Model and Calculation of Voltage Thresholds for Source Schedulaing in a Hybrid Renweable Nanogrid

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Abstract— The world's population becomes more reliant on power, the stability and reliability of power systems also needs to increase. The power supply system of future communities can be considered in the form of a small microgrid or a nanogrid which is mainly based on renewable energy resources.

Keywords: Nanogrid, Hybrid, Voltage Threshold, Dc Bus Signaling

I. INTRODUCTION

Renewable energy technologies not only solve the climate change and reduce the dependence on foreign energy import, but also are suitable for distributed power generation. In remote areas, where there are no transmission lines or the cost of building new transmission lines is high, renewable energy can provide power without expensive and complicated grid infrastructure.

Renewable resources such as solar photovoltaic panels or small wind turbines depend on climatic conditions to operate and produce electrical energy. Thus, when operating alone they are poor power sources. Systems that merge both renewable and non renewable sources are more effective in electric energy production. These solutions are called "hybrid systems". They can supply stand-alone systems (i.e. isolated nanogrid) or grid-connected systems (systems connected to the power grid) [1].

The advantage of the hybrid renewable nanogrid is the combination of the continuously available non-renewable energy and locally available, renewable energy. A storage unit is used to absorb any excess power from renewable sources and releases it to the system when needed.

Such a system can lead to a sustainable development of electrical systems and can help the current and future generations to access the benefits of electricity without adding more emissions and pollutions to the environment. The nanogrid is a small scale power system that Consists of renewable and non-renewable power resources. That supply power to nearby loads. The control structure of the nanogrid aims to schedule the sources, such that the Non-renewable source improves the system reliability during the long-term shortage of the renewable source.

A diesel generator supplies the load demand, during periods of shortage of renewable sources.

For load interface, renewable energy resources need high efficiency power converters which are designed to extract the maximum possible produced power.

Non renewable sources provide a good backup for system reliability. In this paper, storage unit and diesel generator are used as non-renewable sources.

The electricity available from each source, including the storage unit are sensed, controlled and fed to a common dc bus. This provides an optimum mix of electricity from each individual source. In the nanogrid, each source is assigned a voltage threshold which is calculated by a proposed algorithm. The diesel is given the last priority, due to the operating costs and environmental consideration, while the renewable sources are the first priority voltage thresholds.

In this paper, a new mathematical algorithm is developed to schedule sources according to the maximum power and voltage drop of each source. Thus, each source interface converter would be set to a voltage threshold, when bus voltage drops below this threshold the source would come on line.

II. NANOGRID STRUCTURE

Nanogrid consists of renewable sources (wind turbine and PV system), and non renewable sources (diesel generator and storage unit). These sources are utilized in a prioritized fashion to maximize the use of renewable sources.

Step-up converters are used to interface low voltage sources to supply power to the nanogrid and step-down converters allow the loads to draw power from the nanogrid [2]. Bidirectional converters allow storage units to charge from and discharge into the nanogrid as shown in Fig. 1.

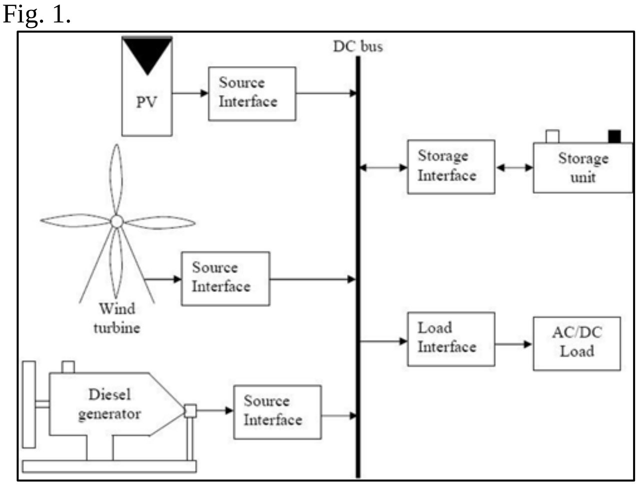

Fig. 1: Hybrid renewable nanogrid.

