

Hardware Implementation for Stability Enhancement of Microgrid Using Hybrid Controlled Storage System

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ABSTRACT: Microgrid is an aggregation of multiple micro-sources such as renewable resources, conventional generators and energy storages providing the electric power. Microgrid comprising various Distributed Generators (DGs), Storage device as energy storage system and controllable load. This paper describes to investigate the dynamic stability of microgrid and given the hardware implementation for stability enhancement of microgrid. The small-signal model of a typical microgrid consists of an asynchronous generator based wind turbine and synchronous diesel generator. With the development of power electronics, energy storage can be controlled to release or absorb active/reactive power flexibly. When ESS is integrated into microgrid, it can maintain system instantaneous power balance and improve the dynamic performance through proper energy management strategies, which equals to system equivalent inertia enhancements. In general, a microgrid operates in parallel with main grid. However there are cases when a microgrid operates in an islanded mode which means in a disconnected state from the main grid. Energy storage is essential for the maintaining the energy balance of the microgrid in islanded operation. And impact of the energy storage on the stability of the islanded microgrid is also verified by the experimental cases. To show the experimental results, the microgrid test bed was built. Two test cases were performed to see the effectiveness of the energy storage in the stability enhancement.

KEYWORDS: Dynamic stability, microgrid, Energy Storage System (ESS), small-signal model, distributed generators, Phase Locked Loop (PLL).

I. INTRODUCTION

Microgrid is the future energy system paradigm, formed by the interconnection of small, modular generation (micro-turbines, fuel cells, wind, PV, etc.), together with storage devices. In this storage devices are flywheels, energy capacitors and batteries. The controllable loads are low voltage distribution systems. Such systems can be operated at interconnection to the power grid, or islanded, if disconnected from the grid. The operation of micro-sources in the network introduces considerable complexity in the operation of an LV grid, but at the same time, it can provide distinct benefits to the overall system performance, if managed and coordinated efficiently [7].

Normally Distributed Generation (DG) is a promising concept that is considered as an alternative solution for addressing technical, economical and environmental issues of conventional power systems [4]. Distribution of generation units within an electric power system offers technical advantages in terms of power quality and reliability as well as energy management and efficiency. It also offers economical advantages in terms of reducing capital investment for construction of power systems since distribution of generation units eliminates the need for having extensive transmission systems. DG power systems provide environmental benefits as a result of offering a more efficient way of generating and distributing electricity as well as enabling the integration of renewable energy resources.

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Energy shortage problem combined with recent high petroleum price has resulted in severe impacts to several technical aspects. Efficiency improvement of high-power apparatuses, research and development of alternative energy, studies of integrated various renewable energy resources, etc., have been eagerly progressing. During the past several decades, large amount of natural resources of the earth have been unlimitedly consumed, and our living environment has been severely destroyed and polluted. Global environmental protection concepts and concerns have been widely excited and several new forms of renewable resources such as Photovoltaic Systems (PV) and Wind Power Generation Systems (WPGS) to supplement fossil fuels have been examined, integrated, and developed in the whole world.

A hybrid power generation/energy storage system may combine all different kinds of available renewable energy associated with available energy storage units. The required power for the connected loads can be effectively delivered and supplied by the proposed hybrid power generation/energy storage system with appropriate control and effective coordination among various subsystems. Due to the international technological progress and promoted experience on the WPGS, the cost of generating electricity from the WPGS has already been reduced and the cost of electricity generating of the WPGS may close to the one of traditional fossil fuel energies.

A microgrid can be operated either in grid connected mode or in stand-alone mode. In grid connected mode, most of the system-level dynamics are dictated by the main grid due to the relatively small size of micro sources. In stand-alone mode, the system dynamics are dictated by micro sources themselves, their power regulation control and, to an unusual degree, by the network itself.

One of the important concerns in the reliable operation of Microgrid is small-signal stability [8]. In conventional power systems, stability analysis is well established with standard models of synchronous machines, governors and excitation systems of varying orders that are known to capture the important modes for particular classes of problems. This does not yet exist for microgrids and may be hard to achieve because of the wide range of power technologies that might be deployed. Therefore, full-order models of microgrids with typical DGs are required.

