Integrated Energy Management for a PV-Wind-Diesel-Fuel Cell Based Hybrid System for a Remote Area Power Supply

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Abstract— ***In order to study uncertainty and intermittent characteristics of wind power and wave power, this paper proposes an integrated wind- and wave-power generation system fed to a power grid or connected with an isolated load using a DC micro grid. The studied integrated system consists of a wind-power generator, a wave-power generator, a bidirectional DC/DC converter, and a grid-tied inverter. An energy-storage device is connected to the DC side of the proposed DC micro grid through a bi-directional DC/DC converter. Both wind-and wave-power generation systems are modeled and simulated using the written program based on MATLAB/Simulink. Steady-state and dynamic responses of the studied system under various operating conditions are carried out. To examine the fundamental operating characteristics of the proposed integrated system, a laboratory-scale platform is also established. The experimental results reveal that the studied integrated system can maintain stable operation to supply power under different operating conditions using the proposed DC micro grid.***

Keywords— Bidirectional dc/dc converter, bidirectional grid-tied inverter, dc microgrid, load dc/dc converter, stability, voltage-source converter (VSC), wave power generator, wind power generator.

I. INTRODUCTION

In recent years, renewable energy and distributed generation systems (DGS) have attracted increasing attention and have been extensively researched and developed. They gradually alter the concepts and operations of conventional power-generation systems. The rise in several countries makes it possible that this kind of DGS can be practically applied to a grid-tied system or an isolated system with wind power, solar energy, hydro power etc. The output of DGS usually includes two kinds: DC and variable AC. Besides, the generating capacity of DGS comparing with conventional large synchronous generators is much smaller and, hence, the DC micro grid can be practically applied to convert the generated time-varying quantities of natural renewable energy and DGS into smooth DC electricity that can then be converted back into AC quantities delivered to other power systems [1], [2]. Since the intermittent of renewable energy and DGS, bi-directional DC/DC converters are usually necessary to feed the connected loads with smooth power [3].

In order to simulate a hybrid AC/DC micro grid system, photovoltaic and wind power generator models, doubly-fed induction generator (DFIG) model, and inverter model were established to simulate dynamic responses of the studied system in [4]. A practical low-voltage bipolar-type DC micro grid was constructed using a gas engine as the power source while a bi-directional DC/DC converter shunting a supercapacitor was utilized as an energy-storage device to balance the power demand of the studied system in [5]. Unexplored energy and resources in ocean such as marine energy, tidal energy, ocean thermal energy, ocean wave energy, and salinity gradient energy etc. are abundant. The simulated results of an Archimedes wave swing (AWS) power convertor coupling with a linear permanent-magnet generator were compared with the experimental outcomes using the measured data obtained from a 2-MW AWS test system along the coastline [6]. A configuration of a marine power plant with two AWSs connecting to a power grid was proposed in [7], and the outputs of the two AWSs were converted to DC quantity by individual diode-bridge rectifiers (DBRs) then subsequently converted into AC quantity by an inverter to reduce the fluctuation of the combined rectified output power.

A hybrid-electric vehicular power system in [8] utilized two motors connected to a DC bus through a voltage-source converter, and a bi-directional converter was connected between a battery and the DC bus. The dynamic average model was used in [8] for all powerelectronics models by neglecting switching phenomena to reduce simulation computational intensity. A non-isolated bidirectional zero-voltage switching DC/DC converter was proposed in [9], and the converter utilized a very simple auxiliary circuit consisting of an additional winding of a main inductor and an auxiliary inductor to reach zero-voltage switching and reduce the reverse-recovery problem of power diodes. Modeling and testing the data centers of a DC micro grid using PSCAD/EMTDC were proposed in [10], [11] since most data centers were sensitive to the variations of electronic loads. The proposed DC micro grid was also used to supply sensitive electronic loads during AC-grid outages in order to offer uninterruptible power-system protection [11]. To achieve power sharing and improve economic benefit, a DC-bus voltage control technique for parallel-integrated permanent-magnet wind power generation systems was proposed in [12], and the technique was based on a masterslave control to solve controller discrepancy problems.

