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Microgrids As Sources of Electricity Generation In The 21st Century

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ABSTRACT

The concern on climate change is driving major changes in electricity generation as well as in the pattern of consumption. By the reason of environmental considerations, large scale changes are likely to occur in the near future in transporting and distributing electricity to the end-users. Presently, the existing power grids do not meet the needs of the 21st century because of increase in power demand, and generation complexity. Also the demand for power supply across the globe is being envisaged to rise even to the highest peak in the future. Therefore there is an immediate need for the development of highly reliable, self- regulating and efficient grid system which will allow for the penetration of distributed generators most importantly the renewable energy sources and other distributed power generation, hence the smart micro-grid technology. In this paper, behaviors of Micro-grid as regards voltage stability and droop control method are analyzed when Distributed Energy Sources (DES) are integrated.

Keywords: *Distributed Generation, Renewable Energy, Voltage Stability, Fossil Fuel, Global Warming Emissions, Reliability*

1. INTRODUCTION

Micro-grid [MG] is an electrical network comprising of distributed sources, loads, intelligent monitoring as well as communication & automation systems as stated in [5. Several types of distributed generations (DGs) including Renewable Energy Sources (RES) can be connected together to form small and intelligent installation known as micro-grid. Micro grid is usually linked to the primary side of the distribution network, operating in the normal connecting mode. But, the MG can be made to transfer to the islanding mode when a severe fault occurs in the distribution network [4]. Also when the power sources are purely of direct current MG, it then requires inverters before being linked to the main-grid network.

Micro-grids provide energy in form of direct current (DC) or alternating current (AC) for a small or local community, military locations, an academic community, a commercial area, trading and residential estates et cetera. MGs can exist as a remote power system in locations where utility supply is not available. They may on the other hand be embedded in a larger electrical utility [3]. With micro grids, sources and demands can be controlled by information technology, enabling us to make appropriate use of natural energy alongside other convectional power sources; all in order to reduce greenhouse gases. The micro grids can be make better hence the Smart Micro-Grid, which is all about information and control. This provides great opportunities to eradicate energy inefficiency, energy insecurity, power quality problem, and equipment aging making use of products and services of high innovation [4]. In the upcoming years, ‘smart’ micro-grids technology will play growing role in meeting local demand, enhancing reliability and ensuring local control of electricity; bringing millions out of darkness.

2. MOTIVATION

The immediate need for the development of highly reliable, self- regulating and efficient grid system which will allow for the penetration of renewable energy sources and other distributed power generation, constitute great concern hence the smart micro grid technology. The conventional power grid is a network that acts as a link for transmission, distribution and control of electric power from power producers to consumers [6]. This is made of generating centers that generate electrical power, high voltage transmission lines that carry power from distant sources to the consumers, and electric lines that connects individual customer. An example of electricity networks is shown in figure 1. Presently, almost all the electricity produced in most countries of the world, is generated from a centralized power system designed around large fossil fuel though reliable, but with low power generation efficiency. This resulting in large quantities of primary energy being wasted as heat [3]. One of the ways out is in the use of smaller scale power supply networks, which can deliver a sort of environmental benefits which can be found in low carbon emission via higher energy efficiency.

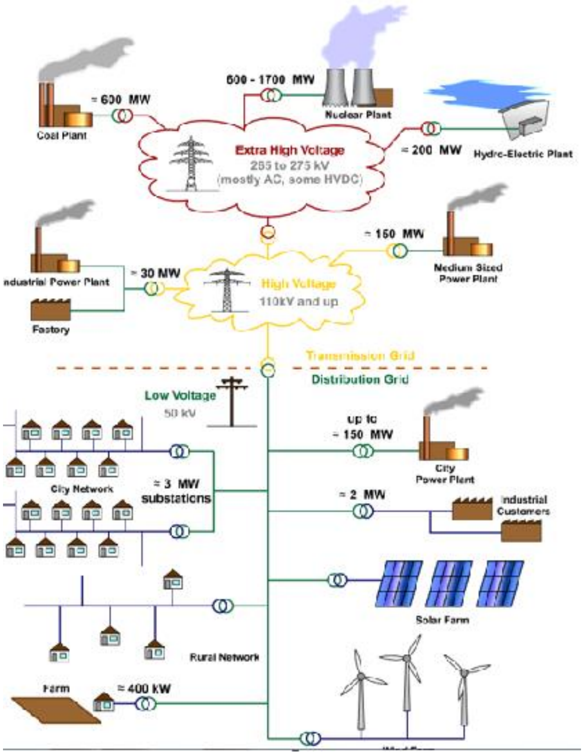

Figure 1: General layout of electricity networks [7]

The success of this work would be useful in providing local communities, small and medium scale industries, sparsely populated areas with always available electricity supplies generated from RES.

