DC-BASED INTERCONNECTED-MODIFIED NANOGRIDS WITHIN AN OPEN ENERGY DISTRIBUTED SYSTEM (OEDS)

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ABSTRACT

This paper introduces a design for several modified interconnected nanogrids via a dc-link within a multilevel direct current (DC) system that is called an open energy distributed system (OEDS). Each nanogrid includes a switched boost inverter (SBI) with a contribution towards improving its performance by offering a new model-reference closed-loop control technique for its dc-link voltage. In addition, a controller technique is devised in this paper for the proposed interconnected nanogrids to achieve the optimum power flow with high reliability.
The proposed system is modelled and simulated using MATLAB/Simulink. The simulation results ensure the system robustness against load fluctuations and its validity to be applied on various power loads in remote areas.

INTRODUCTION

The conventional AC grid system is a rigid architecture which distributes energy over long transmission lines, substations and distribution networks before arriving at the end users [1]. The expansion of the conventional grid became a bottleneck problem as it causes more transmission losses and requires complex protection schemes [2,3]. So, various renewable power grid structures are considered a viable solution for enhancing the capability of the existing utility network. Those renewable grids are classified according to their sizes and ratings [4], [5]. This paper focuses on interconnecting a flexible number of nanogrids - rating from 1.5KW to 5KW - via a local DC power bus within an OEDS. Due to the low power rating of nanogrid rather than microgrid, it has many benefits with less barriers [6].
The conventional nanogrids, however, have some obstacles as their structure depends on several numbers of inverters and/or converter sets. So, they need to separate isolated controllers as well as protection techniques with high cost and losses. Moreover, the interconnection of both inverters and converters leads to noise and interference problems with more personal hazards. In addition, the two-stage converter-inverter technique needs a protection circuit (dead time circuit) for the inverter against overlapping-connection between the two switches of the same limb [7].
In order to reduce some of the previous limitations, optimize the system performance and increase the system reliability, a modified design for a nanogrid will be presented in this paper. The proposed modified nanogrid uses a single stage single-input multi-output (SIMO) switched boost inverter (SBI) that can supply both DC and AC loads simultaneously from the same input source [8 ,9]. It also includes an improved battery fast charging strategy by using a bidirectional buck-boost converter.
This work also overcomes the SBI disadvantage that its duty ratio, D, is limited to a certain value (less than 0.5) by presenting a closed loop control technique to achieve a suitable AC output voltage up to 220 V as discussed in details in [10].
In addition, the proposed work explores different examples for OEDS by grouping interconnected modified DC nanogrids via a DC bus to enhance the system reliability. The DC-link interconnection has many advantages: it doesn't require synchronization, can easily be incorporated with renewable energy resources, has no skin effect, and can easily be connected with the battery management system. Furthermore, this interconnection assures the system operation even after interrupting one of the nanogrid sources. This power exchanging technique is controlled by using simple bidirectional switches to achieve the right and optimum power flow between nanogrids. Test results indicate that the interconnected modified nanogrid-system is robust against disturbances and sudden changes in the reference values. In addition, the test results ensure the validity of the proposed system when applied on low power loads in remote areas, poor villages and recent projects in the modern building that are difficult to be connected to the utility grid.
This paper is organized as follows. Section one gives an introduction for the overall system. Then, section two discuss the OEDSs proposed system while section three introduces the proposed OEDS system with its control scheme. Finally, section four includes the system simulation results followed by the paper conclusion.