The small-signal models containing synchronous generators, inverter based generations and power network were established in [9] and [10], and the dynamic characteristics in autonomous operation mode were analyzed based on the individual models. The global small-signal model of the inverter based Microgrid was setup in [11] to design the controller of inverter based DGs. However, as an important DG, asynchronous wind turbine was not included in the model.

In this paper, a small-signal model of a typical microgrid is presented. It will contain the major types of power interface devices of DGs exist nowadays such as synchronous generator, asynchronous generator and inverter. Each of the small-signal models of the individual DGs will be established respectively together with that of the power network, and then the global model will be set up in a global reference axis frame. Once the small-signal model has been constructed, eigenvalues are identified to indicate the damping of the oscillatory terms under different operation conditions [12]. The analytical nature of this examination then allows further investigation of the relation between stability and system configurations, such as DGs capacity and system operating state [13]. A sensitivity analysis is then conducted by tracking eigenvalues loci under certain conditions, which provides the difference between the situations with/without ESS on system stability [14-15]. The theoretical analysis is verified with both simulations and experiments of a typical microgrid. With the development of power electronics, energy storage can be controlled to release or absorb active/reactive power flexibly [16]. When ESS is integrated into microgrid, it can maintain system instantaneous power balance and improve the dynamic performance through proper energy management strategies, which equals to system equivalent inertia enhancement [17].

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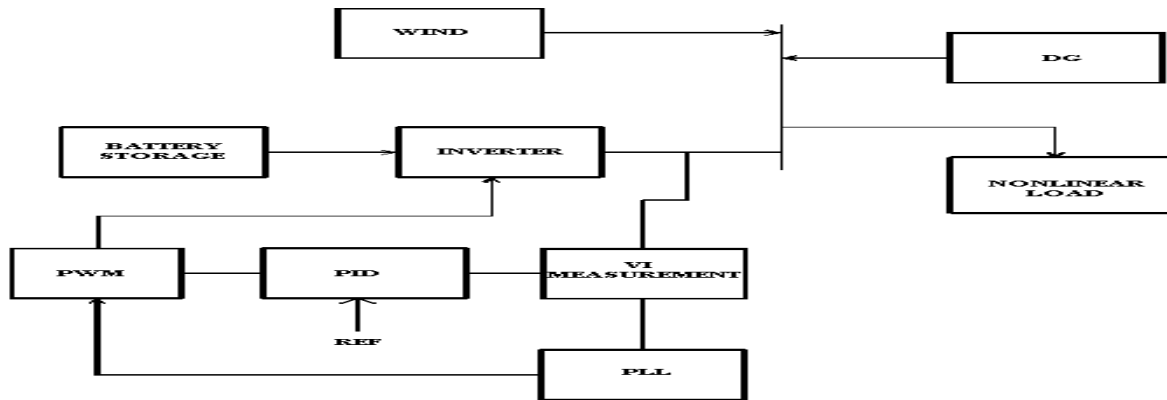


Fig. 1 Block diagram of a typical microgrid in stability control

Therefore, the impact of DGs power fluctuations and other interruptions on system stability and power quality can be mitigated greatly, which is of vital importance for microgrid in autonomous operation mode. Many energy storage technologies and their applications in microgrids were studied recently including Li-ion batteries, Flywheel Energy Storage (FES), Super-Capacitors, Superconducting Magnetic Energy Storage (SMES) and Vanadium Redox Battery (VRB), etc...

The rest of the paper is organized as follow. Section II describes the Microgrid model in autonomous operation. Section III analyzes the dynamic stability analysis of Microgrid. Results and discussions of the simulation and experiment are reported in Section IV. Conclusion is stated in Section V.