3. DISTRIBUTED GENERATION

Distributed Generation (DG) is a technic by which electricity from multiple small energy sources in most cases less than 100 Kw are located near to where it is actually being utilized. [4]. A DG can as well be called embedded generation, on-site generation, dispersed generation, and de-centralized generation. DG technologies are characterized as renewables and non-renewable energy sources. DG supplies green power from locally available renewable energy resources as in figure 2. Hidayatullah N. et al [4] stated that the Electric Power Research Institute (EPRI) defines distributed generation as electricity generated with a power rating from low kilowatts values to about 50 Mega Watt. Integrating distributed generation to power systems is capable of increasing system reliability and power quality.

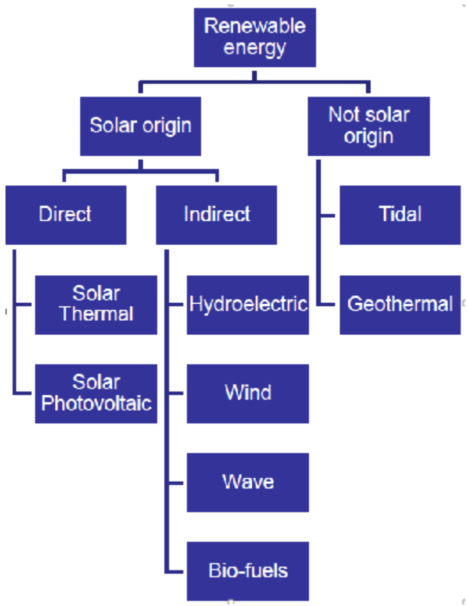

Figure 2: Renewable Energy Sources [8]

4. MICROGRIDS

Micro-grid is that section of electric grid that can disconnect from the main grid (islanded) and operate independently. Generated power is then supplied to the local area and may or may not be connected to the main grid depending on its geographical location. It is made up of all the functions of the main grid, but supply energy to only limited area, hence the name micro grid.

A Micro Grid (MG) comprises of loads and several distributed energy sources that operate as a single controllable system capable of providing power primarily to a local area. SMGs generates, distributes and regulate the flow of electricity to users in a local scale. It is an ideal way to integrate Renewable Energy Sources on a community. It also allow for customer participation in the electricity sub-sector of the economy of any nation. But with the emergence of renewable energy sources such as wind power and photovoltaics especially at a house-hold level, direct current (DC) micro grids can offer a cheaper and more efficient alternative [9]. A micro-grid topology is presented in figure 3.

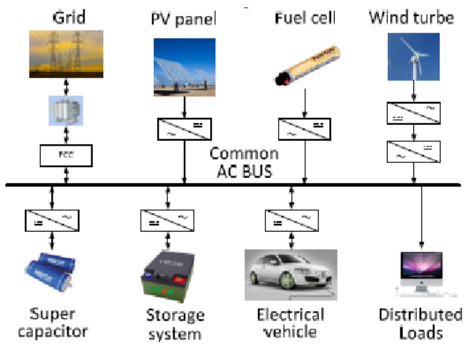

Figure 3: A Structure of Micro-grid [10]

Microgrid technology approaches to improve overall power to be robust, reliable and secure with the use of smart technologies. The smart grid concept as a matter of fact, monitors the condition of electricity consumption and generation, balancing demand and supply. It is also a way of modernizing the power grid. With the deployment of renewables into the grid networks system, there is need to analyze what happens to the three essential primary physical quantities like frequency, voltage and current. There are two operational modes for a MG:

* Islanded Mode or stand-alone method. When the MG operates in this way, DG inverter system operates in voltage control manner, and the load is provided with a constant voltage. Micro grids on islanded mode can as well be intentionally introduced for maintenance purposes.