THE PROPOSED SYSTEM

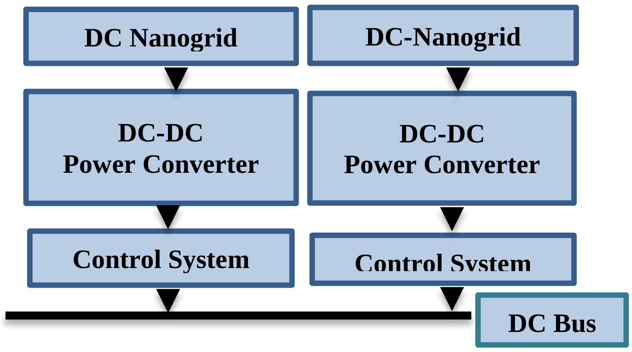


Fig.1 Structure of the proposed OEDS

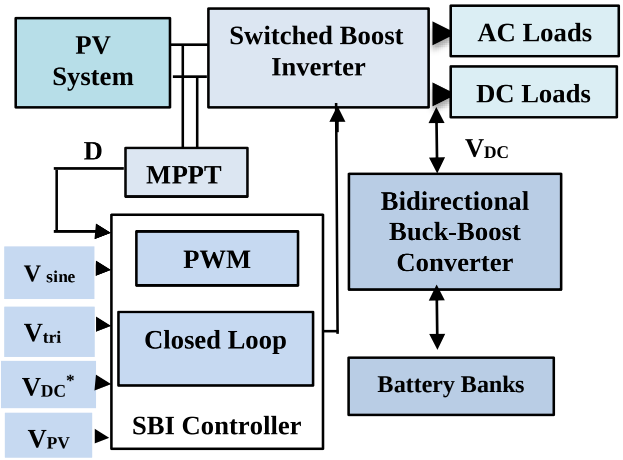


Fig.2 The DC nanogrid construction

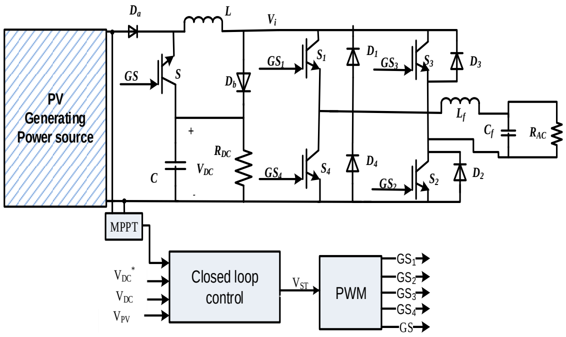


Fig.3 The circuit diagram for the SIMO-SBI

An OEDS is a new type of scalable bottom-up distribution network approach that is represented by building blocks of flexible numbers of interconnected DC nanogrids via a local DC power bus and controlled in a distributed way to make a complete OEDS [6]. The concept and advantages of interconnecting grids are analyzed in detail by Falvo, Martirano [11] and Brenna et al. [12]. They suggested sustainable energy microsystems as a type of multilevel grid systems. The interconnected nanogrids within an OEDS have many benefits. First, the system doesn't require transmission lines due to the close proximity distances between the power sources and the loads unlike the conventional grid system which requires transmission lines. Therefore, the amount of wasted energy in the form of heat and the system overall cost are decreased. Second, this interconnection organizes easily the number of the matched renewable power sources according to the presence/removal of the additional loads. Hence, the OEDS is considered a viable solution towards a significantly reliable environmentally friendly system. The structure of the proposed OEDS is divided into three parts as shown in Fig. 1. The modified DC nanogrid is the main part of the system as it consists of the PV generating power source, SIMO-SBI, battery management system and the system power loads as shown in Fig. 2. The SBI is controlled by a pulse width modulation (PWM) control technique that is described in details in [9]. However, SBI converter is more applicable for the small rating applications since its duty ratio is limited to a certain value (D≤0.5). This makes the system unstable, especially in the critical range for the duty ratio (0.4<D<0.5). So, a new model reference adaptive closed control technique is proposed as shown in Fig.3 for the enhancement of the AC output-voltage stability within a desired value (i.e. 220 V), which is suitable for most domestic loads, especially in Egypt.

Moreover, one of the interconnected DC nanogrids should include a battery management system (BMS) with a more sophisticated fast-charging control strategy which depends on a bidirectional buck -boost converter. This converter can adjust the different voltage levels between both the DC-link and the battery banks. It can also monitor and control the system charging and discharging processes. A new proposed algorithm is introduced for maximum optimality achievement for the power flow and energy management.

