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Implementation of PI Controller of Hybrid DC Microgrid Energy Management

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ABSTRACT- This paper presents energy management in DC Microgrid. Microgrids are a growing power generating source in remote areas than utility grid. It can be operated as a standalone& grid-connected to serve the entities. In this paper concentrates on the DC Microgrid and manages the energy within the system when the grid suffers from an outage of service, and unbalanced load conditions in the grid. During grid conditions, the buses connected to it should synchronize with the grid. The voltage in the buses is same, that is verified in this paper work through controllers to the converter are also discussed. From the outcome of simulation, THD satisfies the IEC 61000-3-2 standards. The energy management in DC Microgrid is achieved by connecting hybrid source is also implemented to prevent the grid outage conditions.

Keywords: Hybrid energy source, Energy Management, pulse loads, PI controller, MATLAB software.

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1. INTRODUCTION

Small-scale supply networks called microgrids are made to meet the needs of a single society, like a trade estate, a commercial district, a housing estate, an industrial site, or a municipal region. They are also made to offer heat and electricity to these types of sites. Power electronic interfaces (PEIs) and controls are necessary from an operational standpoint to give the micro sources the necessary flexibility to guarantee that they operate as a single integrated system and to uphold the specified energy generation and quality of power. A microgrid is a collection of dispersed energy supplies and connected loads that are linked to a single grid-relatable controlled entity. It can be used in both grid-connected and islanding modes. Microgrids are useful for supplying electricity locally and for mitigating Climate change and environmental contamination using low-carbon technologies. Now a day's DC Microgrid are increasing due to their easier connection to dc bus, higher efficiency than AC microgrid, having no power quality issues like harmonics, reactive power, no inrush current to transformer, unbalance current. DC Microgrid raise due to dc power sources, storage, loads with natural dc coupling.

Hybrid energy systems are defined as two different energy system installed at a location to ensure continuity of electrical supply [3-4]. In this paper battery and supercapacitor are used as a hybrid sources. Whereas battery and supercapacitor having high energy and high-power density. Battery storing large amount of energy over a period and supercapacitor storing and releasing more amount of power quickly. DC microgrids can serve the DC loads as well as the AC loads. In case of AC loads, inverter is connected to the DC buses. A microgrid is viewed as a single regulated unit inside the electricity system from the perspective of the grid. Microgrids are useful for supplying electricity locally because they can lower feeder losses, increase local dependability, deliver uninterrupted power, and support voltage. DC microgrid raise due to DC power sources, storage, loads with natural dc coupling. In DC microgrid no need to consider synchronization of utility grid and reactive power, frequency and phase control, DC cables can be used hence investment cost is low. Easy to control by controllers and lack of electrical hazards. Loads connected to the dc microgrids can be constant, varying, or timely varying loads. Pulse loads are short duration current variation occur in an intermittent fashion [4]. This short duration variation affects grid voltage and other sensitive loads connected to the grid [1-2]. To eliminate the outage of grid condition and voltage imbalance in the grid, energy management is provided by hybrid source connected to the grid. Battery and supercapacitor provide necessary voltage when the grid suffers from transient conditions or outages. Hence, the goal of energy management is to control the energy present in the system.

2. HYBRID DC MICROGRID

2.1 AC Source, Transformer and Filters

The sources of power supply are ac source and dc source.ac source can be connected to the dc grid through converters.ac source voltage is step down by transformer and ac filters are used to reduce the ripples and then given to the uncontrolled rectifier to get a DC voltage to connected to the dc bus. Voltage matching and isolation are provided by the transformer. Additionally, it adds to the reactance that exists between the grid and the voltage source converter. To lessen higher order harmonics created by the converters' switching, voltage source converters employ AC filters. These filters are much smaller because they don't have to supply reactive electricity. High frequency obstructing filters safeguard the transformer from dc entering. The DC filters reduce the harmonic currents on the DC side.