*Grid-Linked Mode. When the MG operates as grid-linked, the grid-injected power converters has operational control over the DC link energy level. Here, the DGs provide power support for nearby loads, while the micro-grid is linked to main network [19]. It functions on this mode to enhance system reliability and service continuity.

5. ADVANTAGES OF MICROGRID TECHNOLOGY OVER CONVENTIONAL POWER GENERATION

Micro-grids provide great opportunities that will eradicate issues like energy inefficiency and insecurity, poor quality, and the aging power system equipment as stated by Nur Asyil in his work [4]. Some of the goals of MGs especially with Renewable Energy Sources include: reliability with energy source resilient, carbon emission reduction, diversification of energy sources, a vast and inexhaustible energy supply, stable energy prices, improved public health and environmental quality, and marginal cost reduction. The power system with the 'smart' grid is designed to operate with the goal of achieving high reliability and security standards, low operations cost, high efficiency and minimum environmental impacts and carbon emission reduction.

A good feature of Microgrids is the ability to accommodate various amount of wind turbines, fuel cells, hydro-generators, micro-turbines and photovoltaic cells. The point which difference the MG technology from a conventional power utility is that power generators for the former are small in size and they are located in close proximity to the energy users. Aside the location environment plays vital role as well [11]. The conventional grid system is largely dependent on the planet- warming fossil fuels. For the fact that the conventional grid seems so big and interconnected, it is vulnerable to massive disruption by natural disasters and susceptible to physical or cyberattack [12]. The concept of electricity generation management by smart microgrid power has to do with the ability in matching electricity supplies with demands using identical generators which can control and operate efficiently at chosen load, independently of the others, making them suitable for both base load and peak power generation [13].

Smart Grid as applicable to smart micro-grid (SMG) will integrate all power system components to empower and encourage consumers to develop good relationship with the operators [4]. Two-way communication enables energy curtailment strategies such as load shedding and demand response, both of which reduce peak demand. Electricity outages can be more quickly and easily identified. The increased quality of the grid leads to both cost and pollution reductions. By moving towards MGs, the amount being spent on power loss in transmitting power over long transmission lines can be saved [14]. Stability problem can be minimized. After a severe fault may have occurred in the primary distribution system, the MG can transfer to islanding approach of operation as explained by Kamel [2]. Other benefits include: High efficiency, high quality, reliability of electricity supply, more flexible power network operation coupled with environmental benefits [15]. Ashraf observed that the micro grid technology is proved to be one of the promising solutions that can effectively cope with the increasing energy demands and the negative environmental efforts of fossil- power plants [16]. Micro-grids have the potential to increase the use of renewable generation and micro CHP.

6. VOLTAGE CONTROL OF DC MICROGRIDS

For the purpose of this work, a DC Microgrid is being considered. This section actually provides the general review of the work especially from other researchers' points. It also provide the essential background of distributed generation including renewable energy sources and recent developments in Smart Grid technologies and its adaptation on micro-grid. The micro sources with or without the energy storage system are unsuitable for direct supply of voltage to the grid, hence energy storage devices like batteries, flywheel, and electric vehicles be connected.

With smart micro grid quality of demands and supply is increased. Electricity outages can be more quickly and easily identified. The increased quality of the grid leads to both cost and pollution reductions. The micro-grid may supply three-phase as well as single phase loads. The whole essence of micro grid as a solution to insecurity of power supply especially in sparsely-populated areas. The adopted DC micro grid network consists of two RES and a fuel cell. When all the three distributed power sources used are combined in a single system, they function complementarily, for example in reducing the harmonic tendencies of the output power though they depend on environmental conditions [18]. Other components included in the DC Micro grid system considered in this work, are loads and converters. DC-MG components are modelled using the MATLAB-Simulink software setting. The DGs are inter-connected in order to obtain greater power.

