4000	69kV/13.8kV
Tf3	55	900/220
Tf4	3500	13.8kV/2.4kV
Tf5	1000	13.8kV/0.25kV
Tf6	15	220/150

2.2 Microgrid Power System Model

Main Grid source is considered as thevenin's equivalent rated 69KV and 4 MVA transformer is used to step down to required bus level voltage of 13.8KV.

2.3 Renewable Energy Sources

Two Solar PV arrays with irradiance 999W/m2 are connected to use and selected ratings are shown in table1.

The current versus power and voltage characteristics of two PV arrays are shown in Figure 1 & Figure 2.Diesel Generator considered is another source rated 2.4 kV,50 MVA.Battery source selected details are given in Table 2.

2.4 Various Loads

Different types of loads are considered to know the impact on various power quality issues. Details of various loads are given in Table 3.

2.5 Transformerratings:

Interconnecting transformer ratings are given in Table 4.

2.6 Converters Used:

The three different types of converters in Hybrid microgrid are:

2.6.1: Buck-Boost Bidirectional Converter

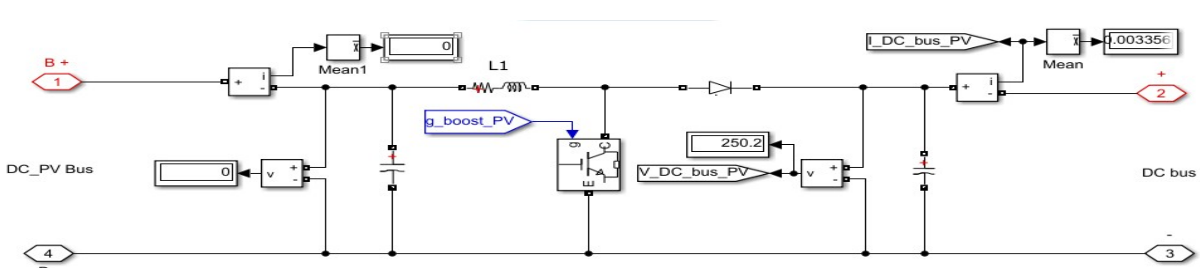

Figure 3: Buck-Boost Bidirectional Converter

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2.6.2: BOOST CONVERTER:

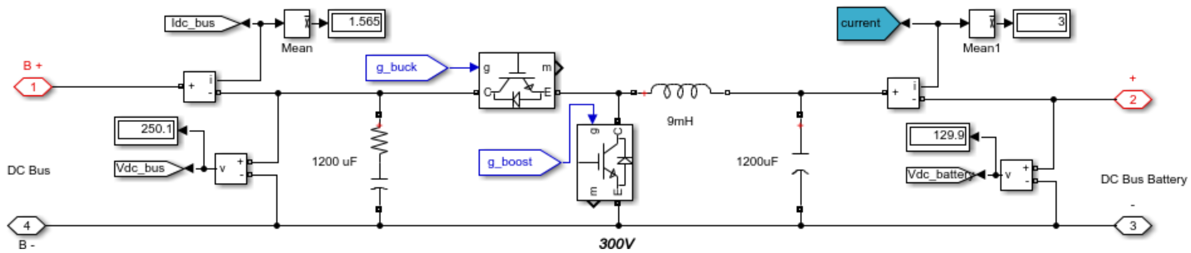

Figure 4: Boost Converter

2.6.3: GRID SIDE BIDIRECTIONAL CONVERTER

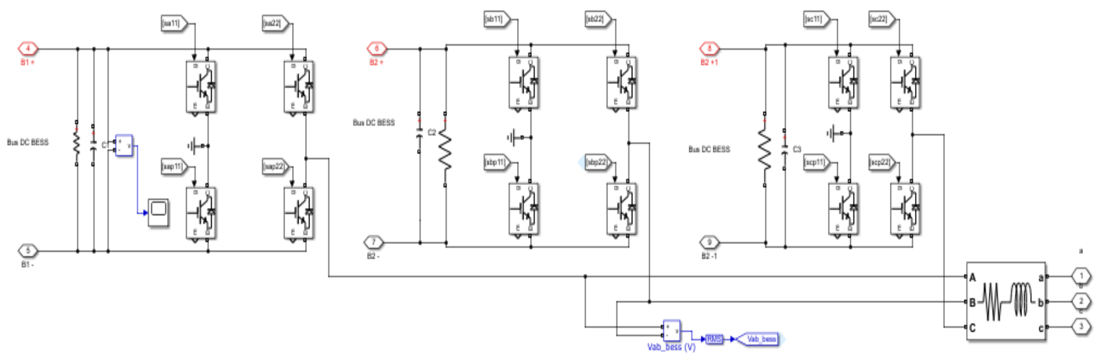

Figure 5: Grid side Bidirectional Converter

3. BASIC STRUCTURE OF DESIGNED MICROGRID:

Now-a-days' mostly DC Microgrids are playing important role due to the absence of reactive power and harmonics and no need of synchronization to main grid [11].Power flow in distribution grids can be improved by integrating renewable energy sources, battery energy storage system and loads. Power losses can also be reduced by interconnecting various distributed energy sources [5-7].Designed parallel microgrid consists of AC bus to that ac loads and generation systems are directly connected. Solar generator and battery energy storage system with respective converters are connected to DC bus. To gain the advantages of both AC, DC microgrid Hybrid microgrid is designed [8] as shown in Figure 6

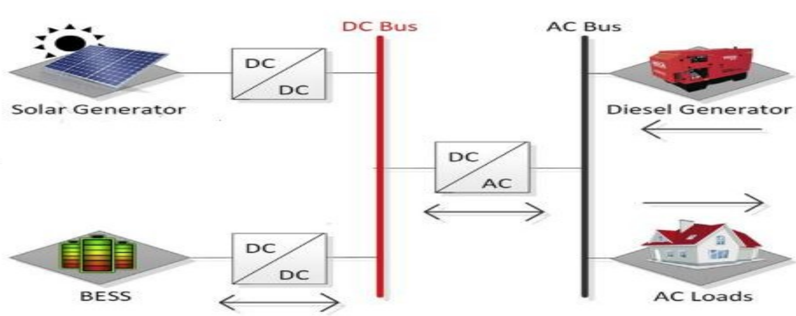

Figure 6: Interconnected Hybrid Microgrid can handle bidirectional power flows using converter

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4. ASSESSMENT OF POWER QUALITY AT VARIOUS LOCATIONS IN HYBRID MICROGRID

Requisites of Power Quality Assessment

The intermittent nature of various renewable sources and the load variations leads to the microgrid voltage deviations. The reason behind this is due to unexpected change of one or more loads in the microgrid.In contrary to the conventional systems, MG has its own independent demeanour and various PQ problems. The challenges of MG power quality are due to its intermittent nature, different modes of operation, type and resources [22].There are four major categories of MG power quality issues[23].The operating conditions of distributed energy sources are in first category, current and voltage harmonics caused by power electronic devices of distributed energy comes in second category, third one includes various voltage and current harmonics generated by nonlinear loads in MG system. The fourth category is voltage unbalance in MG. Mainly unbalance is generated by unbalanced three phase loads and presence of various single phase loads.

In the grid connected mode, disturbances such as unbalanced utility voltages and voltage sag are the most frequent problems [24].Sag and swell issues in MG are the most serious PQ challenges that are caused due to changes in system such as faults and leads to the various stability issues [25].Voltage sag is the most common event which disrupts the operation of sensitive electronic devices in distributed energy source systems consisting of MG [26].The increased integration of distributed energy source and MG impose new regulations such as LVRT & HVRT in case of sag and swell respectively. These regulations impose MG sources to disconnect from the grid in case the sag/swell exsts for certain duration of time [27].

Different studies are conducted on low voltage systems to analyze power quality on the basis of harmonic problems. MG’s are low voltage networks, therefore power quality is a major problem for this type of low voltage network that needs to be investigated and understood [28].

Power Quality disturbances are simulated by considering test model. In the designed model at different locations based on load changes and fault conditions, various power quality issues are assessed. Voltage and frequency variations/deviations are analyzed in both on-grid and off-grid mode of MG operation at varying generation and load conditions.