III. MODELING AND SIMULATION

A complete model for simulating the above architecture of the nanogrid is done using MATLAB/SIMULINK. Each source is simulated in one sub model; there is also a sub-model for the storage unit and the load [3]. All the sub-models are put together to constitute the main model of the nanogrid. The sub-model of each source contains source model, and model of interface converter and its controller. The sub-model of storage unit contains models of storage and storage interface converter. Load model and its interface converter are included in one sub model. The simulation model in the Fig. 2 simulates the discussed architecture of the hybrid renewable nanogrid accurately.

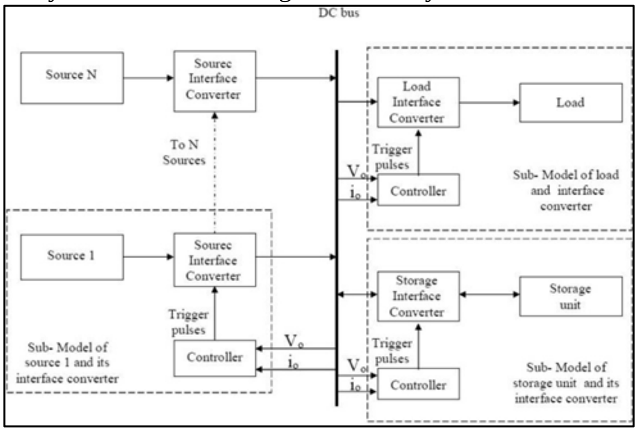

Fig. 2: Simulation model of hybrid renewable nanogrid.

IV. CONTROL SYSTEM

A. Discharge Control of Source/Storage Interface converter

This section describes the control structure required for the source/storage interface converters. Source scheduling is done by assigning a voltage threshold for each source, then controlling the source interface converter to exhibit three different modes of operation [4 , 5]:-

1) Off mode: the converter remains off while the bus voltage is below its voltage threshold.
2) Constant voltage with droop mode: when the bus voltage drops below the voltage threshold of the converter.
3) Constant power mode: when the power drawn from the converter exceeds the maximum power of the source or the power rating of the interface converter, the converter enters constant power mode, limiting its output power to this maximum value.

The operating mode of each converter is dependent on the level of the dc bus in relation to the voltage threshold of this source, and the maximum output power of the source. The control structure comprises of a slower outer PI voltage control loop, a faster inner current control loop and a dynamic current limit as shown in Fig. 3.

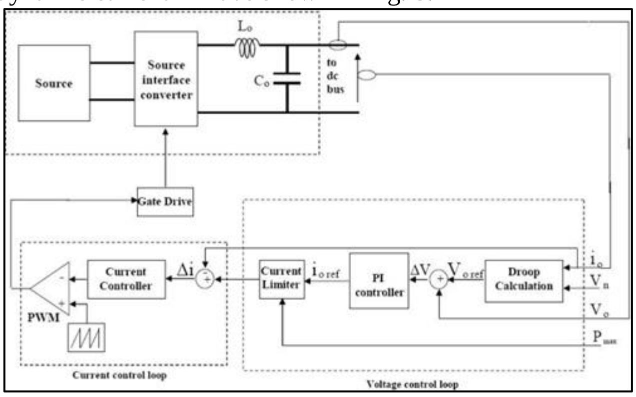

Fig. 3: Controller of source interface converter.

1) Voltage Control Loop

The voltage control loop regulates the output voltage by providing a reference current to a fast inner current loop, and also it governs the response of the converter. It has a droop characteristic of 0.1 V/A to permit sharing of the load current between other source/storage interface converters assigned to the same voltage threshold [6].

The droop method is commonly used in distributed DC systems to maintain power sharing between sources. In this method, the output voltage of the source decreases as its load current increases. Dc bus signaling (DBS) is a nonlinear form of voltage droop that allows groups of sources to be scheduled in a prioritized fashion. Each source is assigned to come online at particular voltage threshold in order to meet the load demand in a prioritized fashion [7, 8]. In constant voltage mode, the PI controller regulates the output voltage of the converter to its voltage threshold with voltage droop, the set point for the output voltage is given by:

$$V_{o\,ref} = V_n - k.i_o \tag{1}$$

Where $V_{o\,ref}$ is the reference load voltage, V_n is the source voltage threshold, k is the slope of the source's droop curve, and i_o is the load current.

The difference error between reference load voltage and the load voltage, is controlled by the PI controller to provide the reference load current.

$$V_{o\,ref} - V_o = \Delta V \tag{2}$$

Where V_o is the load voltage.