7. MICROGRIDS STABILITY

Micro grid stability is all about control and regulation of the sources of power utility. For basic operation of the Micro-Grid, the controllers use local information to control the micro sources. The converters as controllers must be able to respond to any change in load automatically [6]. A system experiences a state of voltage instability when there is an uncontrollable drop in voltage magnitude after a disturbance, increase in load demand with changes in operating conditions. A power installation experiences a state of insecurity when there is a noticeable drop in voltage after a disruption, increase in load demand and a change in the conditions at which it operates. [20]. One of the factors that can cause these unacceptable change in voltage trends is the inability of the distribution system to meet reactive power demand in normal operating conditions. Voltage stability refers to ability of the power system to maintain steady voltages at all buses after being subjected to a disturbance from a given initial operating and subsequent conditions [21]. Steady state stability has to do with small and gradual changes in the operating conditions of power system. The micro sources have to be interconnected to the network through power electronics like the voltage source inverters (VSI).

The behaviour of this micro grid will depend on type of intermittent energy resources, point of connection and type of load distribution in the system. For the case being studied, the integration takes place at the distribution side of power network. So the voltage stability analysis is to be assessed at low or medium voltage level. The micro-grid being considered consists of three distributed generation sources. These are wind turbine (WT), photovoltaic (PV) system, and fuel cell (FC). Other components are dc-dc converters for the improvement of direct current power, inverters to link alternating current with the main grid if and when necessary. To connect the micro grid power sources in parallel power electronics devices are used [17].

8. MODELLING AND SIMULATION ON SIMULINK

This section is on the modelling and simulation of the DC micro grid observing its stationary (steady) and dynamic loads behaviors.

8.1. MODELLING

The three DGs are connected in parallel and modelled as DC sources. In general, to parallel power sources for Micro grid use with power electronic VSCs for each of the sources has an advantage compare to when a single power converter is used [1]. Each droop controller is like a resistive or reactive element that increases the converter output current with reduced source voltage. The transient and the steady-state system characteristics are analysed with established models. A prototype-based model of the three power sources is presented in figure 4.

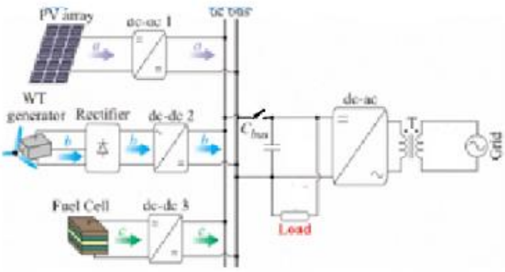

Figure 4: Power Flow in a DC microgrid [19].

When the micro-grid operates on stand-alone mode, power flow has its power balance as in [19] to be:

$$P_{PV} + P_{WT} + P_{FC} = P_{Load} \quad (1)$$

$$P_{grid} = 0$$

If the DC micro grid operates on grid-connected mode, the power balance is [19].

$$P_{PV} + P_{WT} = P_{grid} + P_{Load} \quad (2)$$

$$P_{FC} = 0$$

$$P_{PV} = I^2R = VI \text{ (kW)} \quad (3)$$

$$I_{total} = I_1 + I_2 + I_3 = I_L \quad (4)$$

For this work, at ideal and steady state, each of the DGs is source voltage = 240V and reference power P_{ref} = 15kW. The total output current will be determined by the resistance of the converters. Finally, the DC Micro grid consisting of three DG sources, each with a controller and loads was modelled on the MATLAB-Simulink software environment [1]. The focus of this project work was on the stand-alone manner and not grid-linked [19].

The output voltage V_0, is the DC link voltage and it can be determined as:

$$\frac{V_0}{R_P} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} - I_L \quad (5)$$

$I_T = I_L$ is the load or the inductor's current, and R_P is the parallel resistance of the three DGs for the DC micro-grid which can be expressed as:

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad (6)$$

The reference power $P_{ref,}$ also represents the desired power and can be calculated using equation (7) as in [22].

$$P_{ref} = G(s)\left[V_{ref} - \left(\frac{w_{I,P}}{s+w_{LP}}\right)V_{dc}\right]V_{dc} \quad (7)$$

