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Testing of a Solar-PV/Wind Operated AC-DC Microgrid with LabVIEW Controller

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ABSTRACT

This paper discusses about a LabVIEW based controller for the hybrid renewable energy system operated AC-DC microgrid with the major objectives of: i) predicting the power generation potential of the solar–PV and wind generators ii) effective power management iii) load scheduling based on the available power with the renewable sources and iv) grid/islanding mode of operation of the microgrid. In order to predict the output power of wind generator and solar-PV system, an artificial neural network is developed.The laboratory-scale model of three phase, 400 V, 10 kVA microgrid structure is developed at National Institute of Technology Calicut, India. The developed LabVIEW based controller has been tested successfully for a real-time load and source in the laboratory environment. Test results show that the designed controller is effectively managing the output power of the primary energy sources under different scenarios.

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1. INTRODUCTION

For the past few decades, efforts are made to develop a zero-emission electricity generation system from clean energy sources such as biomass, solar–PV (SPV), wind, small-hydro etc., throughout the world. Matching the diverse characteristics of the renewable energy sources to widely-varying rural needs is facilitated by employing the integrated energy systems which are often called as a Hybrid Energy System (HES) using power electronic converters[1–4]. HES based on wind and solar sources are highly utilized to electrify villages, powering lamps and small appliances, small industries, health clinics, school and community centres. In general, the intermittent nature of solar and wind energy do not match the time distribution of the load demand. A better way to realize the emerging potential of these renewable sources is to take a systematic approach, which views local control of the sources and the loads as a subsystem called microgrid.

Power electronic converters are used as a power conditioning device, which extracts energy available with the renewable sources and delivers to the load in the appropriate form. Development of a control system for the effective power management in the microgrid structure is a real challenge. This paper discusses a LabVIEW based controller for the hybrid renewable energy system operated AC-DC microgrid as follows: Literature review of controllers developed for HES is summarized in Section 2. In Section 3, SPV/Wind/Battery HES integrated with AC-DC microgrid is described. Development of LabVIEW based controller for HES operated AC-DC microgrid is reported in Section 4. Section 5 shows the fabrication of a SPV and wind based microgrid structure and also test results of the developed controller for the microgrid structure. This article is concluded in Section 6.

2. LITERATURE REVIEW OF THE CONTROLLERS DEVELOPED FOR HES

A techno-economic evaluation of HES for rural applications has been conducted in [5]. A real-time energy management for a single microgrid system that constitutes a renewable generation system, an energy storage system, and an aggregated load is presented in [6]. A novel double-layer co-ordinated control approach for microgrid energy management is proposed in [7]. Baboli et al. proposes an up-down operational model of a hybrid microgrid which consists of system and device level. In the system level, a mixed integer linear model is suggested to balance the generation and load considering the interconnection of AC and DC subgrids for minimizing total operating cost of the system in a 24-hour period [8]. A control strategy for the effective microgrid power management under grid connected and islanded modes was proposed in [9]. AC-DC microgrid structure to integrate different voltage-current characteristic renewable sources, storage units, local loads, and utility grids was reported.

Application of a genetic-evolved fuzzy system for maintenance scheduling of generating units is presented in[10]. The presented approach has been tested on a practical Taiwan Power system through the utility data. An intelligent power management scheme has been proposed in [11] based on multi-agent systems for a stand-alone hybrid energy system. Control of SPV/diesel HES is proposed in [12] for a small ship in consideration of the fluctuating SPV power due to solar radiation. The aim of the control is to minimize the fuel consumption and storage capacity of the battery. A new control method for battery storage to maintain an acceptable voltage profile in autonomous microgrids was proposed in [13],which ensures that the bus voltages in the microgrid are maintained during disturbances such as load change, loss of micro-sources, or distributed generations hitting the power limit. Output power control of a solar/wind stand-alone system is discussed in [14]. The control system regulates the generation of wind subsystem in order to satisfy jointly with SPV, a load and a battery.