2.2 Hybrid Energy Sources

A place has two distinct energy systems established to guarantee the uninterrupted supply of electricity. Here battery/super capacitors are used as Hybrid energy system [5-6]. Among all storage devices, batteries are the most used for ESSs. The utilization of batteries alone in the ESS can lead to a reduction in battery life due to a longer response time of the battery under rapidly varying environments [8-9]. Here, the SC has a higher power capacity to meet power fluctuations during the transient period, and similarly, the battery has a high energy capacity to compensate for power requirements during a steady state [10-11]. When a battery is attached to a load, it stores chemical energy and releases electrical energy. A battery's most basic configuration consists of a positive and a negative electrode submerged in an electrolyte. The electrodes trade electrons with the external circuit and ions with the electrolyte. Three elements can influence battery voltage: temperature (temp), current (I), and state of charge (SOC). Internal resistance exists in every electrochemical cell. As current moves through the cell, cell's voltage change of internal cell resistance. Higher the recharging current, higher the voltage raises. If cell is discharging cause discharging current cause cell's voltage to drop. Battery100A/hr, divided by 10hrs, and then gets a charge and discharge rate of 10A. The current and battery capacity are in the same proportion. Battery SOC is connected to voltage. With a two-layer construction, the Supercapacitors employ porous electrolytes such as polyethylene terephthalate. Because of the two-layer structure's enormous surface area increase, energy storage capacity is greatly increased. Supercapacitors store and release larger amounts of electricity more quickly thanks to their electrostatic operation.

2.3. Loads

In a microgrid, the micro sources or generators are often distributed energy resources (DERs) that are integrated to produce power at distribution voltage. The operations of the power system are impacted by the procedures occurring in the load centre. The parameters of the load determine the extent of influence. Static and dynamic characteristics, as well as the static dependency of power, torque, or current, voltage, and frequency for gradual changes in the load, are the two types of load characteristics. The same traits identified for quick adjustments to the power system loads are called dynamic. Examples of static loads are constant loads resistive, dynamic loads are time varying loads motor starting, pulse loads are radars, electromagnetic rail weapons, battery charger, ship board appliances. In this proposed work the manuscript focusses only on static load conditions.

3. ENERGY MANAGEMENT AND THEIR CONTROLLERS

The goal of energy management is to control the energy in the system. The voltage and frequency at the grid should be properly maintained for power system stability in the system. The stability of the system is affected during voltage imbalance or any of the generating source connected to the grid get outage condition. The reliability and stability of the grid condition can be meeting by providing additional energy storage devices in the system and its performance are controlled by controllers linked to the system. A bidirectional converter is used to link the battery store to the grid. The converter is in the mood of a buck while the battery charges and during discharging process the converter is in boost mood. The switching operations of the converter are controlled by controllers connected to the bidirectional. Energy management for monitoring and control the grid performance, reduce cost of charging and a greater number of converters to the system, increase dispatchable efficiency, maximizes renewable utilization.

3.1 PI Controller

The measurements of the converter's parts vary with temperature, pressure, and other factors. Hence, utilizing the concepts of inverse feedback, the output voltage should be controlled in a closed loop [7]. The voltage-mode control as well as the current-mode control are both the most frequently utilized closed-loop PWM dc-dc converter control techniques. The output control voltage in the voltage mode control is created by sensing the converter output voltage and subtracting it from the voltage used as a reference in an error amplifier. The control voltage's value determines the PWM signal's duty ratio. The drivers of the controlled switches in the DC-DC converter get a PWM signal from the comparator. An additional inner control loop in the current-mode control sends back an inductor current signal. After being converted to its analogy voltage, this current signal is contrasted with the control voltage. One significant benefit is that voltage-mode control may be implemented with ease in hardware, whereas current-mode control requires complex hardware design.
PI controller *equation (1)* is given below:

$$PI = K*(1+1/(Ti*s)) \tag{1}$$

Let K refers to the gain and Ti represent the time constant and, the PI controller equation can be written as Kp+Ki/s

$$K_p = K;\ K_i = K/T_i$$

Where K_p and K_i is proportional gain and integral gain, respectively. In this study, Kp = 1.983 and Ki = 1.969 are selected with MATLAB.

4. PROPOSED SYSTEM WORK

In this paper DC microgrid problems are analysed. Here the DC microgrid consists of four dc buses of different source and load.

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Figure 1 represents a block diagram of proposed System. *Figure 2(a)* and *figure 2(b)* shows a block diagram of Proposed System with and without PI Controller. *Figure 3(a)* and *figure 3(b)* shows a block diagram of (a) AC-DC Bus 3 System and (b) AC-DC Bus 4 System. The four Buses are separately picturized in the above diagram with linear loads. of which bus1&2 are hybrid source (battery and supercapacitor) and bus 3&4 are ac source. The microgrid can get input from both ac and DC, to reveal that here AC source is connected to DC bus through converter circuit.