According to Ferreira R. et al in [17], G(s) is the transfer function of the controller, V_{ref} is the reference voltage, w_{LP} stands as cut-off frequency of the low-pass filter, and V_{dc} is the dc grid voltage when the converters were coupled together. From equation (8) the reference current for each converter can be determined as in [17]:

$$I_{ref} = \frac{P_{ref}}{V_s}, \quad (8)$$

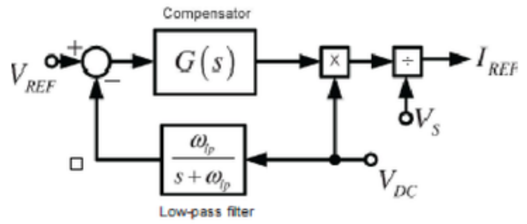

Figure 5: DC-DC Voltage Controller [17]

Where V_s stands for the direct current distributed generation source voltage. Voltage controller model for DC-DC converter is on figure 5. The proportional-Integral controller is designed to force a sag on the operation characteristic of the converter. This will as also improve the droop on the operation of the converter.

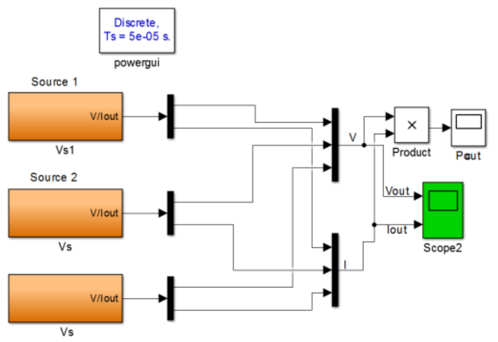

Figure 6: The Model of the DGs and Paralleled- Inverters on Simulink

Voltage droop is that loss in output voltage from a device as it drives a load. The design model for RES used for this work is as presented on figure 6.

The model is used to control parallel converters connected to the direct current (dc) micro-grid. The droop control system is regarded as a distributed primary control whether the DGs are main grid connected or not (islanded).

PI Controllers

Droop control is used to control and regulate micro grid in island mode as well as in grid-connected mode when necessary. It is an example of decentralized control system which relies on local information for operation. In the parallel inverters the controllers has good current sharing while maintaining the system stability [16].

Proportional Controller

The distributed generations' voltages as well as the inductor current are the two parameters that are being controlled. Average inductor current is:

$$I_L = \frac{V_d}{(1-D)^2 R} \quad (9)$$

$$V_L = V_i - V_o \quad (10)$$

The gain k_p of the transfer function is:

$$G(s) = k_p = \frac{1}{R_{d,n}} \quad (11)$$

If P controller is used, there is probability that a large gain is introduced to improve steady-state error. The n subscript indicates the converter number. From the above equations, the rated power of the source is expressed as:

$$P_{rated,n} = \delta_n(1 - \delta_n)\frac{V^2{}_{ref,n}}{R_{d,n}} \quad (12)$$

$$\delta_n = \left(1 - \frac{V_{dc}}{V_{ref,n}}\right). \quad (13)$$

The nominal voltage droop for the rated power of the converter is as in equation.

Proportional- Integral Controller

A PI controller can easily be designed by using the Simulink environment as:

G = k_p =the proportional gain

$\frac{G}{\tau} = k_I$ = integral gain

P depends on the present error while integral I is based on the build-up of past errors.

A Proportional-Integral controller in equation (14), is used to cancel the steady state error that may have resulted. The actual plant model is:

$$G(s) = k_p\left[1 + \frac{1}{sT_i}\right] \quad (14)$$

The integral time constant of the controller is T_i and may be assumed to be the PI time constant. The gain of the controller for the purpose of this work can be taken as the reciprocal of the number of integrated DGs which is:

$$k_p = \frac{1}{3} = \frac{1}{R_d} = 0.335$$

PI time constant as in [19]

$$T_S = \frac{4}{w_{LP}} \quad (15)$$

Direct Current transfer function is taken as in equation (30) [23].

$$\frac{V_O}{V_i} = \frac{T_S}{t_{off}} = \frac{1}{1-D} \quad (16)$$

D has its value to be = 0.53 as applied in the model.