A simple, low power control circuit intended to manage the power within a remote autonomous microsystem hybrid power supply is presented in [15]. Control strategies for adopting distributed generation units to autonomous microgrid was proposed in[16]. In addition to the control of active power flow, voltage regulation and frequency control to the autonomous microgrid is also done by the proposed distributed generation interface. A comprehensive supervisory control for a hybrid system that comprises of wind and SPV generation, a battery bank and AC load is developed by Fernando et al.[17]. The objectives of the supervisory control are to satisfy the load power demand, to maintain the state of charge of the battery to prevent blackout and to lengthen the life of batteries. The problem of economic and stable power sharing in an autonomous microgrid including a variety of distributed energy resources and wind turbine generator distributed energy management system to control the energy flow in the HES is proposed by Thanaa et al.[18]. This distributed controller is based on multi-agent system technology.

A novel fuel cell/ultracapacitor/battery power train with a fuzzy logic based energy management strategy is presented by Farid et. al.[19]. Design and implementation of an energy management system with fuzzy control of a DC microgrid system are carried out by Chen et al.[20]. A generalized formulation for intelligent energy management of a microgrid is proposed using artificial intelligence techniques jointly with linear programming based multi-objective optimization by Chaouachi et al.[21] A dual-loop controller for voltage source inverter control is proposed by Khaled et al. for reliable operation of distributed energy resources in smart microgrids [22].

3. SPV/WIND/BATTERY HYBRID ENERGY SYSTEM

An SPV/Wind/Battery HES integrated with AC-DC microgrid, which is operated in grid connected and autonomous mode, is considered in this work. SPV and wind generator are integrated into the DC grid using a Dual Input DC/DC converter (DIDC)[23]. The battery storage system is used as a backup in the HES to supply power to the primary load and it is connected to DC microgrid using a bidirectional DC/DC converter. Both DC grid and AC grids are integrated through a bidirectional DC/AC converter. In this microgrid structure, a load management system based on priority is considered such as the primaryload (Load 1), secondary load (Load 2), tertiary load (Load 3) and dump loads for dissipating the excess energy generated in renewable energy sources. Among these priority-based loads, primary load has first priority to provide electricity. Secondary and tertiary loads are the loads that may be turned on within some time period.

4. LABVIEW BASED CONTROLLER FOR HES OPERATED AC-DC MICROGRID

A controller for the hybrid renewable energy system operated AC-DC microgrid is developed with the major objectives of: i) predicting the power generation potential of the solar–PV and wind generators, ii) effective power management, iii) load scheduling iv) grid connected/islanding mode of operation. Figure 1 shows the block diagram of the proposed control hardware developed for the microgrid. Solar radiation, SPV cell temperature, wind speed, voltage and current waveforms of different loads and state of charge of battery are accessed through Analog to Digital (A/D) converters from the respective sensors. The power generation potential of SPV and wind generators is predicted using a trained Artificial Neural Network (ANN). Power management strategy for the HES, which has been reported in [24], schedules various loads according to different modes of the microgrid. Output derived from the controller is given to the corresponding units of the HES operated microgrid through Digital to Analog (D/A) converters and signal conditioning circuits. However, the dual input DC/DC converter with a fuzzy logic scheme, shown in Figure 1 is not discussed in this paper. Implementation of the LabVIEW based control hardware for the DC-AC microgrid is the main focus of this paper.