The voltage controller equation is given as:

$$i_{o\,ref} = \Delta V\left(k_p + \frac{k_I}{s}\right) \tag{3}$$

Where $i_{o\,ref}$ is the reference load current.

k_P and k_I are the PI controller gains.

2) Current Limiter

A dynamic current limiter is included between the voltage and current loops to allow the output power of the converter to be limited to the source's maximum power during constant power mode.

$$i_{o\,ref\,max} = \frac{P_{max}}{V_o} \tag{4}$$

Where P_{max} is the source maximum power, and $i_{o\,ref\,max}$ is the maximum reference load current. Thus, P_{max} or the bus voltage changes, the reference current changes, such that the converter tracks P_{max}.

3) Current control loop

The current loop controls converters' output current by providing the switching pulses to the interface converter. Using the equations of the switching function of source interface converter [8]:

$$u = 1 \text{ if } S(x) > 0$$

$$u = 0 \text{ if } S(x) < 0 \tag{5}$$

Where S(x) is the switching boundary and u is the switching state.

The switching boundary is determined according to the current controller equation as given below:

$$S(x) = k_o (i_o - i_{o\ ref}) \quad (6)$$

Where k_o is the gain of the current loop.

V. Calculation of Voltage Thresholds

The voltage thresholds are calculated beginning with the highest threshold, which is set to the nominal operating voltage of the system. Voltage droop characteristic is added to permit sharing of the load between other source/storage interface converters.

Each successive voltage threshold is then calculated

For off-mode:

$S(x) \langle 0$

(No switching pulses generated to the source interface converter).

For both constant voltage with droop mode and constant power mode:

$S(x) \rangle 0$

(switching pulses are generated to the source interface converter).

At constant voltage made $i_{o\ ref}$ is given in equation (3).

At constant power mode $i_{o\ ref} = i_{o\ ref\ max}$ (7)

At boundary between constant voltage and constant power modes: from equations (3), (4), and (7) we get:

$$i_{o\ ref\ max} = \Delta V \left(k_p + \frac{k_I}{S} \right) = \frac{P_{max}}{V_o} \quad (8)$$

using (1), (2) and (8) then we get

$$\frac{P_{max}}{V_o} = (V_n - k i_o - V_o) \left(k_p + \frac{k_I}{S} \right) \quad (9)$$

$$V_n = V_o + \frac{P_{max}}{k_1 V_o} \quad (10)$$

$$\text{where } k_1 = k_p + \frac{k_I}{S} \quad (11)$$

$$\text{By substituting with } i_o = \frac{V_o}{R_L} \quad (12)$$

Where R_L is the load resistance, and here the load is assumed to be resistive for simplicity.

The voltage threshold values are then calculated by:

$$V_n = V_o + k.\frac{V_o}{R_L} + \frac{P_{max}}{k_1 V_o} \quad (13)$$

From equation (13) it is clear that the calculation of source interface converter voltage threshold is a function of its maximum power, load voltage, PI controller gains, and droop coefficient.

The values of system parameters used in simulation are set to:

$k_p = 0.0316$, $V_0 = 60$ V, $R_L = 250\ \Omega$, $k_i = 140$

The voltage threshold of each source is varying according to its max. power and the droop coefficient. Usually the first voltage threshold, is set to approximately the nominal operating voltage of the system.

According to equation (13) the voltage threshold of the nanogrid is calculated approximately as given in the following table:-

Source	Max. power	Droop coefficient	Calculated Voltage
		k	threshold
PV	20 KW	-0.35	60 V
wind	20 KW	-0.35	60 V
diesel	50 KW	-0.2	50 V
battery	100 KW	-0.2	50 V

A. *Charge Control of Storage Interface converter*

This section describes the control algorithm required for the storage interface converters during charging.

It exhibits the same modes of operation as the charging control and each storage node has its voltage threshold for charging. Thus, the charge controller takes the same form as the discharge controller, except that the charge controller has a power limit to prevent damage of the charging device when charging is at a dangerously rate. The only difference is that the mode of charging occurs when the bus voltage is relatively higher than its voltage threshold of charging. A droop characteristic may be added when the system is having more than one charging node.

VI. Simulation Results

This section presents simulation results that verify the operation of the DBS and scheduling of the sources. The DBS is verified by applying changes to the maximum power point (MPP) of the renewable sources (PV and wind) in order to block the renewable generation and bring conventional sources on line.