Switching period $t_{on} + t_{off} = T_S = \tau$ (17)

$Vi\ t_{on} + (Vi - V_O)\ t_{off} = 0$ (18)

8.2. SIMULATION

To determine the control strategy for the parallel converters, models for simulation were implemented on MATLAB/Simulink software. Simulation models for all the cases considered are presented in the subsequent paragraphs. The following cases were considered:

A. DC-DC Converter

In this case, before simulation, the three DC energy sources were modelled as ideal sources and each has a voltage of 240 V and 15 KW. In the case of the controllers, the resistance R = 3.55 Ω, Inductor L = 2.33 mH, while the Capacitance C = 50 mF, frequency cut-off of the low-pass filter $w_{LP} = 100\ \pi$ rad/s. The controller has the following parameters: Gain $k_p = 0.335$ (W/V^2), and integral time constant $T_i = 0.0127$ s. 650 V was used as the reference voltage to the controller. On figure 8 is a design model of DC Micro-grid for a RES.

B. Simulation with dc-ac Converter

In this second case the behaviour of the DC micro-grid when dc sources are being converted to alternating voltage was observed. The run- time t = 250ms when the inverter connected DGs are on no-load state. The result of the simulation is in section 9.

C. Simulation with Load

A load model which consists purely of resistive components is connected to the DC bus. The result for this model is as presented in section 9.

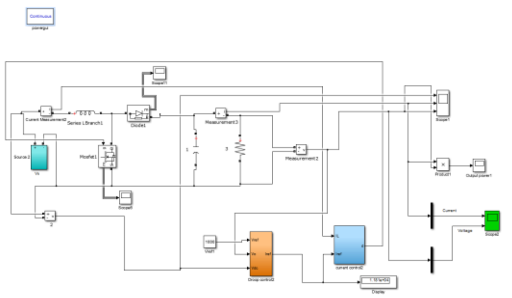

Figure 7: A complete model of DC Micro grid for one DG

D.Load Step-Change

This same model was used to observe the micro grid behaviour in case of step–change by incorporating a timer device block as the fourth case. The time for simulating the switching model is about 0.15s while 250ms run-time was used for the simulation. The result for this case is presented in figure 12 and 13.

9. RESULTS AND DISCUSSION

A.Results

The voltage values for all the results appear the same because the energy sources are integrated in parallel. In each case the main focus was on how DC micro grid behaves in terms of current, voltage and power consumption with respect to time. Most of the simulation results are for both the transient and steady state stability has to do with small and gradual changes in the operating conditions of power system.

Case 1. DGs with DC-DC Converters

The simulation results when the DGs are integrated with the DC micro grid and paralleled using VSC is presented in figure 8, showing both the current and voltage of the dc-dc converter output with respect to time. The values of P and I parameters are 0. 003 and 1.35 respectively**.** The output power characteristic is on figure 9. At a run time of 250 ms, average dc voltage V_O = 238 V, Iout =

The output power characteristic is on figure 10. At a run time of 250 ms, average dc voltage V_O = 238 V, Iout = 68 A while average output power is P_{out} = 48.22 kW.

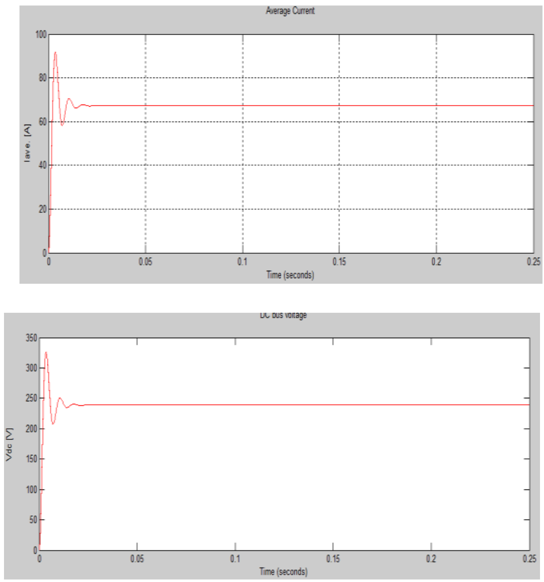

Figure 8: Voltage and Current Output

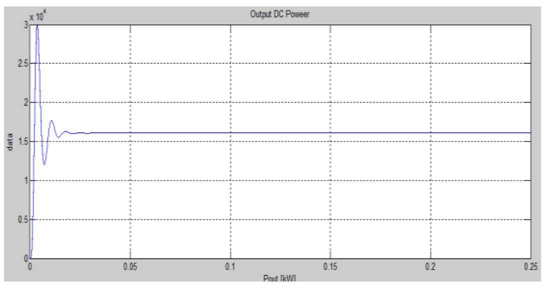

Figure 9: DC bus Average power supplied

Case 2: DC Micro grid with Inverter on Load

Result details with pure resistive loads earlier used for simulation as connected to DC micro grid are as presented in this section. Figure 10 shows voltage and current output of the micro grid behaviour with respect to time. While power output is in figure 11. The output values are: I out = 23.58 A, V_O = 238V and average output power P_{out} = 5.63 kW.