II. MICROGRID MODEL IN AUTONOMOUS OPERATION

Fig. 1 shows the single-line diagram of a typical microgrid. It comprises, instead of local loads, DG1 representing an AWT with stall regulation, DG2 representing a synchronous generator equipped with excitation and governor control systems, and an ESS based on a Voltage-Sourced Converter (VSC) with active/reactive power controller. It is connected to a distribution network at the Point of Common Coupling (PCC), and operates autonomously when the main grid is fault. [6]

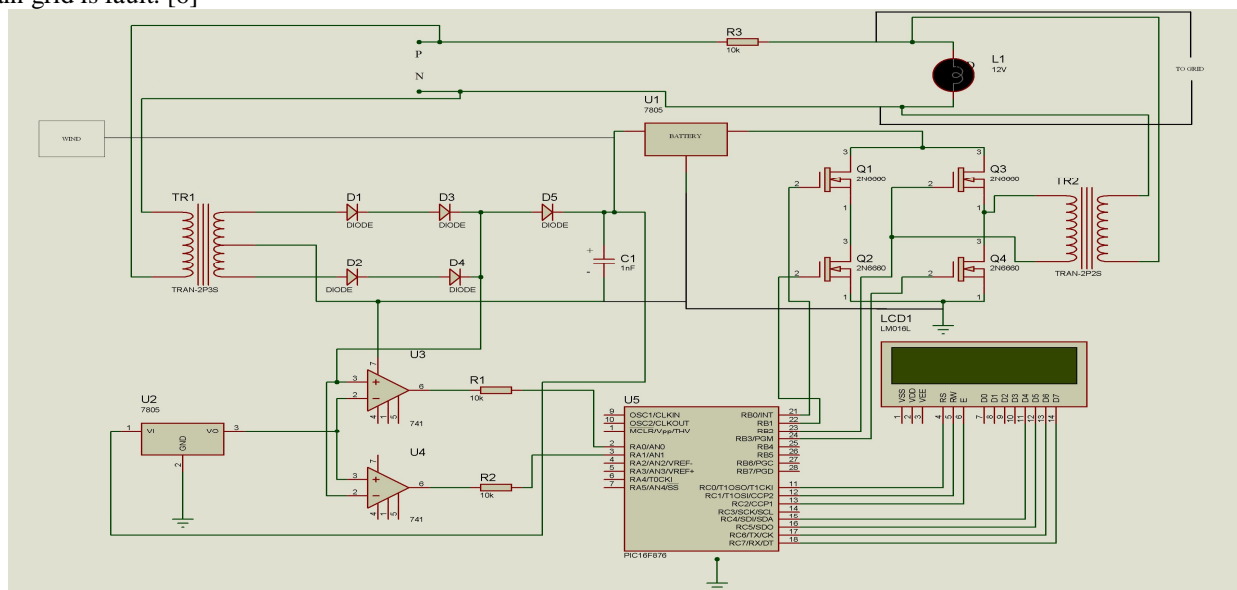


Fig. 2 Circuit diagram for hardware implementation of microgrid

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The state-space model of DG1, DG2, ESS and power net-work are represented on their individual local reference frame, respectively. A common reference frame is chosen as the global reference frame of the microgrid system, and all of the subsystems are shift to the global reference frame using the transformation method shown in Fig. 3 and formulated.

As shown in Fig. 3, the d-axis and q-axis is taken as the global reference frame which is defined on the microgrid network rotating at angular frequency of ω_e . d_1 -axis and q_1 -axis, d_2 -axis and q_2 -axis, d_c -axis and q_c -axis are the local reference frames of DG1, DG2 and ESS rotating at ω_w, ω_s and ω_c , respectively. $\delta_n (n = \omega, s, c)$ denotes the angle between the local reference is the frame of $d^n-q^n (n = 1, 2, c)$ and the global reference frame, respectively:

$$\begin{bmatrix} \Delta f q^n \\ \Delta f d^n \end{bmatrix} = [T] \begin{bmatrix} \Delta f q^g \\ \Delta f d^g \end{bmatrix} \times \begin{bmatrix} -f^o dn \\ f^o qn \end{bmatrix} \Delta \delta n$$

$$T = \begin{bmatrix} \cos \delta n & -\sin \delta n \\ \sin \delta n & \cos \delta n \end{bmatrix} \text{----- (1)}$$

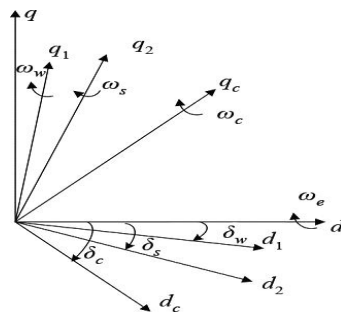


Fig. 3 Global and local rotating reference frames of the microgrid.