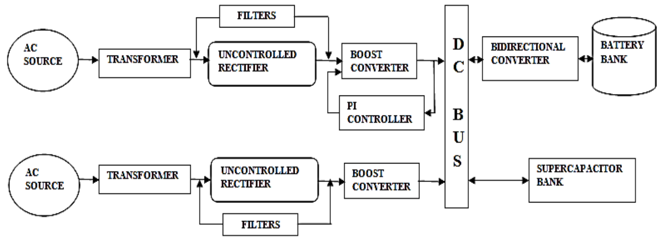
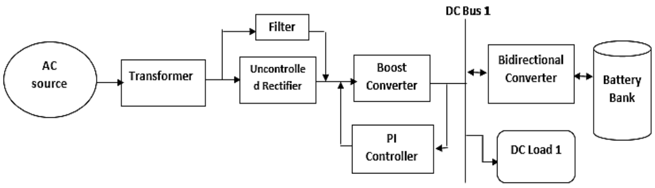
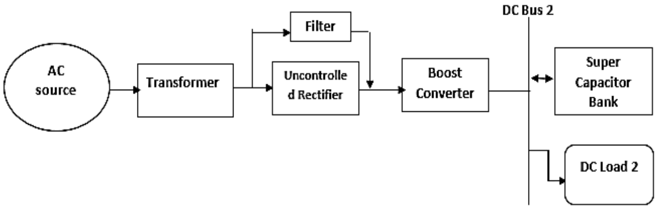


Figure 1. Block diagram of Proposed System

AC input voltage and input current at the Bus1 are shown in the *figures 4* and *figure 5*. Whereas battery and supercapacitor get charged from the grid source and discharge during unbalance load and transient conditions, when the grid suffers. AC source is connected to transformer for step down of voltage and the ac filter to reduce harmonics and then given to uncontrolled rectifier for dc conversion from ac voltage. The converted DC voltage contains ripples in the voltage waveforms they are eliminated by dc filters and the ripple free voltage is boosted through boost converter and then connected to dc buses. Both the ac source in this paper work is connected to the DC microgrid in this manner. And the battery bank is linked to the DC bus through bidirectional converter whereas the supercapacitor bank can be directly connected to DC bus. Because supercapacitor having higher power density than battery and they can quickly charge and discharge than battery, whereas battery having higher energy density they can able to store charge for a long period of time than supercapacitor.



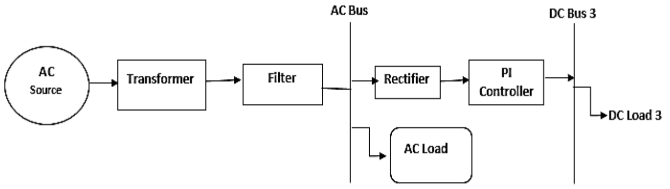
(a)



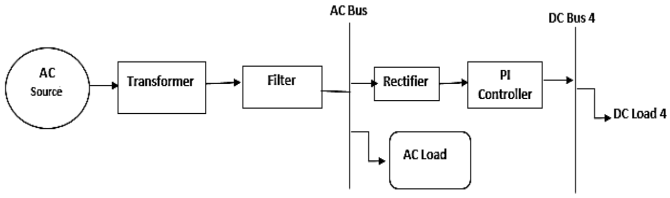
(b)

Figure 2. (a) Proposed System with PI Controller (b) Proposed System without PI Controller

For this reason, these hybrid sources are used in this work. The loads connected to the grid may differ; to analyze the dynamic behavior of the grid here constant load and time varying load and short duration loads are connected to this DC microgrid. During these conditions grid suffers from voltage unbalance and fluctuations, to regulate voltage and current in the dc microgrid the controllers to the converter are used, after connecting controllers to the converter the oscillated dc voltage in the dc grid settles and the ripples are reduced is analyzed in this paper.