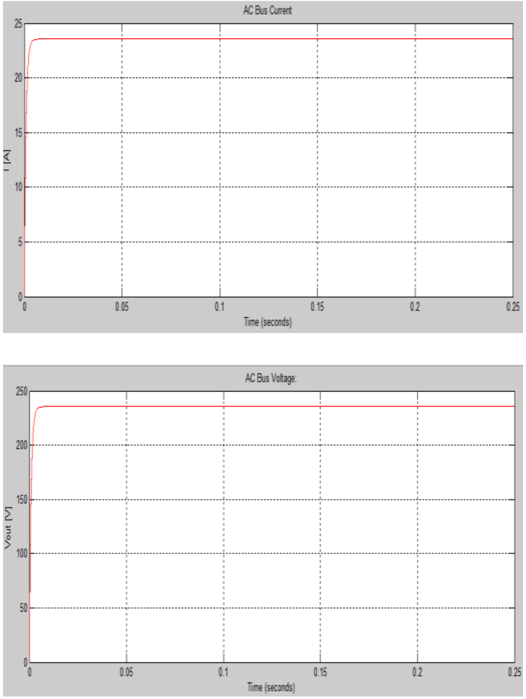

Figure 10: Voltage and Current- time characteristics of Inverter with loads

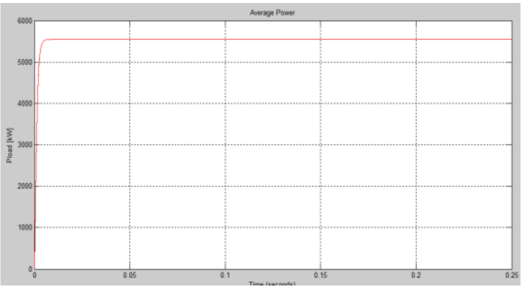

Figure 11: Power output for microgrid inverter connected DGs.

Case 3: Load Step-Change

Case three has to do with the behaviour of the micro-grid when step-change is applied. When a resistive load is connected to each of the DGs. With a run time of 250 ms, the value of the voltage drops from 238 V to 215 V. When load is introduced to the circuit, the step change definitely affects the amount of power being drawned by the load with a step changed from an average of 8.5 kW to 95 Kw. Each of the DGs has load resistance $R_L = 50\Omega$. The simulation results are as in figures 1 for voltage and current while figure 13 is power. With high resistance of 250 Ω in parallel, the results showing the grid behaviour indicates an increase in the value of output power as determined by the current drawn by the loads.

V = ≈ 218 V, I = 6 A ↑ 430 A, P_{out} = ≈ 15 kW ↑ ≈ 92 kW. Detail of the bus voltage with these results are shown in figure 14 for the voltage nd current and power output due to the step change is in figure 15.

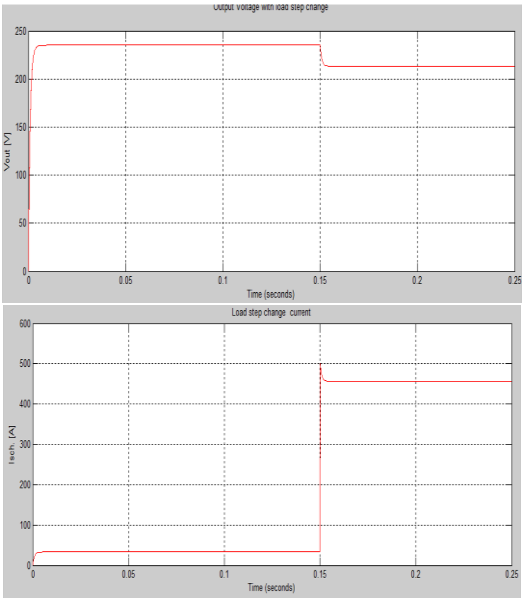

Figure 12: Behaviour of DC micro grid at step change for a load (a) voltage) (b) current and power