III.DYNAMIC STABILITY ANALYSIS OF MICROGRID

The small-signal model can be used for eigenvalues analysis to investigate the dynamic stability of microgrid system. System stability margin and corresponding operation strategies can be obtained by tracking the loci of the eigenvalues with the variation of system parameters or steady-state operating state.

A. System model

The system model of DG1, DG2, ESS and network, the small-signal model of a multi-DG Microgrid system can be obtained. Fig- 4 describes the block diagram for developing state-space equations with all of the subsystem models integrated together. The node voltages (outputs of network) are taken as the input variables to the corresponding subsystems and the node current are taken as the output variables to the network

B .State space model of ESS

The energy storage system of battery storage system has state model of PID controller. Universal bridge model is connected to energy storage system.

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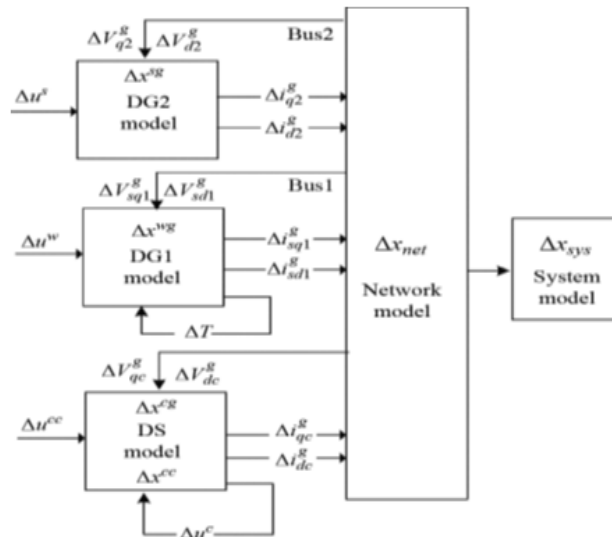


Fig. 4 Block diagram of the global small-signal model of a multi-DG microgrid system.