(a)



(b)

Figure 3. Block diagram of (a) AC-DC Bus 3 System (b) AC-DC Bus 4 System

4.1 Design of Rectifier

One circuit that changes an ac voltage into a dc voltage is a rectifier. Diodes are used in rectifier circuit for conversion from ac into dc voltage. In a three-phase circuit, each diode conducts for a period. The phase when the voltage is higher than the other two phases' diodes is when the diode associated with that phase conducts. In a three-phase circuit, each diode has a conduction angle of 2π/3 as opposed to π. From π/6 to 5π/6, diode D conducts while taking the R phase. The output's average value can be determined as

$$V_{dc} = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} V_m \sin\theta d\theta \quad (2)$$

$$V_{dc} = V_m \frac{3\sqrt{3}}{2\pi} = 0.827V_m \quad (3)$$

The output voltage's root mean square value can also be determined as

$$V_L = \sqrt{\frac{3}{2\pi}\int_{\pi/6}^{5\pi/6}(V_m \sin\theta)^2 d\theta} \quad (4)$$

$$V_{dc} = 0.84V_m \quad (5)$$

Each secondary winding of a transformer's rms current can be determined as

$$I_s = I_m\sqrt{\frac{1}{2\pi}\left[{}^{\pi}/_{3} + {}^{\sqrt{3}}/_{4}\right]} = 0.485I_m \quad (6)$$

$$where\ I_m = \frac{V_m}{R}$$

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4.2 Design of DC-DC Converter

The functions of dc-dc converter are

- To change the voltage coming from a DC source into a DC output. To regulate the voltage of the DC output in response to variations in the load and line.
- To get the ripple in the AC voltage of the DC output voltage down to below the required level.
- To create separation between the load and the input source.
- To prevent electromagnetically generated interference (EMI) from damaging the input source and the supplied system.

4.3 Boost Converter

The output direct current voltage of the boost converter exceeds the input voltage. It is made up of the filter capacitor C, controlled switch S, boost inductor L, diode D, load resistance R, and dc input voltage source. A linear increase in the boost inductor's current occurs when the switch is turned on. Now, the diode D is off. Upon turning off the switch, the energy contained in the inductor is released via the diode and enters the input RC circuit.

Using faraday's law for the boost inductor

$$V_s DT = (V_o - V_s)(1 - D) \qquad (7)$$

It indicates the dc voltage transfer function is

$$M_V = \frac{V_o}{V_s} = \frac{1}{1-d} \qquad (8)$$

Where d represents the duty ratio, which is the ratio of the on-to-off switch times.

$$d = \frac{t_{on}}{t_{on}+t_{off}} \qquad (9)$$

The output voltage and current are given by

$$V_2 = \frac{1}{1-K} V_1 \qquad (10)$$

$$I_2 = (1 - K) I_1 \qquad (11)$$

Where K is the duty ratio, $V_1 I_1$ are input voltage and current.

4.4 Bidirectional Converter

In bidirectional converter both buck and boost operation are performed in the converter. During the charging process of the battery the converter is in buck mode and during the discharging process of the battery the converter is in boost mode. A dc input voltage source, a programmable switch, an inductor, a diode, a filter capacitor, and load resistance make up the converter. Hence, the buck-boost converter's dc voltage transfer function is

$$M_V = \frac{V_o}{V_s} = -\frac{d}{1-d} \qquad (12)$$

The output voltage and current are given by

$$V_2 = \frac{K}{1-K} V_1 \qquad (13)$$

$$I_2 = \frac{1-K}{K} I_1 \qquad (14)$$

Where K is the duty ratio, $V_1 I_1$ are input voltage and current.