A 12-kW experimental system was constructed in [12] to confirm the effectiveness of the proposed scheme. In order to achieve power sharing and optimizing DC micro grid, the control strategies for islanded micro grid with a DC-link voltage control was developed in [13], [14] while the control strategies were combined with P/V droop control and constant-power band to avoid frequent changes and voltage-limit violation on generation devices. A battery/ultracapacitor hybrid energystorage system (HESS) was proposed in [15] for electricdrive vehicles. To satisfy the peak-power demands between the ultracapacitor and battery, a larger DC/DC converter was necessary. The studied system utilized two storage devices to compensate mutually in order to prolong the life of the battery. The simulated and experimental results were carried out to verify the proposed control system [15]. This paper proposes an integrated wind and wave powergeneration system fed to a power system or connected with an isolated load using a DC micro grid.

II. Micro Grid Topology

Micro-grid is one of the important forms of distributed generation which improves the flexibility and reliability of power supply, it only need one-time investment especially suitable for stand-alone power system. Because of the features of convenient maintenance, low cost and long service life, there is a longterm benefit for users. This achievement can be widely applied to situations which have strict requirements for stand-alone power supply and stability of power system.

Around the world there are few installations greater than 1 MW where off-grid PV hybrid system is installed [15]. For instance, Fig. 1(a) is shown an overview of MW micro-grid installations implemented in the Dong'ao Island, where located in the southern region of Zhuhai city (Latitude 22.01° N, Longitude 113.42° E). The proposed hybrid micro-grid structure shown in Fig. 1(b), it contains PV panel and battery banks used as the main power generation systems, the DG is considered as a back-up source to increase the reliability of the system, and the battery considered as damping power fluctuation. Each module of the battery and the capacity of the photovoltaic ratio are calculated according to the local load demand. Batteries and bidirectional converter in module A composed of mains power supply unit for the microgrid, and *V/f* control is adopted as the BESS operation mode, to provide stable voltage and frequency reference of power grid. Diesel generators works for standby power supply, automatically opened only when the residual capacity of battery is low. Module B and C have the same structure, the bidirectional converter working in *PQ* mode, receive charging/discharging power signal according to the local residual capacity of battery and maintain power balance between generation and battery. Through the coordinated control of the converter in module A, B and C, which can reduce fluctuations in power generation and realize electric energy balance, bring down the battery charge and discharge energy fluctuation, improve the battery life, improve the quality of micro-grid electricity. The photovoltaic adopt traditional gridconnected inverter in the form of current source, working in the MPPT control transform maximum power supplying to load and feed the excess energy back to utility grid line.

After preliminary investigation and communication, the PV-diesel-battery hybrid power system for stand-alone micro-grid was built and already normal operation well. Besides the photovoltaic generation and battery energy storage, this demonstration project also has wind power generation, monitoring system, as well as controllable loads.

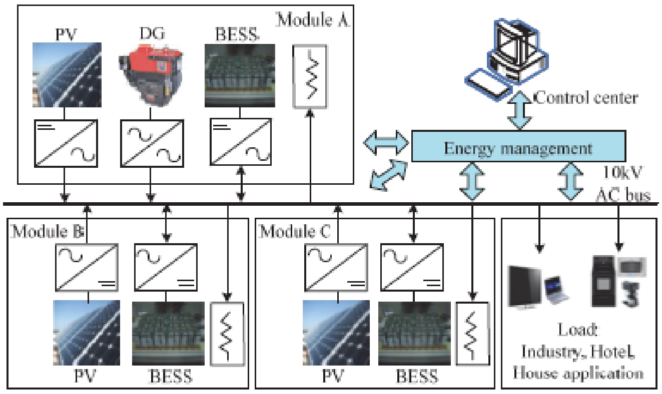

Fig : 1proposed hybrid micro-grid structure

III. Hybrid Power System

Island electricity demand has strong seasonal and periodic characteristic, the electricity requirement peak is very high on weekend and summer tourism season, while at ordinary times the electricity is decreased and unbalance. Due to the high cost of photovoltaic power station at present, the photovoltaic total installed capacity given priority to meet with the demand of the island during the off-peak average load. Battery energy storage capacity should be able to meet at least one day of photovoltaic power so as to avoid solar curtailment.