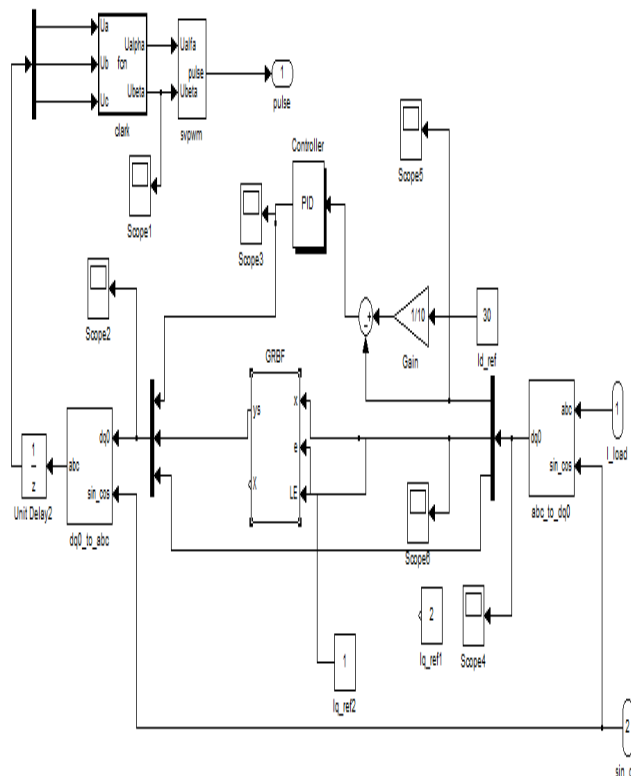


Fig.5 State model diagram of ESS

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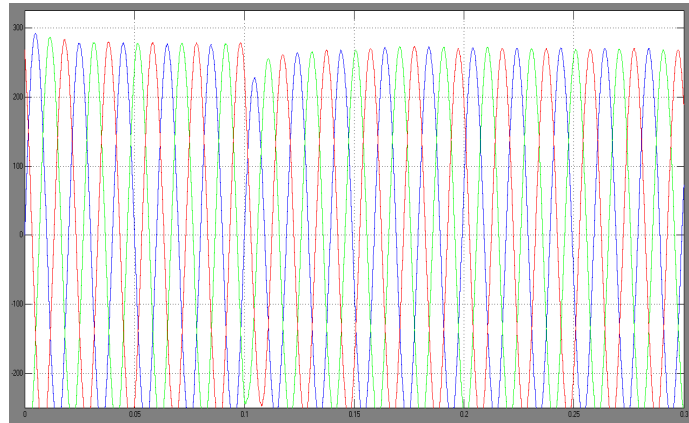


Fig.6 Output scope of State model ESS

IV. SIMULATION AND EXPERIMENT RESULTS

A simulation platform of the study microgrid system shown in Fig. 1 is established under MATLAB/SIMULINK environment. The simulation is implemented in time-domain to test and verify system performance under wind gust disturbance with/without energy storage.

The microgrid is controlled to operation in autonomous mode. It stays originally in a steady operating state with wind speed of 10 m/s.

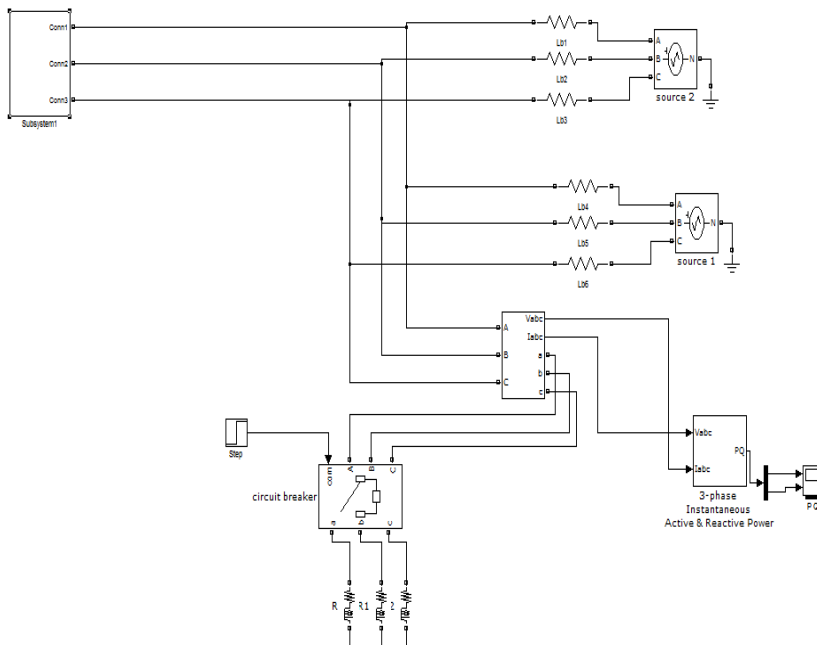


Fig.7 Simulation diagram of dynamic stability in microgrid

Then a wind gust occurs at the power output process of DG2 under the gust disturbance with/without ESS, respectively. As the gust disturbance lead to DG2 active power fluctuating obviously with the fluctuation ratio of 10% when ESS is not equipped. However, the active power fluctuating is restrained largely with the fluctuation ratio of

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around 1% and shortened recovery time when ESS is used. Meanwhile, the wind gust disturbance lead to DG2 reactive power fluctuating with the fluctuation ratio of 12% when ESS is not equipped, and decreased to 1.6% with ESS used.

The simulation results reveal the fact that ESS can release or absorb power quickly and flexibly which track and compensate the change of wind power precisely to mitigate system instantaneous power unbalance. ESS absorbs active power and releases reactive power when wind speed increases, and releases active power and absorbs reactive power when wind speed decreases.