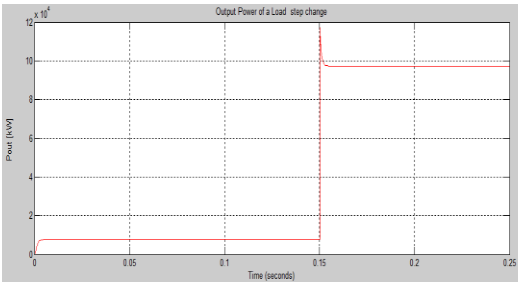

Figure 13: Power Output for step change

DISCUSSION

Several operational issues are associated with the Integration of distributed generation to power systems, such as poor quality and instability. With the emergence of Smart Grid technologies, some of the shortcomings being encountered by power system networks can be minimized if not totally eradicated.

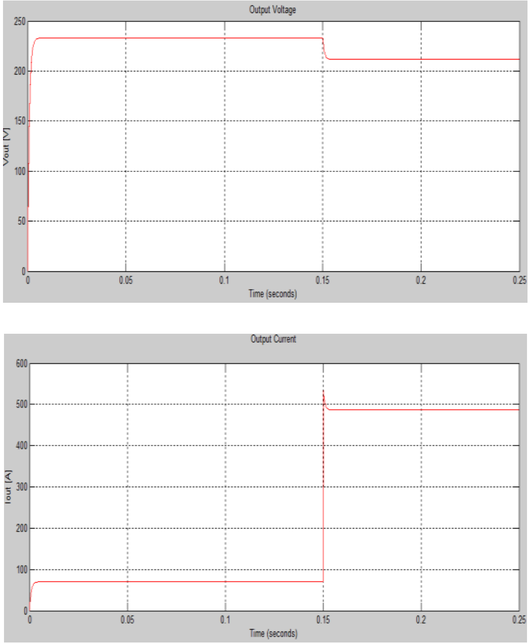

Figure 14: DC micro grid at step change with high value of R_L(a) voltage (b) current

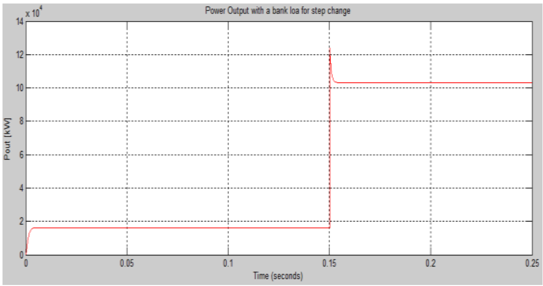

Figure 15: Power Output.

One of the ways to achieve this is by the use of FACTS devices such as a Static VAR Compensator (SVC). However, this research only focuses on analysis of voltage steadiness of smart micro grid with integration of renewables and dispersed generation sources.

By virtue of a good match between generation and load MGs have low impact on the electricity network, despite their potentially significant level of generation; due to the fact that a number of technical, regulatory and economic issues are not yet in place [3]. Also the viability of MGs is dependent on how stable are the generation parameters, like the voltage and frequency as a result of grid interconnection, disconnection and reconnection [12]. The results indicated that the voltage droop with a PI controller adopted is good option when distributed energy sources are annexed with the analysed DC micro grid. Since all the dc sources are of equal voltage and connected in parallel, the three converters exhibit the same behaviour. But it was observed that in the droop voltage control method, increase in supply current reduces the converters output voltage.

10. CONCLUSION

The DC simulation was purely for the islanded mode, while the AC output made possible by the inverters is for the purpose of connection to the main grid when the need for it arises. The model can be used to supply electricity of dc and ac modes to small scale industries, schools, hospitals, villages and small communities, remote and marine locations inclusive. This concept of micro grid stability study arose to cope with the increase in the renewable energy sources penetration into the grid. The voltage droop method is a good strategy used in order to share the currents between converters of the three DGs. PI controllers are used to provide precise control, excellent performance and robustness of the system. From the results of the simulation, it is evident that the DC micro grid operating condition can be made possibly stable.

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