AN OPEN ENERGY DISTRIBUTED SYSTEM (OEDS) CONTROL TECHNIQUE

This system proposes an alternative controller technique for exchanging discontinuous energy between different distributed nanogrids in either off-grid system or on-grid system. The concept and advantages of the OEDS should be widely used in off grid remote and rural areas. In this way, DC nanogrids connection offer many benefits as it enhances the system performance, increase the system reliability and ensure the system continuity. It also guarantees the system operation even after interrupting one of the nanogrid sources since the output loads of the interrupted source nanogrid can be fed from the other accessible nanogrid sources. The nanogrids power exchanging technique is controlled by a bidirectional switch to satisfy the system continuity. These nanogrids may have either same or different generating power source. The nanogrids are connected together via a DC power bus to exchange power through the DC connection. The OEDS structure depends on two main DC layers [6]: the first layer is the DC nanogrid and the second layer is the DC power bus that connects nanogrids with each other. The DC links are chosen for both levels due to their benefits. For example, the power merging is so much easier in DC connection than in AC connection. The DC connection makes the system analysis easier as it need no synchronization (no frequency, no phase shift and no waveform control). Moreover, the DC connection increases the transmission lines efficiency and improves the system stability due to the absence of reactive power and the external disturbances. In addition, the spread of the DC output renewable energy sources and the batteries make the DC connection so much easier without requiring AC/DC conversions. The same is true for most of the consumer equipment and the residential structures of approximately 80% of the loads in commercial and residential structures are DC which result in an increasingly attention for DC distribution. Finally, developments in the DC conversion technologies have led to increased DC connection efficiency.

Figure 4 shows an example of two nanogrids each with its own PV source. The two PV sources are chosen to be of different ratings. In the first nanogrid, the load power is chosen to be 6.5 KW distributed as follows: total DC loads of 5 kW and AC loads of 1.5 kW. The DC load consists of two separate loads: one is 3.5 kW and the other is 1.5 kW. The loads are designed to consume the whole power generated by the PV of the system. At t = 0.4sec, the 1.5 kW DC load is disconnected from the first nanogrid. At the same time, the second nanogrid is loaded with an additional load of the same value. This change in loads, will cause power exchange between the two nanogrid systems. The DC- interconnection nanogrids permit the flow of power from one grid to another by using a controllable technique to arrange this power exchange. In addition, a bidirectional switch is used to allow either the connection or disconnection between the nanogrids to authorize the excess power flow as shown in Fig. 4.

The switch Sng1 operates when both the DC and AC loads of nanogrid 1 are consuming power less than its PV rating power. The switch Sng2, on the other hand, operates when the DC and AC loads of nanogrid 2 are consuming power more than its PV rating power. So, the excess load power demand will flow from nanogrid 1 to nanogrid 2. The switching control technique of operation depends mainly on the signal that comes out from the comparator results. The same controller algorithm will be used in each interconnected nanogrid within an OEDS to exchange power with the other grid. The switches operation algorithm are shown in detail in the controller block diagram in Fig.5 and in the flow chart in Fig.6.