The island electrical load average demand at ordinary times is 600 kW refer to the historical data, electricity for basic energy needs for industry, hotel, house appliances, illumination and etc. According to the above principles, PV total installed capacity of 1MWp, it consists of 300kWp building attached photovoltaic (BAPV) and 700kWp solar photovoltaic power plants operate with MPPT mode. 1800kWh lead-acid batteries as energy storage to smooth power delivery, three phase diesel generators make up 1MW power generator system, Wind power installed capacity only

50kWp due to the land space limitation. The main elements of hybrid micro-grid are given in Fig. 2.

Distributed photovoltaic power generation system is composed of photovoltaic array, grid-connected inverter. Electricity generated by these PV arrays is converted to micro-grid through the inverters and energy surplus is stored in the batteries. To achieve the goal of low cost and high efficiency, the number of panels and batteries was designed according to the supply and demand. For the construction of the module B and C, here the form of photovoltaic power generation using BAPV, that means photovoltaic components installed in the building roof. The PV power capacity make as far as possible matched with local demand, and realize photovoltaic power elimination on the spot, reduce energy transmission loss.

BAPV with 254kWp capacity was installed on cultural center building roof, using 1843 pieces 138wp photovoltaic components. Besides, there were 362 pieces 138Wp crystal panels with 50kVA gridconnected inverter installed near wharf as shown in Fig. 2(a). Another form of photovoltaic power generation is centralized ground PV power plant which demand good solar irradiation condition, it configured on the mountain near diesel generators, and installed capacity reach 700kWp in Fig. 2(b). Battery storage system was equipment with two group 480V/1000Ah lead-acid battery and one group 480V/1860Ah battery banks. The generator and load around the island is connected by 10kV bus medium voltage network.

Fig. 2.Main elements of hybrid micro-grid (a)BAPV; (b) PV power plants; (c)BESS; (d)DGs.

IV. Energy Management Strategy

As the energy storage system in the island stand-alone micro-grid can coordinate and stabilize power fluctuation, Energy storage unit occupy a vital role in reaching efficient equilibrium towards reconciling power supply and demand response management, but it is also one of the weakest link in micro-grid. Renewable energy power generation have electricity power fluctuation and intermittent characteristics, in order to satisfy the long uninterrupted electricity supply, need for power optimization control and energy management, through configure the large capacity of energy storage unit to solved the energy gaps.

Batteries under state of uncontrolled charge or discharge conditions will decreased the battery life rapidly, at the same time also makes the power quality poorer. The proposed energy management strategy adopts two-level structure: the bottom level is for the module layer, and top level for system layer. The local controller in module layer forecast the state of charge (SOC) in real time based on the current sampling information, as well as forecast photovoltaic power generation and power load in a certain period of time scales to determine whether the module of energy deficiency or surplus. System layer controller received the current battery capacity and energy deficiency or surplus information of each module, then the top layer proceed comprehensive analysis, use appropriate optimization method to finally confirmed the transmission power exchange between various modules controlled unit, and send start-stop or power reference instruction of the diesel generator power from the local controller based on the system layer.

In this micro-grid structure scenario, the power control strategy of bidirectional converter ease the module power fluctuations, make the battery cells in stable and controllable state of charge and discharge, greatly provides the battery service life. Through coordinated controls between the various modules, it can maximize extent to allocate renewable energy power with random fluctuations, reduce the energy impact, and improve power quality within the scope of the entire micro-grid network.