5. SIMULATION RESULT AND OUTPUTS

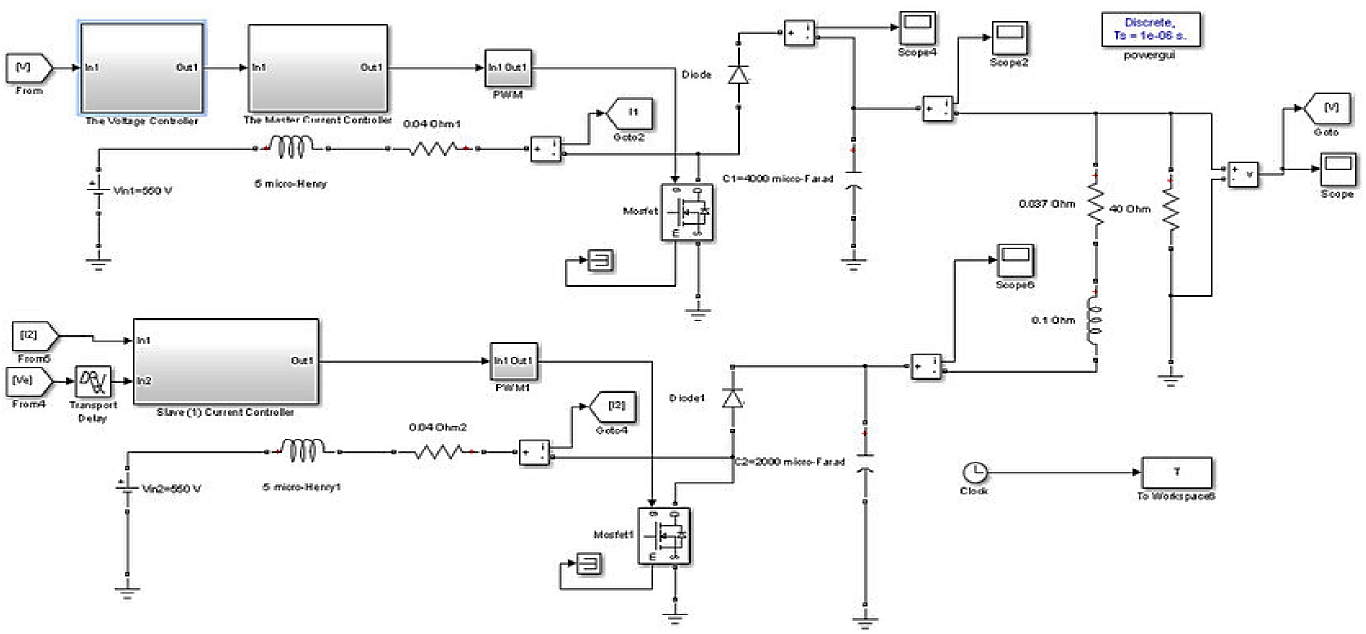

Figure 4. Overall Simulation model of PI Controller in DC Microgrid system

The Overall Simulation model of PI Controller in DC Microgrid system is shown in *figure 4*. AC output voltage at transformer side and Rectifier conversion from AC to DC are shown in the *figures 5* and *figure 6*. Although the DC buses having different voltages during standalone condition and having same dc voltages in the dc buses during grid connected condition, there by satisfying the grid connected condition is also verified in this paper.

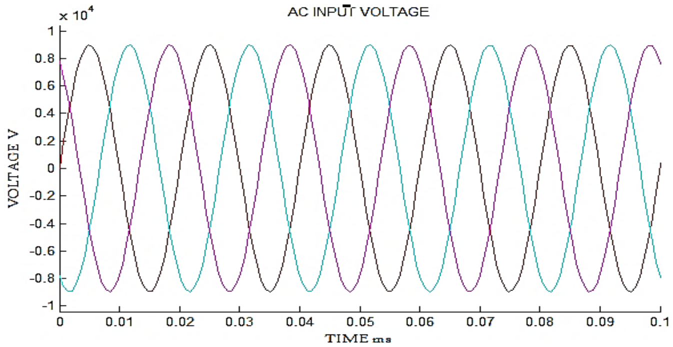

Figure 5.AC input voltage at the Bus1

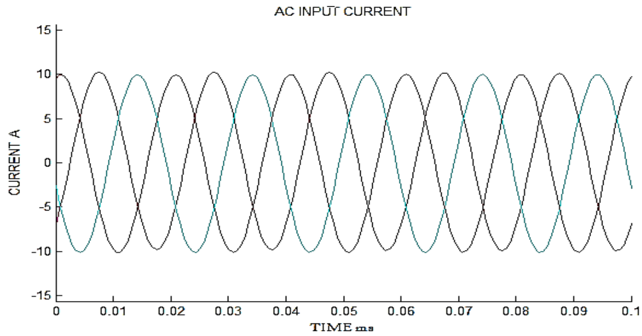

Figure 6.AC input current at Bus1

Figure 7 represents the AC output voltage settles after 0.2 Sec. Rectifier conversion from ac to dc is shown in *figure 8* which settles after 0.8 Sec. *Figure 9* shows the load current during varying conditions.