Under these operating conditions, the DBS works to maintain the power balance in the model of the nanogrid by scheduling the storage and backup generator. Some of the results achieved from nanogrid model are shown in the figures below. The grid load voltage and current are shown in Figs. 4 & 5 respectively. It is noted that at first, the load is lower than the renewable power. By changing the MPP of the PV and wind after 0.4 sec. to zero (worst case of renewable generation), then the bus voltage drops below the voltage thresholds of the non- renewable sources. Thus DBS will bring battery and diesel unit to keep the power balance of the system. After 0.7 sec., the online controller senses that the power of the PV and wind is restored and get on line. When there is sufficient renewable energy, DBS shuts down the diesel generator and started to charge the battery when the renewable generation reach the maximum level. Figs. 6 & 7 show the load current drawn from each PV and wind source interface converter. The current drops to zero when the MPP of these sources changes to zero.

The current of the storage unit is shown in Fig. 8, at first the battery is charging when renewable sources MPP is at maximum level. When bus voltage drops below the discharging voltage threshold of the battery, it starts to discharge into the system till the renewable sources power is restored.

Fig. 9 shows the current drawn from a diesel unit during absence of renewable sources.

It is noticed from the figures that there is power balance of the nanogrid during the switching between sources.

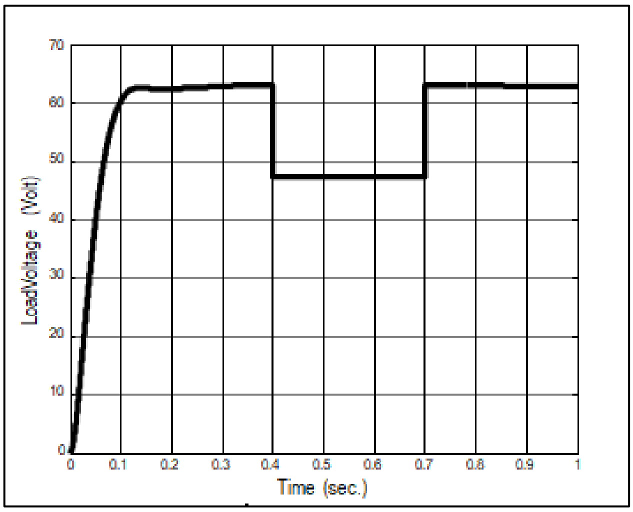

Fig. 4: Load output voltage.

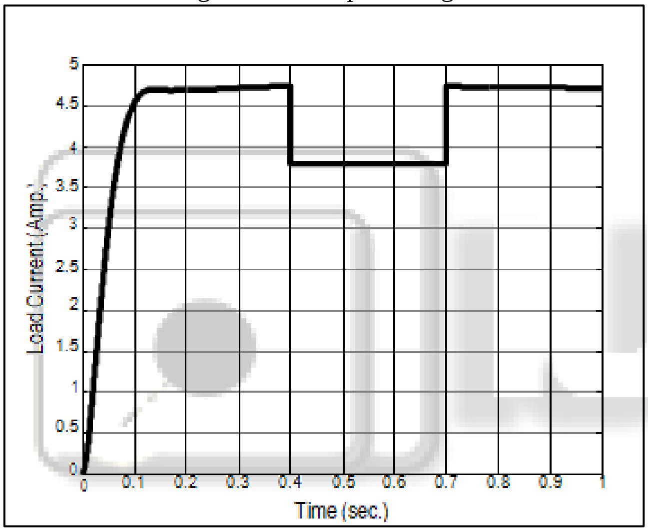

Fig. 5 Load output current.

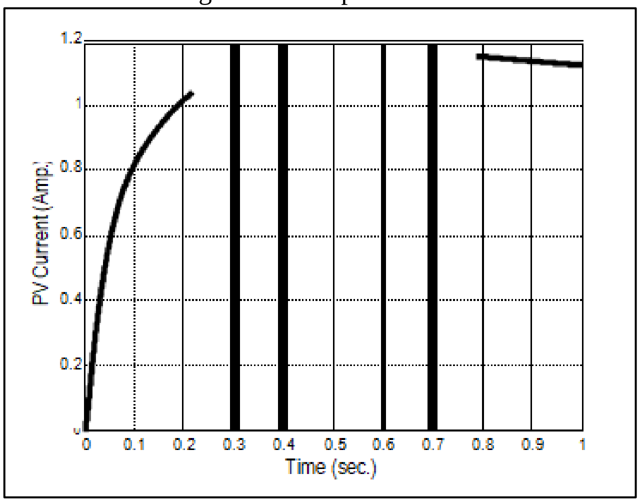

Fig. 6: PV output current.