V. Simulation Results

In this section, the proposed control structure is simulated in MATLAB SIMULINK environment. An integration of both wind power and wave power generation system models has been proposed while a laboratory-grade test system has been presented in this paper to examine the fundamental operating characteristics of the studied integrated system fed to isolated loads using a DC micro grid.

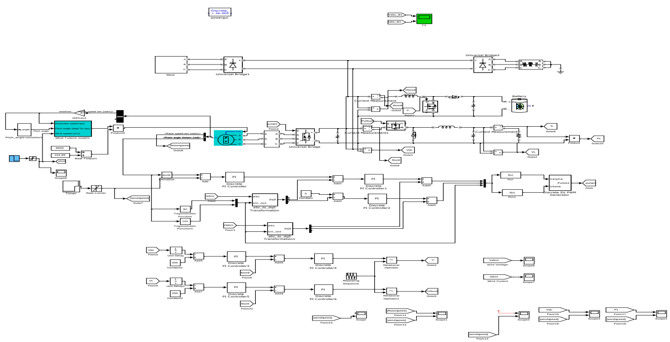

Fig: 3.Simulation Circuit Diagram

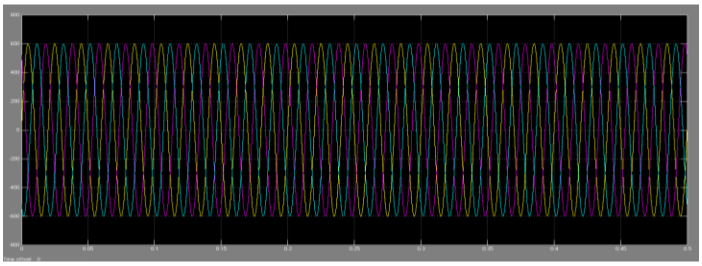

Fig: 4.Wind Voltage

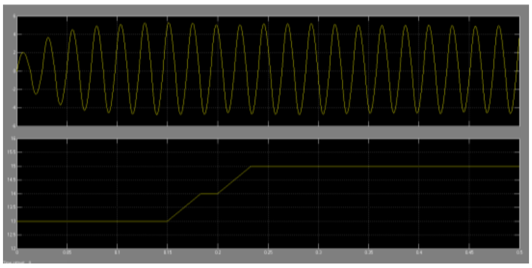

Fig: 5.Rotor Speed and Wind Speed

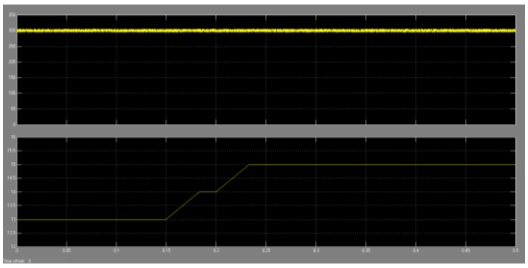

Fig: 6.DC Link Voltage and Wind Speed

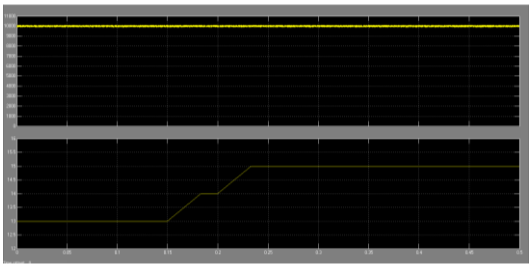

Fig: 7.Load Power and Wind Speed

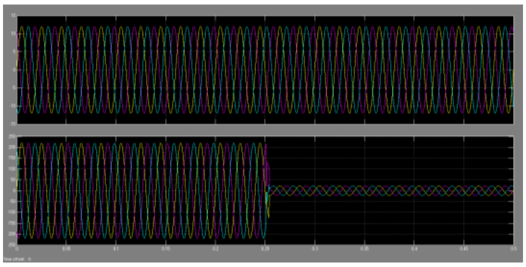

Fig: 8.Wave Power Current and Voltage

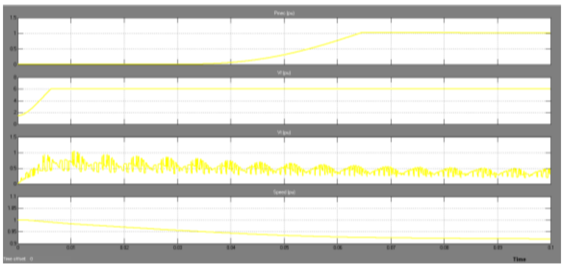

Fig: 10.Diesel Engine Parameters

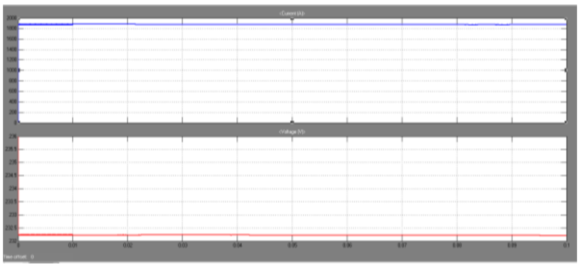

Fig: 11.Battery Voltage and Current

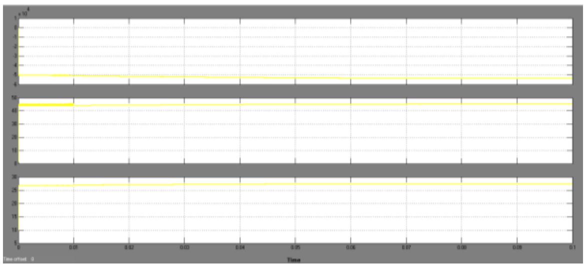

Fig: 12.PV Power, DC/DC Converter output voltage, PV output voltage