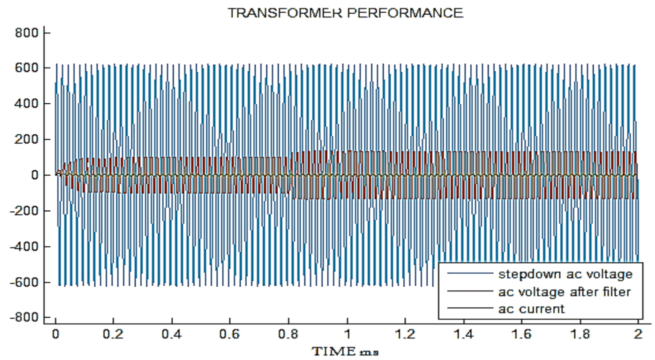

Figure 7. AC output voltage at transformer side

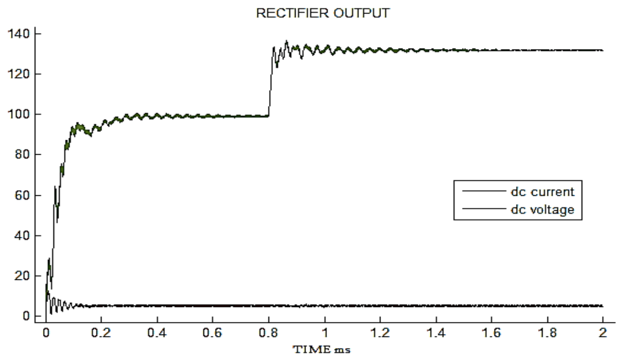

Figure 8. Rectifier conversion from AC to DC

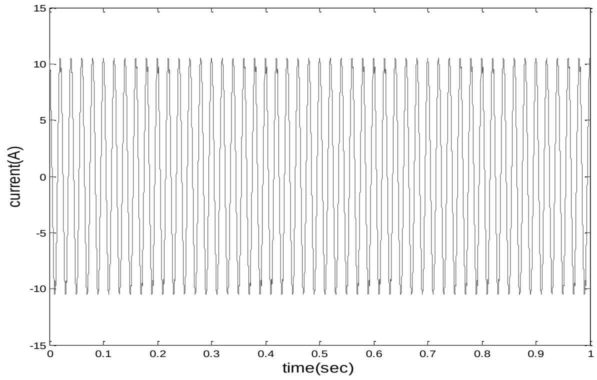

Figure 9. Load current during varying conditions

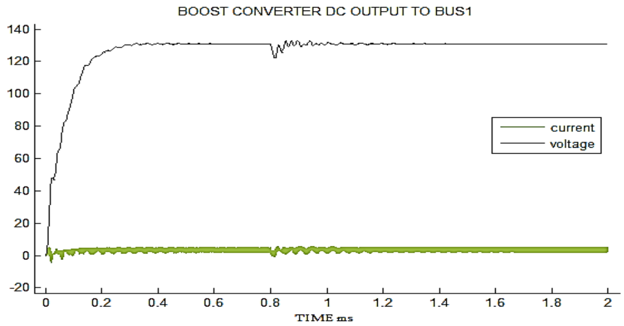

Figure 10. Boosted DC output Voltage to the Bus1

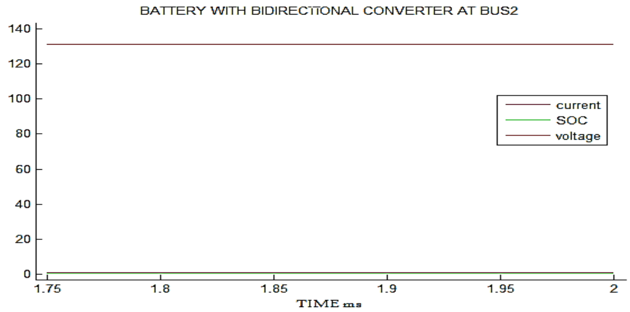

Figure 11. Bidirectional converter at Bus2

Boosted DC output Voltage to the Bus and Bidirectional converter at Bus2 are shown in the *figure 10* and *figure 11*. From *figure 11* it is observed that approximately 130 voltages getting as an output. *Figure 12* and *figure 13* represents different DC bus during standalone and grid conditions at DC microgrid.