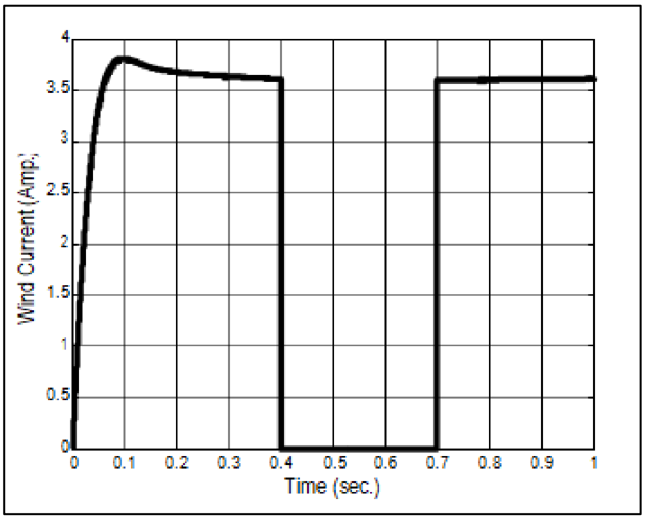

Fig. 7: wind output current.

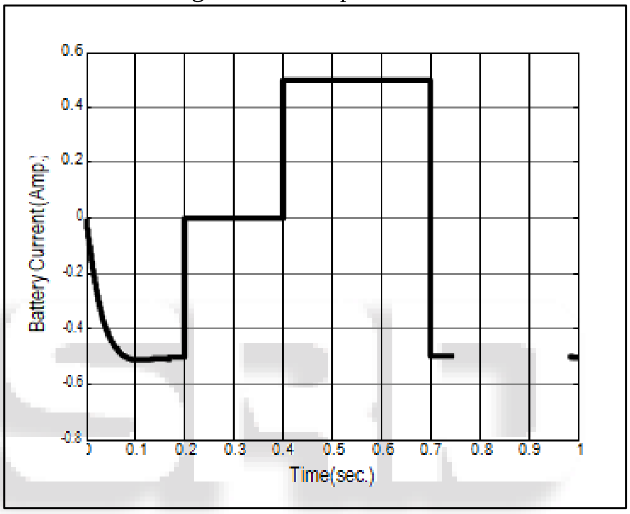

Fig. 8: battery output current.

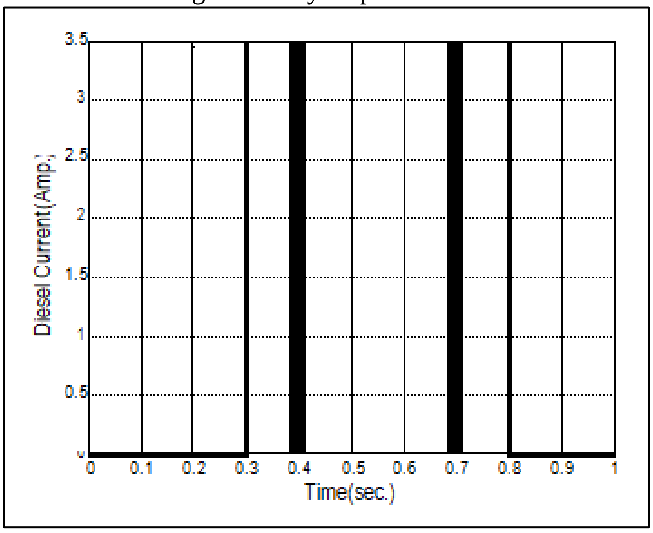

Fig. 9: diesel output current.

On the other side, DBS can be also verified by making overload condition. In this case, the renewable generation is less than the load demand. The low priority sources battery and diesel unit come on line. Figs. 10 & 11 show load voltage and current. After 0.5 sec. the load is doubled causing bus voltage to drop as this load exceeds the power of renewable sources indicated in figs. 12 & 13. This drop of bus voltage would bring battery and diesel to come on line in order to maintain the power balance as shown in figs. 14 & 15.