4.1 Main Grid

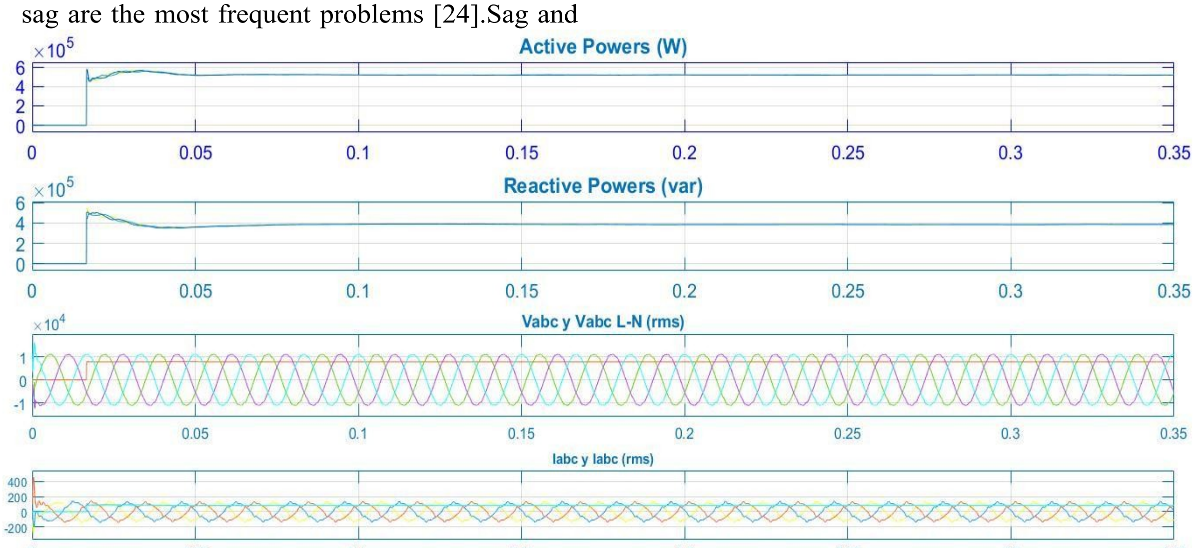

Figure 7: Active, reactive power, voltage, current measurement at main grid

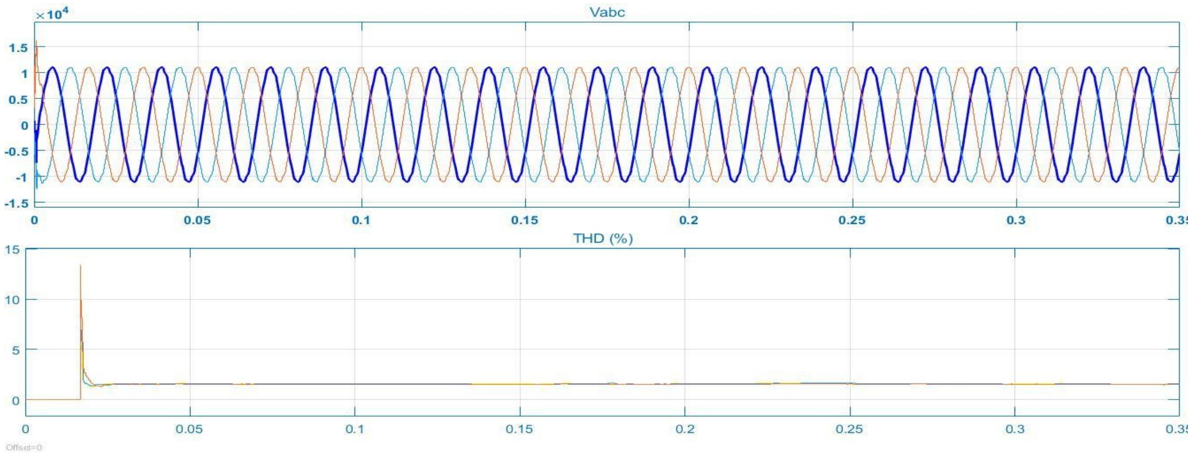

Figure 8: Supply Voltage, % THD at main grid

4.2 PV Grid Inverter

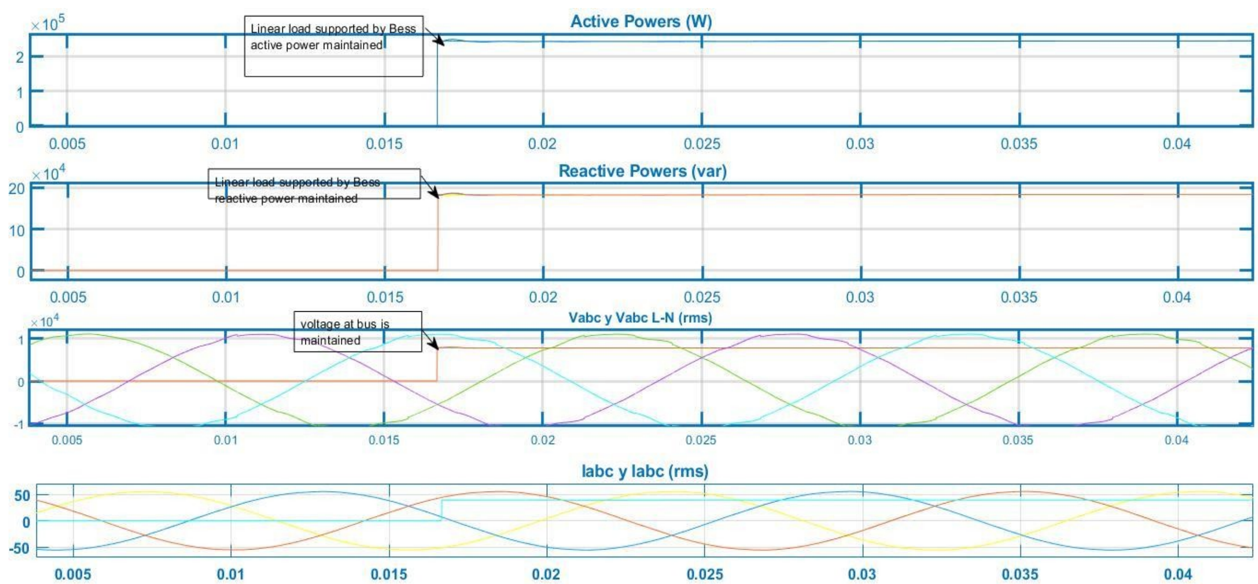

Figure 9: Active, reactive power, voltage, current measurement at main grid

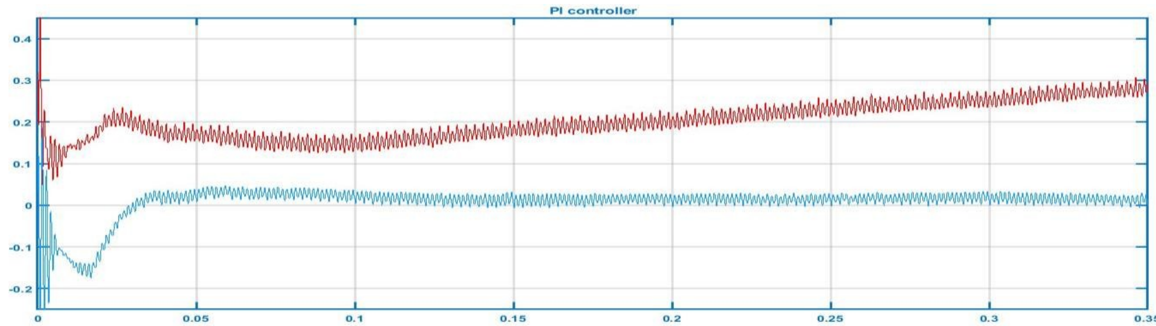

Figure 10: PI controller variation at PV Grid inverter

4.3 Buck-Boost Bidirectional Converter

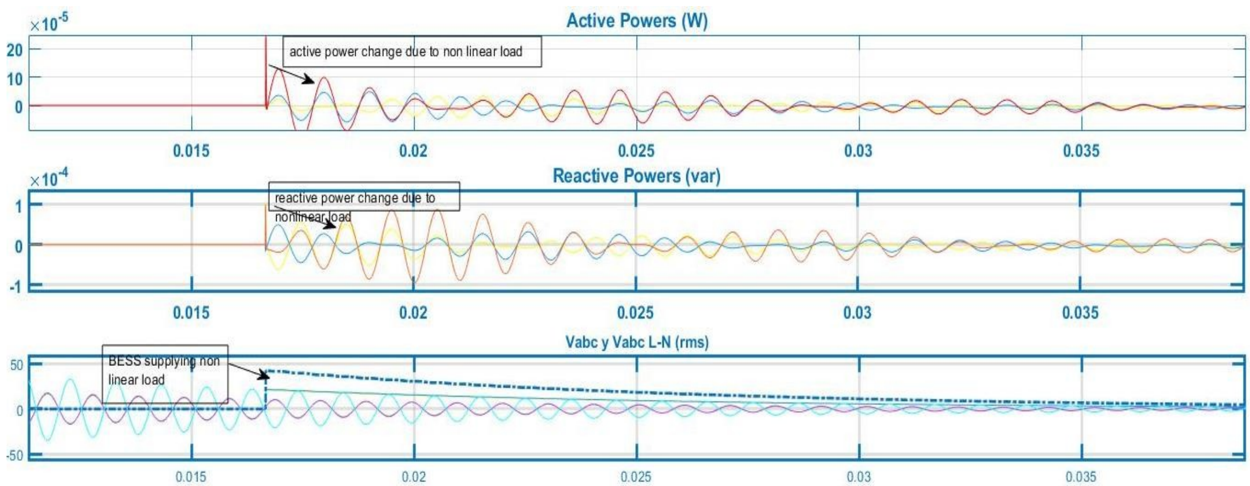

Figure 11: Interruption and sag events at bus nearer to solar PV Bidirectional Converte

5. ASSESSMENT AT VARIOUS LOCATIONS IN DESIGNED MG WITH DIFFERENT LOADS

Considering momentary load increment case with specific percentage change. Momentary voltage sag is produced by the load increment and three disturbances sag, interruption and oscillatory transient are mixed. This is termed as mode mixing problem. Misclassification of sags and mode mixing problem leads to accuracy reduction of various disturbance transformation techniques [14-15]. We cannot ignore major count of residential loads due to considerable generation of harmonics. By field measurement, harmonic models for various household appliances are developed and effect of harmonics is investigated. [16-18]

For necessary implementation of mitigation plans by utility companies, harmonics generated by residential loads should be properly evaluated. Bottom up method is needed to ponder distribution of harmonics by various residential loads and substitution upgrades on the generation of

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Harmonics [19].For different types of non-linear loads harmonic spectrums related to their behavior for various system changes are defined in [11-12].The increased discrimination of nonlinear power electronic devices, various measures over safety and proper operation of electronic equipment is needed. Major outlook on cost effective harmonic mitigation techniques to reduce system losses are given in [20-21]

(a) AC load14 1600Kva, cosφ = 0.8

Considering the designed microgrid, active and reactive powers are measured at load 14.At t= 0.02 sec, due to the change in load, active power reduced and reactive power slightly increased with 0.2% variation.