The amount of active/reactive power released/absorbed by the ESS can be altered conveniently through the control of the VSC between energy storage and microgrid shows system response to wind gust disturbances without ESS.

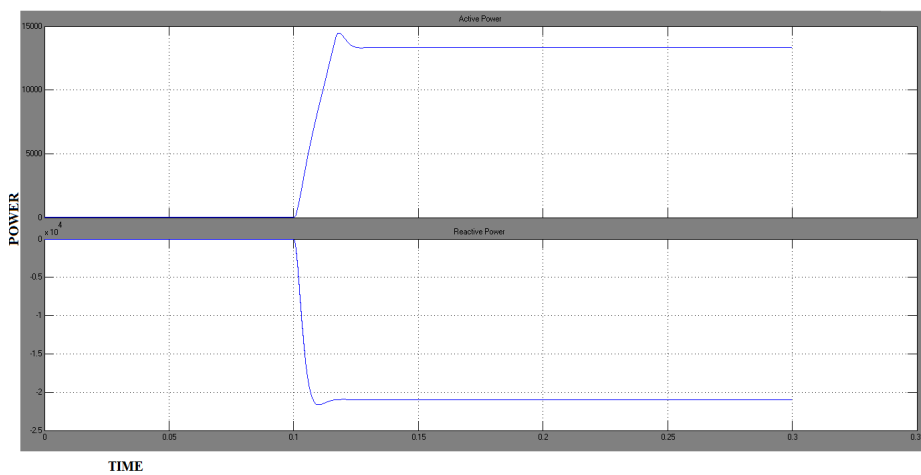


Fig. 7 System response to gust disturbance without ESS (a) Active power. (b) Reactive power.

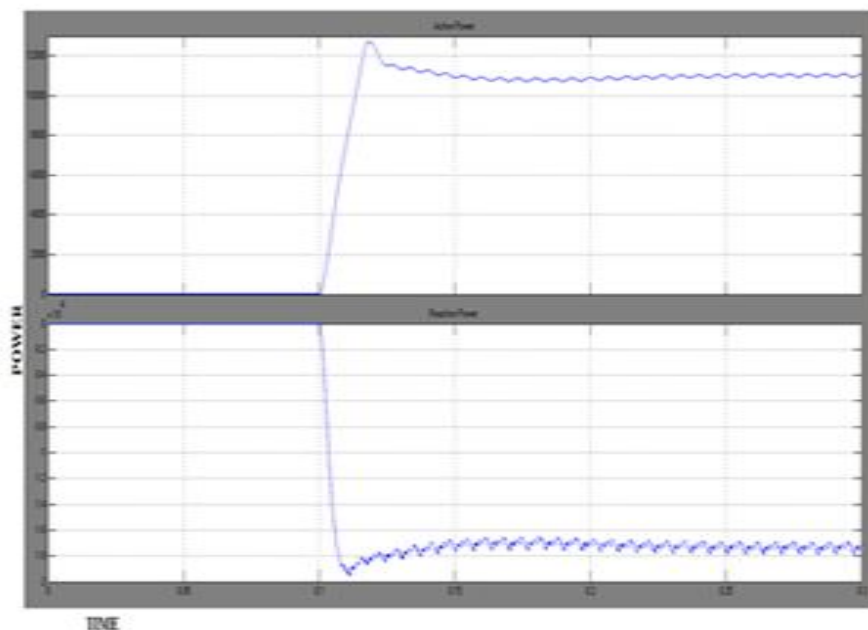


Fig. 8 System response to gust disturbance with ESS (a) Active power. (b) Reactive power.

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The microgrid system is originally in autonomous mode with 6 kW power output of DG1. Following the gust occurs at, the output power of DG1 and DG2 change accordingly, as shown in Fig. 12(a) and (b). The active power output of DG2 decreases when that of DG1 increases with wind speeds to maintain global active power balance. Meanwhile, the reactive power released from DG2 increases too to compensate the rising of reactive power absorption of DG1. On the contrary, when wind speed decreases, the active power output of DG1 decreases and that of DG2 increases. Meanwhile, the reactive power output of DG2 decreases with the decline of the reactive power absorption of DG1. The experiment results show that the active/reactive power of DG2 fluctuates obviously during the gust disturbance without ESS. This is not favorable for a thermal engine since the frequently changing of operation state may impose extra mechanical and electrical stress on the units. Fig. 13 shows system response to gust disturbance with ESS.