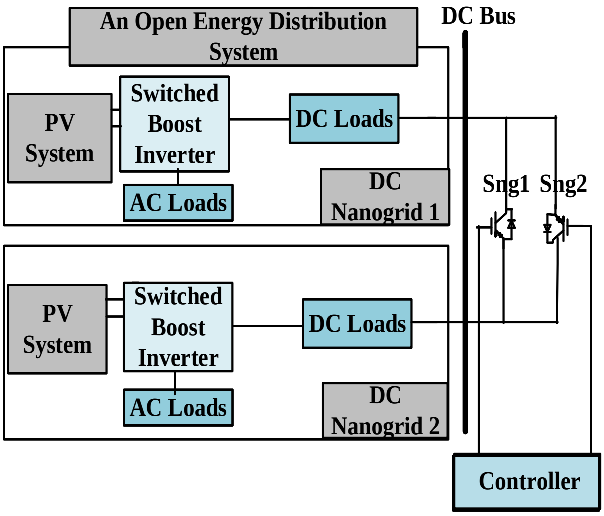


Fig.4 Two interconnected nanogrids within an OEDS

SIMULATION RESULTS

The following results show the investigation and evaluation of the performance of the proposed OEDS under different conditions. They also show the SBI system output response with its robust model reference closed loop control technique. Matlab/Simulink software package is used to simulate the operation schemes for the proposed system [13]. Figures (7,8) show the robustness of the SBI closed loop control technique by adapting the actual, reference DC output voltages, the controller signal voltage V_{ST}, duty ratio D, and the AC output voltage respectively to track any variation in the reference DC voltage. They show the system response with any sudden increase/ decrease in the controller DC reference voltage (from 622 to 311and vice versa at step time 0.3 sec) with the same load values. They confirm the ability of the controller system to justify its output according to the new value of the reference voltage. Also, these figures illustrate the capability of the controller to recover any variation happening on the reference value at once.

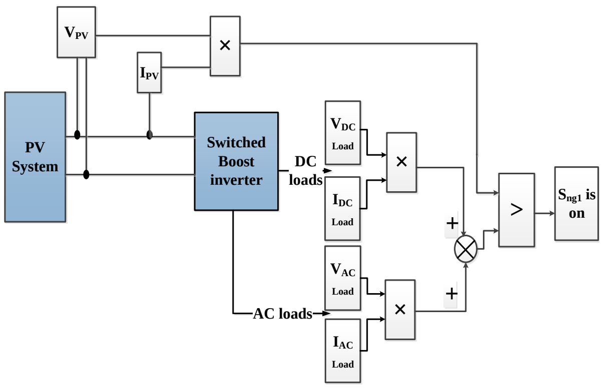


Fig.5 The controller block diagram of one DC nanogrid

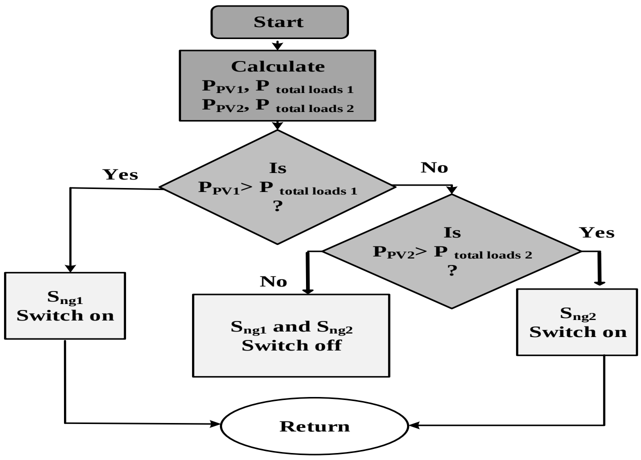
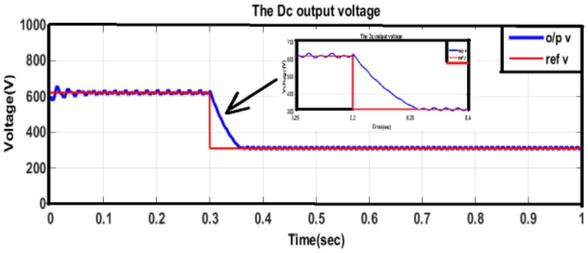
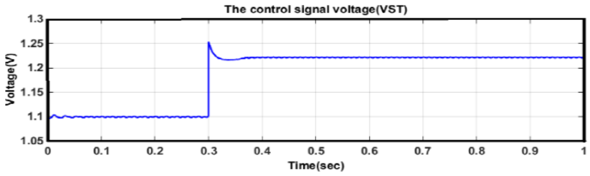


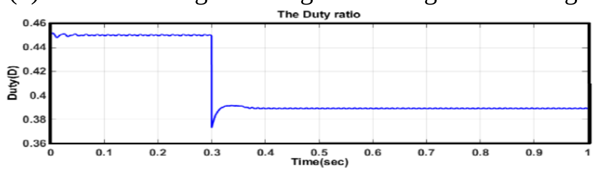
Fig.6 OEDS controller algorithm flow chart