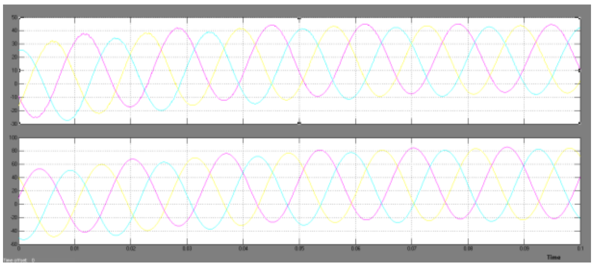

Fig: 13.Grid Voltage and Current

Proposed Circuit:

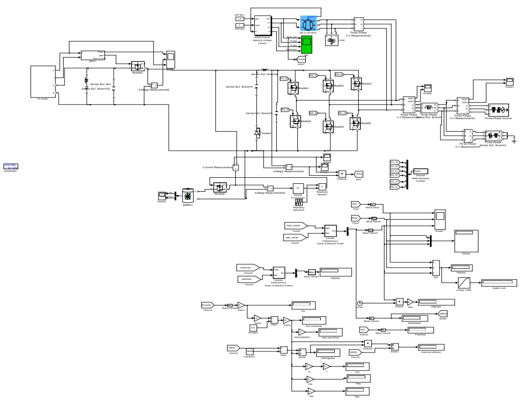

Fig: 9.Proposed Simulation Circuit with PV, Battery and Diesel Generator

VI. CONCLUSION

An integration of both wind power and wave power generation system models has been proposed while a laboratory-grade test system has been presented in this paper to examine the fundamental operating characteristics of the studied integrated system fed to isolated loads using a DC micro grid. For simulation parts, the results of the root-loci plot and the time-domain responses have revealed that the studied integrated system with the proposed DC micro grid can maintain stable operation under load switching conditions. Comparative simulated and measured results under load switching have been performed and it shows that the studied integrated system with the proposed DC micro grid can be operated stably under different load switching conditions while both measured and simulated results can match with each other.

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