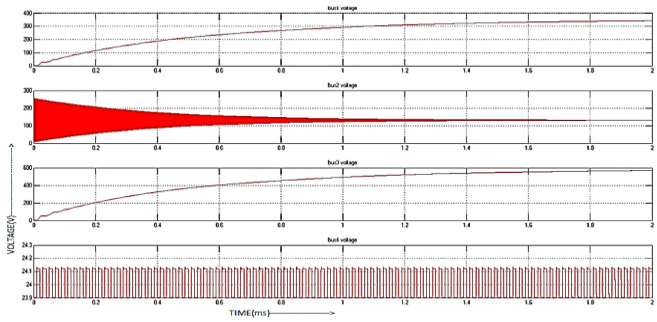

Figure 12. Different DC bus connection at standalone condition (Islanded mode)

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Table1. Different DC bus at DC microgrid during standalone and grid conditions

BUSES	BUS1	BUS2	BUS3	BUS4
At no Grid Condition	205.6V	65.41V	569.8V	22.18V
During Grid Condition	130.9V			

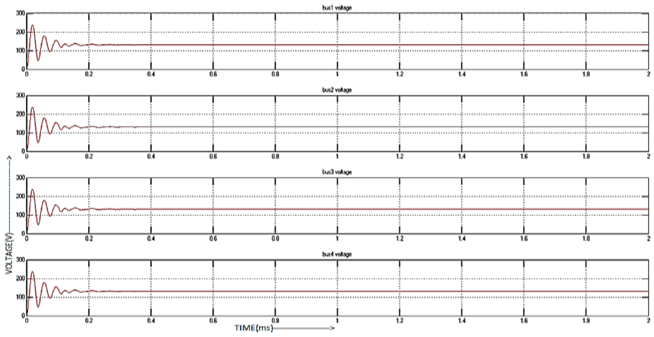

Figure 13. DC bus voltage at grid condition

Table 2. Voltage level at the DC buses

BUS1	11KV	439.5V	134.2V	198.5V	205.9V
BUS3	11Kv	439.5V	190.9V	243.2V	569.8V

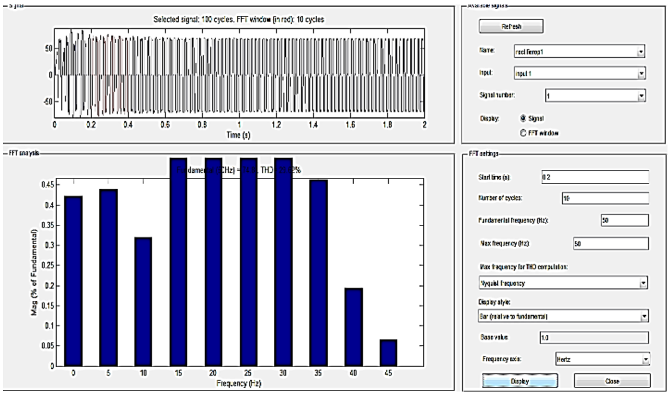

Figure 14. THD spectrum before controller to the converter in DC grid

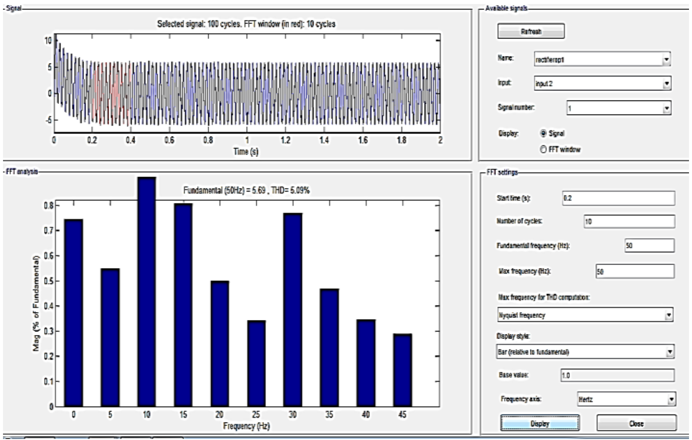

Figure 15.THD spectrum after PI controller to the converter in the grid

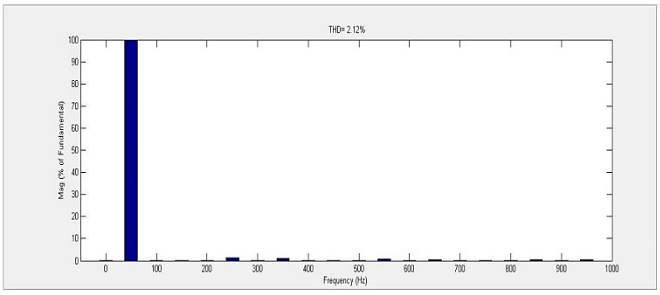

Figure 16.THD spectrum after PI controller to the converter in the grid during Inductive load