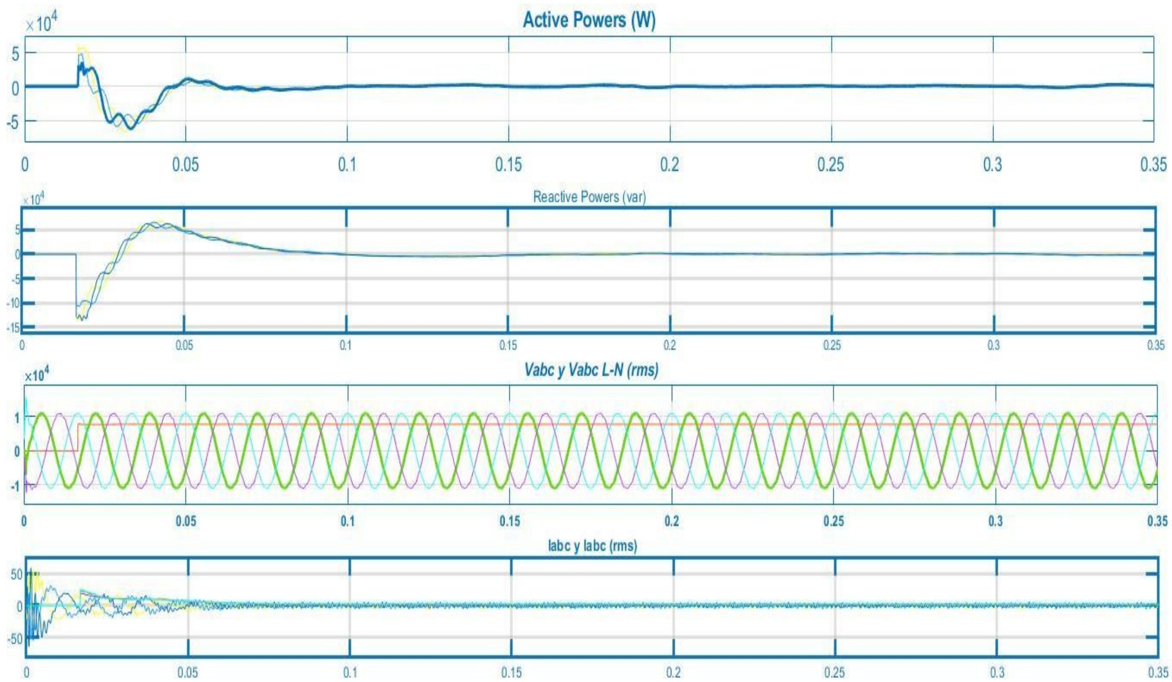

Figure 12: Active, Reactive Power and Current Measurement

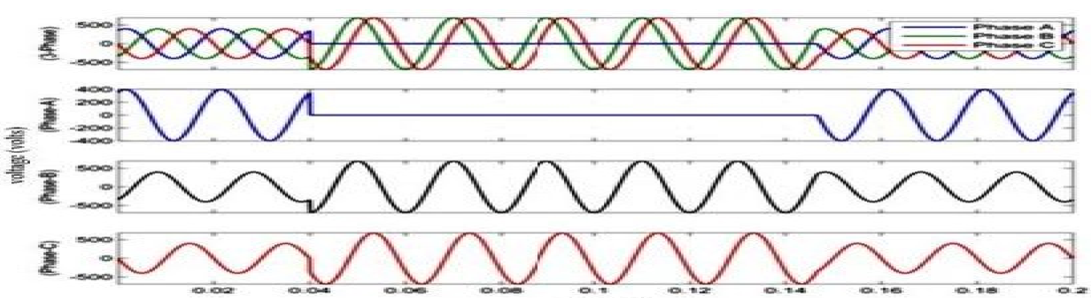

Figure 13: Voltage Swell and Interruption at bus 3,bus 5 due to changes in the system

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(b) **Non-linear load** (diode bridge rectifier) Diode Bridge rectifier is chosen as a nonlinear load at bus 11 nearer to solar PV array. The effect of the main grid and PV source is analyzed in terms of active, reactive power measurements.

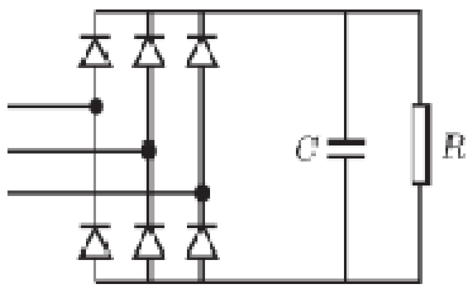

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Figure 14: Diode-bridge rectifier used as Nonlinear load C = 3000μF, R = 60 Ω

(c) Electric Arc Furnace

Power Quality in the power system gets reduced only because of the nonlinear load. Electric arc furnace which is the mostly used nonlinear load in many industries causes more harmonics and hence power quality gets reduced. The origin for the change in voltage at point of common coupling is the quantum jump in reactive power requirement in electric arc furnace.