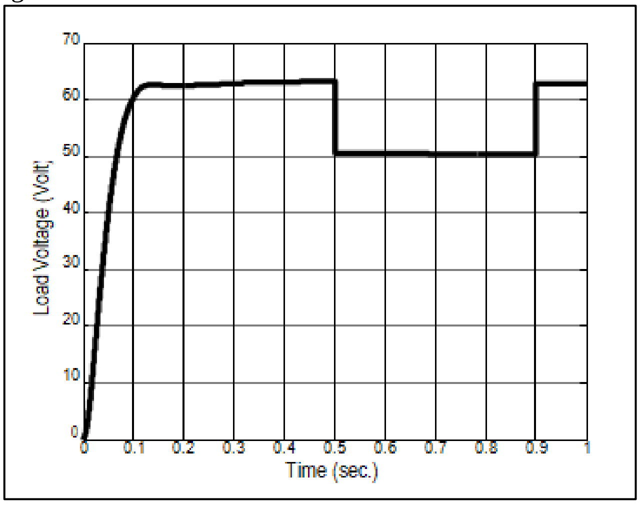

Fig. 10: Load output voltage.

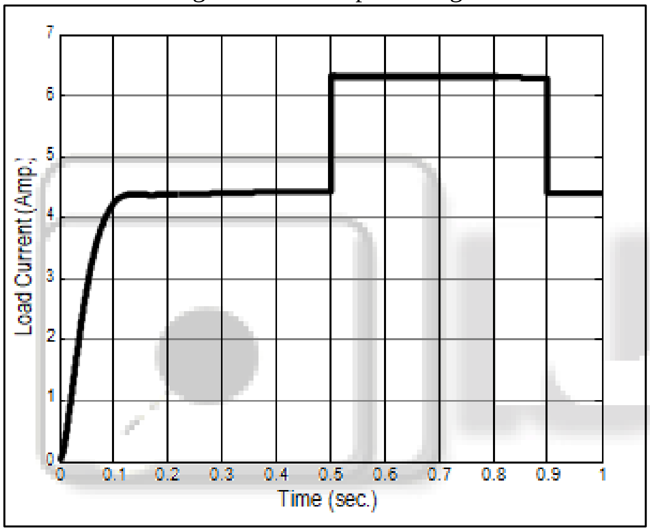

Fig. 11: Load output current.

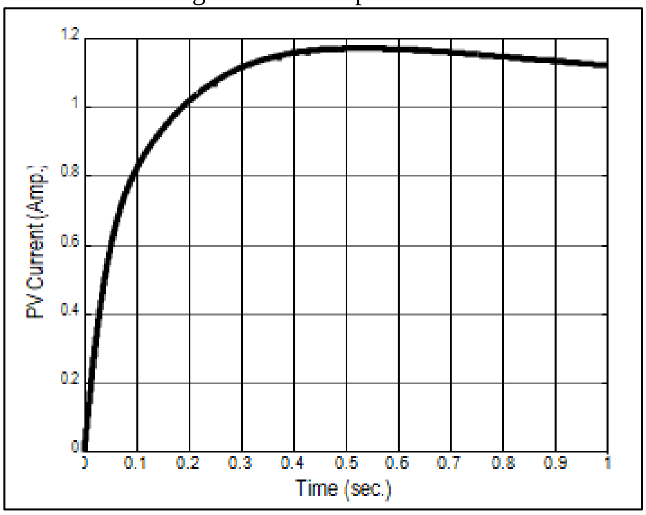

Fig. 12: PV output current.

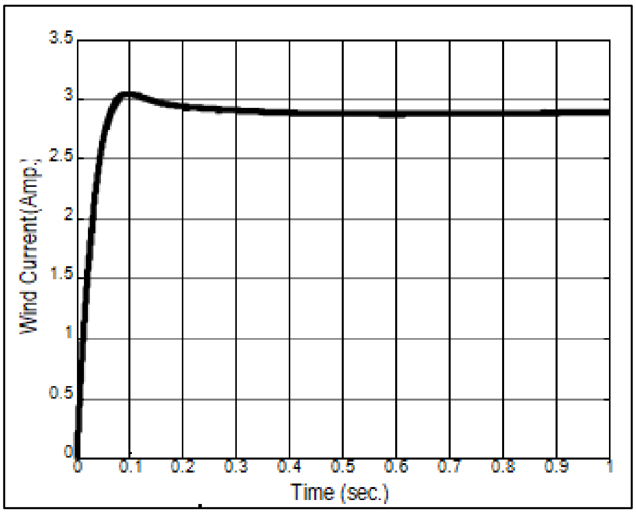

Fig. 13: wind output current.