Table 1 and *table 2* represents different DC bus voltages at DC microgrid during standalone and grid conditions from *figure 12* and *figure 13* and compared THD spectrum before and after controller to the converter in DC grid. The THD is obtained the before controller connection to the converter in DC grid. Current waveform is measured and the results are obtained with harmonics. From the observed result, before compensation the THD value is 29.62 % in the *figure 14*. The compensated current after controller connection to the converter is shown in the *figure 15*. It can be observed that the amplitude of the 50Hz component is high in the system. Here, THD value is 5.09 %. *Figure 16* shows the THD spectrum of 2.12% after PI controller to the converter in the grid during Inductive load.

6. CONCLUSION

Before implementing controller to the converter, the distortion in the current & voltage is high, which disturb the whole system performance. After implementing the controller to the converter, the voltage ripples reduced and oscillations in the voltage, quickly settles to the needed grid voltage is verified using MATLAB/Simulink. Although any of the bus outages can be able to manage by the grid using the hybrid sources. The performance of the system under static load conditions are only tested and thus the grid performance improved by implementing controller and the harmonics at the ac side of triples harmonics is reduced and it is verified using THD analysis. Under such conditions, the grid voltage, grid frequency is properly synchronized and verified. Thus, the energy management in the dc microgrid is maintained by incorporating controller and hybrid sources are achieved in this paper work.

Future Work

Although the THD is reduced it can be further reduced by implementing new technique of adaptive controller, that work based on load with respect to the changes in grid. The lagging characteristics of PI controller can be overtaken by that new adaptive controller technique and it can be further analysed by Machine Learning algorithm.

REFERENCES

[1] Mustafa Farhadi,Osama Mohammed, "Adaptive energy management in redundant hybrid DC microgrid for pulse load mitigation," IEEE Transaction On SmartGrid, vol.6.No.1,pp. 54–60, Jan.2015.

[2] Ahmed Mohamed,Vahid Salehi,Osama Mohammed, "Real-Time energy management algorithm for mitigation of pulse loads in hybrid Microgrids," IEEE Trans.On Smartgrid, vol.3,No.4, pp. 1911–1922,Dec.2012.

[3] Isaac J.Cohen,Jay P.Kelley,David A.wetz,"Evaluation of a Hybrid energy storage module for pulsed power applications," IEEE Trans.On Plasma Science,Vol.42,No.10,pp.2948-2955,Oct.2014.

[4] Monika Jain,Sushma Gupta,Deepika Masand,Gayatri Agnihotri, "Analysis of a microgrid under transient conditions using voltage and frequency controller," Hindawi Publishing Corporation Adva.in pow.electronics,Vol.2012,Article Id 208231,18pages,Oct.2012.

[5] Micah Ortuzar,Jorge Moreno,Juan Dixon,"Ultracapacitor-Based auxillary energy system for an electric vehicle:implementation and evaluation," IEEE Trans. On Indus.Electro., vol. 54, pp.2147–2156, Aug.2007.

[6] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.
[7] Muhammed H. Rashid, "power electronics handbook third edition.

[8] Ibanez, F.M.; Florez, A.M.B.; Gutierrez, J.S.; Echeverrria, J.M. Extending the Autonomy of a Battery for Electric Motorcycles. IEEE Trans. Veh. Technol. 2019, 68, 3294–3305.

[9] Choudhury, T.R.; Nayak, B.; De, A.; Santra, S.B. A comprehensive review and feasibility study of DC-DC converters for different PV applications: ESS, future residential purpose. EV Charg. Energy Syst. 2020, 11, 641–671.]

[10] Dougal, R.A.; Liu, S.; White, R.E. Power and life extension of battery, ultracapacitor hybrids. IEEE Trans. Compon. Packag. Technol. 2002, 25, 120–131.

[11] Lu, D.; Fakham, H.; Zhou, T.; Francois, B. Application of petri nets for the energy management of a photovoltaic based power station including storage units. Renew. Energy 2010, 35, 1117–1124.