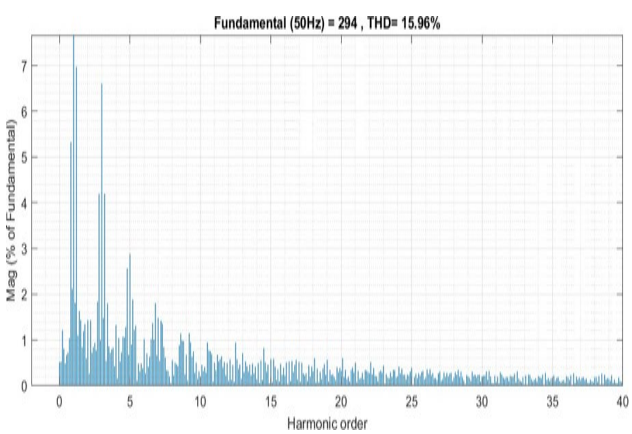

Figure 15: Harmonic Spectrum at bus 11 due to Electric Arc Furnace

Table 5: Variation of THD at bus 11 due to diode bridge rectifier

Harmonics	Frequency in Hz	Voltage THD in %
DC component	0	30.66
Fundamental	60	100
2nd Harmonic	120	2.64
3rd Harmonic	180	8.88
4th Harmonic	240	8.07
5th Harmonic	300	11.49
6th Harmonic	360	8.51
7th Harmonic	420	2.15
8th Harmonic	480	0.77

Table 6: Variation of THD at bus 11 due to Electric arc Furnace

Harmonics	Frequency in Hz	Voltage THD in %
DC component	0	73.33
Fundamental	60	100
2nd Harmonic	120	11.13
3rd Harmonic	180	7.45
4th Harmonic	240	5.64
5th Harmonic	300	4.61
6th Harmonic	360	4.08
7th Harmonic	420	2.99
8th Harmonic	480	3.14

6. RESULTS

The Performance of Microgrid is observed considering various linear and nonlinear loads. Total harmonic distortion is compared as a part of power quality assessment. In the transmission line depending on the operating loads active power loss is measured in various lines. The comparison is given in Table 7.

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Table 7: Comparison of various parameters with different loads

Type of load	Rating of the load	%THD(V)	%THD(I)	Active Power loss
Linear load	400 kVA; cos (phi) = 0.8	1.88	6.83	3.52 KW
Balanced load	320kVA; cos (phi) = 1	3.64	4.23	2.63KW
Non Linear load	Diode bridge rectifier	21.64	12.89	12.64 KW
Non Linear load	Arc furnace	75.96	58.67	24.78 KW

Table 8: Comparison of various parameters at different buses

Bus number	PF	%THD(V)	Bus number	PF	%THD(V)
1	-0.8786	2.35	8	0.9842	1.57
	-0.8699	2.36		0.9841	1.56
	-0.8483	2.37		0.9852	1.64
2	-0.9228	1.88	9	0.9998	1.64
	-0.8985	1.91		0.9994	1.72
	0.8566	1.92		0.9998	1.73
3	0.8676	1.53	10	0.8	1.26
	0.8615	1.6		0.8	1.31
	0.8617	1.6		0.8	1.73
4	0.8874	1.54	11	0.8	1.26
	0.8769	1.61		0.8	1.31
	0.876	1.62		0.8	1.71
5	0.8894	1.25	12	0.8	1.25
	0.8913	1.31		0.8	1.3
	0.885	1.32		0.8	1.32
6	0.8027	1.25	13	0.7931	1.24
	0.8026	1.3		0.7937	1.29
	0.8034	1.32		0.7947	1.3
7	0.9994	1.54	14	0.7666	1.48
	0.9997	1.61		0.767	1.55
	0.9994	1.62		0.7668	1.56

An advanced Microgrid installation necessitates the analysis of various power quality issues and development of new control strategies for mitigation of related power quality problems. For effective evaluation of optimal energy management systems (EMS) operation in a microgrid including power quality assessment mixed integer linear programming (MILP) energy scheduling algorithm is developed [29]. In order to evaluate the impact of steady state power quality events in alternating current microgrids, wavelet packet based signal processing method proposed in [30]. This decides distributed energy resources optimal dispatch based on a given operational objective satisfying microgrid's load requirement. Based on load, power quality at a particular section can be analyzed .In the developed system, nonlinear loads are considered and thd is measured and compared at different locations. Future research interest is to identify various soft computing techniques for assessment of power quality in microgrid.

7. CONCLUSION AND FUTURE OUTLOOK

The power quality in the power system is affected by various operating conditions. Major change is observed due to nonlinear loads. Electric arc furnace is one of the major non-linear loads where observed THD is more compared with other loads. There is a need to improve power quality for safe operation. The results show a path for optimization measures to be taken for reducing various power quality problems.

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