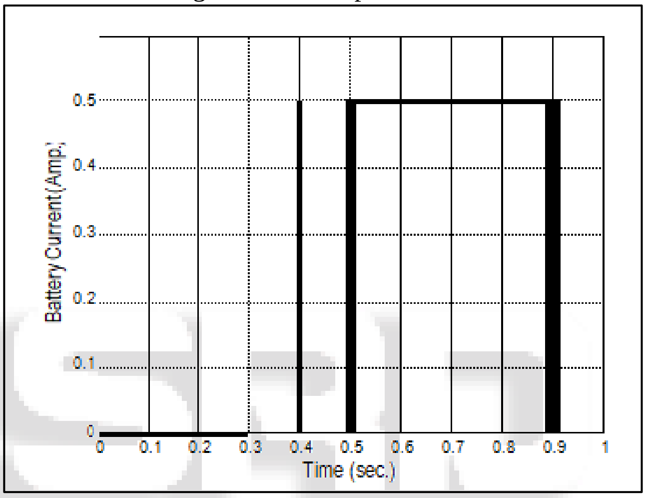

Fig. 14: battery output current.

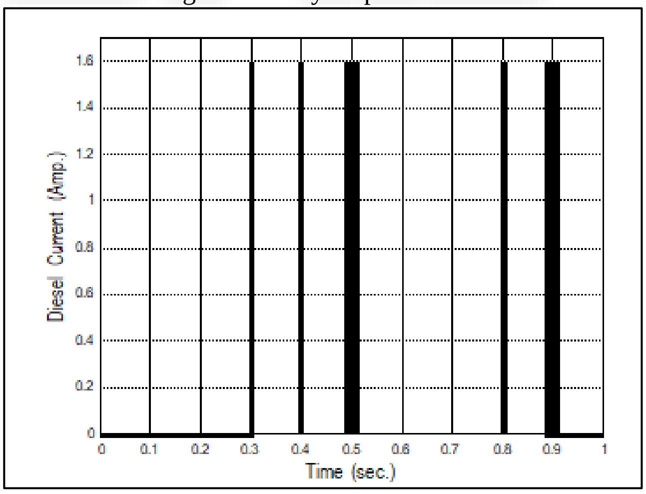

Fig. 15: diesel output current.

VII. Discussion

From the simulated results, it is found that :-

1) Calculation of voltage threshold is a function of the maximum power of each source and its voltage droop. This is a general solution which can be applied to any type of sources and even for any number of sources, whereas published work related to the topic concerned only a limited number of sources [7,8].

2) The simulation of the system is based on the real modeling of each part of the system. This allows having results based on changing both the MPP of the renewable sources, and step changes on the load.
3) The controller used in this paper is a distributed controller, which has an advantage over the centralized controller [7]. By using this controller, the threshold voltage of each source is compared to a constant reference "DC bus voltage". This allows developing the equation of the threshold voltage for any number of sources.

VIII. CONCLUSION

In a hybrid renewable nanogrid, the sources are utilized in a prioritized fashion to maximize the use of the renewable sources. To achieve this, the voltage thresholds of the interface converters are prioritized according to their utilization priority.

This paper develops an algorithm to calculate the voltage threshold of each source, using DBS controller for implementing source scheduling management scheme in a nanogrid. Voltage threshold is calculated based on the voltage level of the dc bus and the maximum power of each source.

Changes in the load and available generation create voltage-level changes on the dc bus as the converters switch between constant voltage and constant power operation.

The dc bus therefore acts as a communication link between the sources, allowing source scheduling to be implemented through a local control of each source converter. Simulation results have shown that implementing source scheduling in a nanogrid using DBS is possible provided that the voltage threshold of each source is calculated. The results confirm that the DBS successfully maintains power balance of the system in the presence of supply and load changes. However power imbalance introduces steady-state changes in the voltage level of the dc bus. This signaled and makes the storage and backup generation to come online.

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