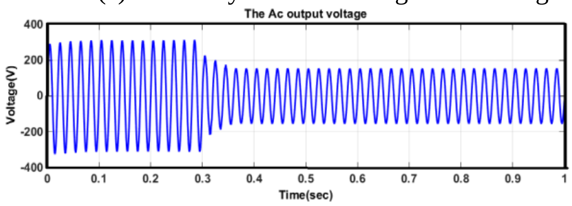
(a) The actual and reference DC output voltages



(b) The control signal voltage according to ref. change

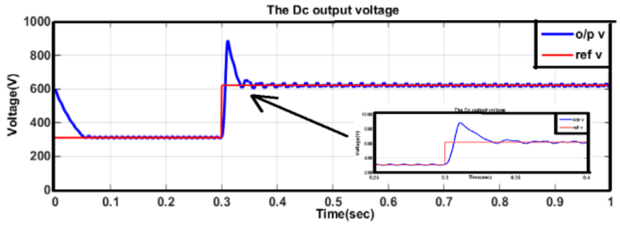


(c) The duty ratio according to ref. change

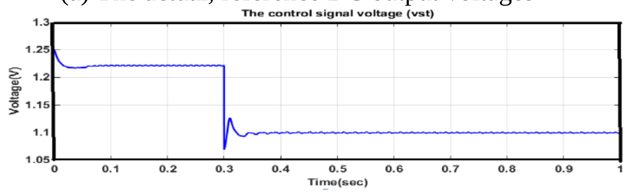


(d) AC output voltage according to ref. change

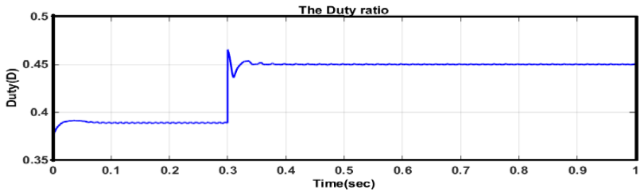
Fig.7 Study the controller response with the effect of a sudden decrease in the DC output reference voltage



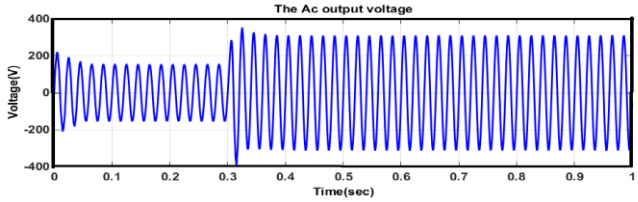
(a) The actual, reference DC output voltages



(b) The control signal voltage according to ref. change



(c) The duty ratio according to ref. change



(d) AC output voltage according to ref. change

Fig.8 Study the controller response with the effect of a sudden increase in the DC output reference voltage

Figures (9, 10) illustrate the exchanging of power in a complete OEDS with two interconnected nanogrids supplied from different ratings of PV sources. Each nanogrid is feeding from a separate PV power source to test the system operation with its control technique under different ratings. Each figure illustrates the total load power, the DC load power, and the AC load power of the switched boost inverter (SBI).

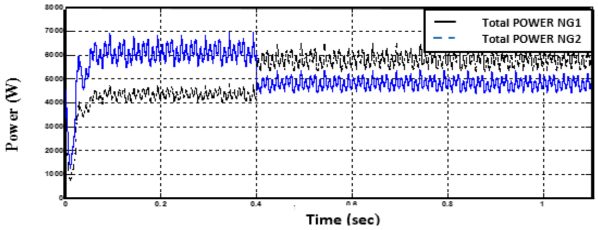
In figure 9, the rating power of the PV source of the first nanogrid is 6 KW and the load of this nanogrid will consume the whole power in the first 0.4 sec. After this period the load will reduce suddenly its consumption to 4.5 KW only. The excess power will transmit immediately to meet the power shortage in the load of the second nanogrid since the load demand of the second nanogrid will increase by 1.5 KW at the same time (0.4 sec).