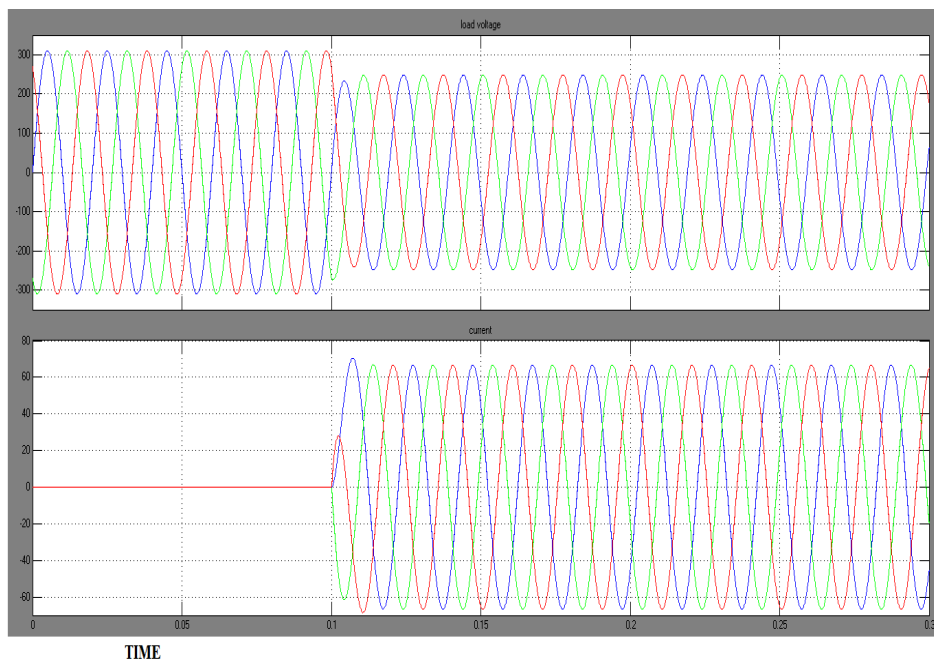


Fig. 9 Output for VI measurement in microgrid with ESS. (a) Load voltage (b) Current

As mentioned above, ESS can track the output power changes of DG1 precisely and mitigate the adverse effects through active/reactive power output/input of ESS quickly and flexibly due to its decoupling controller. As a result, the instantaneous power unbalance is mitigated and the frequency and voltage quality and stability of the microgrid is improved greatly. Specifically, ESS absorbs active power and releases reactive power when wind speed increases, whereas output active power and absorbs reactive power when wind speed decreases, as shown in Fig. 13(a) and (b). According to the experiment results, the active/reactive power of DG2 is maintained stable during the gust disturbance with the help of ESS. Moreover, the thermal engine in a microgrid can be maintained at a high-efficient operating state and system fuel economic is improved.

V. CONCLUSION

In this paper, a comprehensive small-signal model of a typical microgrid is presented including synchronous generator, asynchronous generator, and voltage source converter with corresponding control systems. The model covers almost all the possible power interfaces of DG and ESS existing in microgrid or distributed generation system. All the subsystems are modeled individually and then combined on a global reference frame. The model of different kind of microgrids can be obtained easily based on this paper with proper adjustment of the number and parameters of the subsystems. Their sensitivity to different operating state and control of DG or ESS. It is observed that the dynamic stability of an autonomous microgrid is influenced by system configuration and the variability of intermittent generation. It can be improved remarkably with ESS equipped due to its ability to mitigate the instantaneous

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active/reactive power unbalance. Therefore, properly designed and controlled energy storage is an essential solution to the reliable operation of microgrid as well the effective utilization of renewable energy.

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