Note: In case of the presence of excess power from Ng_1 and Ng_2, this excess power will store in the battery management system for reuse at a later time. While in figure 10, the rating power of the PV source of the first nanogrid is 6.5 KW. The load of this nanogrid will consume the whole power in the first 0.4 sec. However, after this period the load will reduce suddenly its consumption to 5.5 KW only. The excess power will transmit immediately to meet the power shortage in the load of the second nanogrid as the load demand of the second nanogrid will increase by 1KW at the same time (0.4sec).

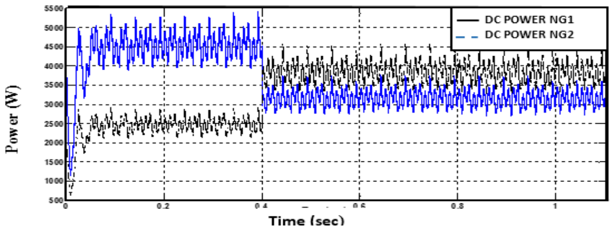
These test results ensure the system ability for exchanging power according to the load demands and the power generated condition for each nanogrid.

CONCLUSIONS

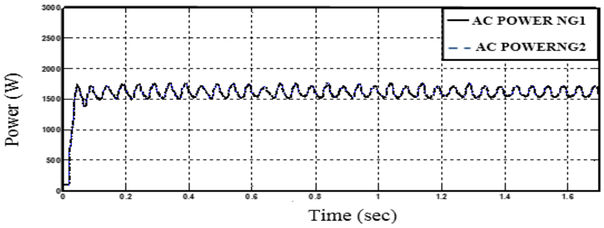
This paper introduced a full design for a complete OEDS with a simplified bidirectional controller technique to achieve the optimum power transfer between the interconnected nanogrids. It also presented a simple modified self-tuning adaptive control technique for a SIMO power electronics SBI that was used in each modified nano-grid. In addition, the proposed work contributed towards raising the DC-link output voltage of the inverter to high-rating values to achieve an AC output voltage with 220V rms rated value. This value is suitable for most of the domestic and industrial loads. Also, the robustness of the controller was insured against dc-link voltage fluctuation. In addition, the validity of the proposed OEDS to be used in off-grid was achieved.



(a) The total load power for both nanogrids

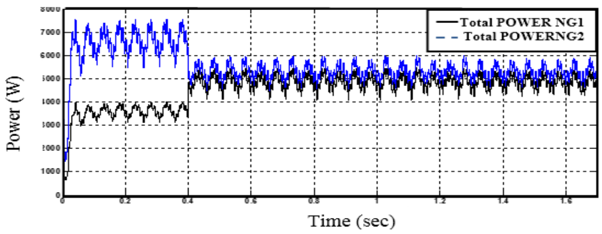


(b) The power of the DC loads for both nanogrids

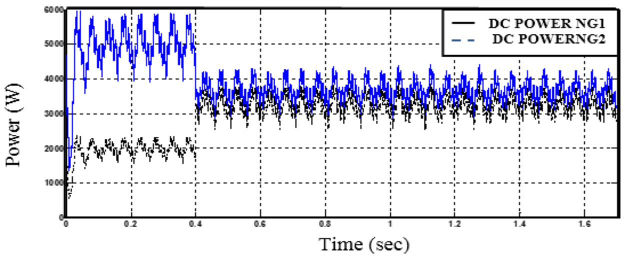


(c) The power of the AC loads for both nanogrids

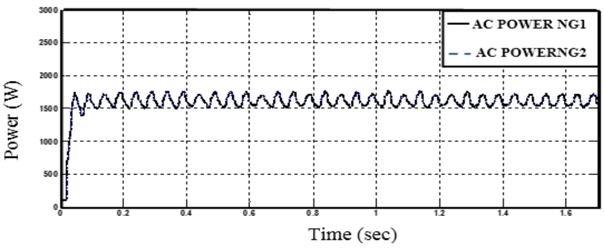
Fig.9 two-interconnected nanogrids fed from two different rating PV sources (6- 4.5 KW) within an OEDS



(a) The total load power for both nanogrids



(b)The power of the DC loads for both nanogrids



(c) The power of the AC loads for both nanogrids

Fig.10 two-interconnected nanogrids fed from two different rating PV sources (6.5-5.5 KW) within OEDS

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