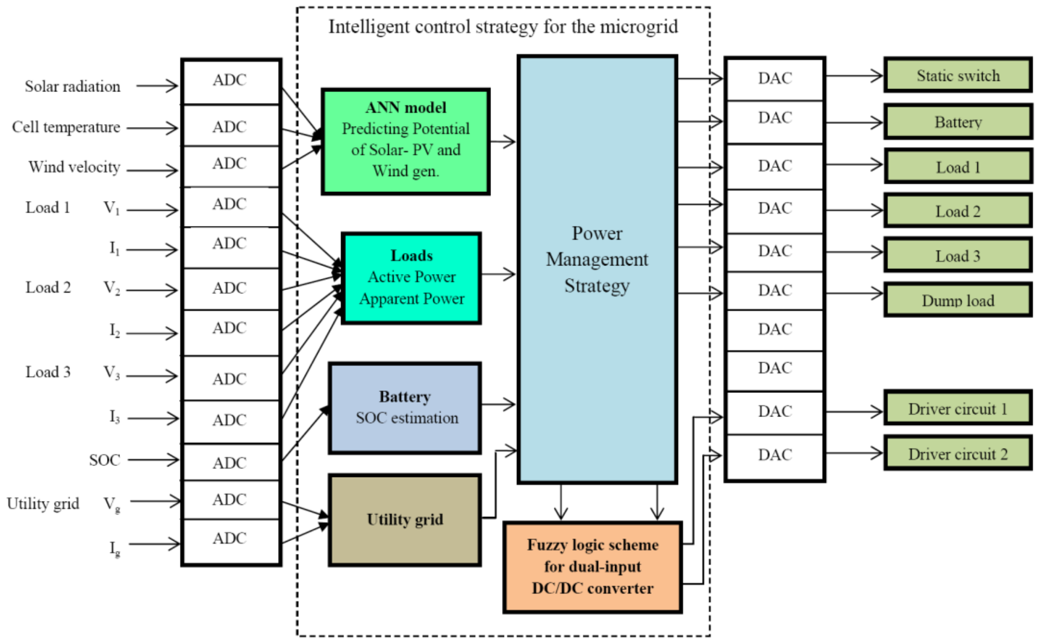


Figure 1. Block Diagram of Proposed Control Hardware for Microgrid

4.1. Data Acquisition for Source Potential, Battery, Loads and Grid using LabVIEW

Data Acquisition (DAQ) of SPV and the wind source potential, status of battery, loads and the grid is developed in LabVIEW platform. DAQ assistance block in LabVIEW is programmed to access the given input analog signals of solar radiation, SPV cell temperature, wind speed, voltage and current waveforms of different loads and utility grid, and the state of charge of battery. An input limit of A/D converters of the measurement unit is specified as 5V for maximum and 0V for minimum to measure the signals such as solar radiation, cell temperature, wind speed etc. Current transformers with the conversion ratio of five and potential transformers with the conversion ratio of hundred are used to access the load demands. Overall control scheme of the proposed controller shown in Figure 1 is developed in LabVIEW platform and the developed front panel of the controller in LabVIEW platform is shown in Figure 2.

5. FABRICATION AND TESTING OF THE LABORATORY-SCALE MODEL OF THE HES OPERATED MICROGRID

Laboratory-scale model of the HES operated microgrid structure developed at National Institute of Technology Calicut (NITC) is shown in Figure 3. HES operated microgrid structure consists of a 220V, 3.5kW SPV and 220V, 5kW DC wind generator along with the battery storage which contains three stacks with eighteen batteries of 12V, 42Ah capacity in each stack. Two renewable energy sources are integrated through the dual input DC-DC converter. Power available in the DC bus is delivered to local load/grid through an inverter. The voltage and current waveforms observed from the various parts of the microgrid are shown in Figure 4.

Testing of the controller in LabVIEW platform has been conducted for real-time load and source, and the test results are given in Table 1. Voltage range of 0-5 V is considered with respect to the variation of solar radiation, cell temperature and wind velocity. State of charge of the battery is also given in 0-5 V range corresponding to the state of charge of 0-100%. Three loads are considered as local loads, which are connected to the microgrid according to the priority. The load profile, solar radiation, cell temperature, wind velocity and state of charge of battery considered for the performance evaluation are shown in Figure 5to 7.

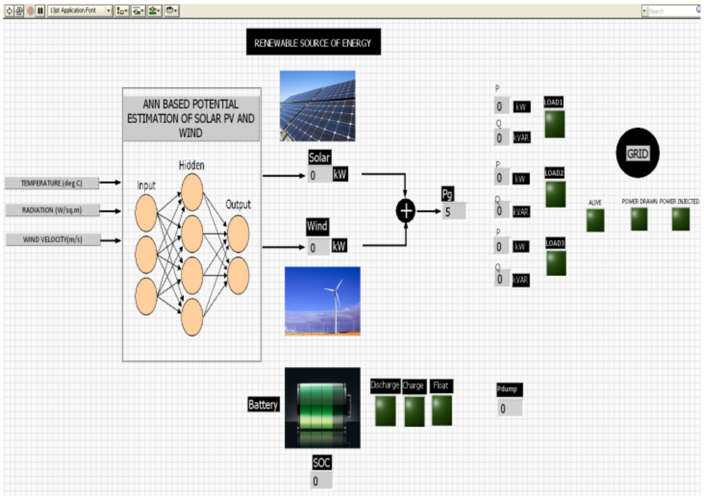


Figure 2. Front Panel of the Control Strategy Developed in LabVIEW Platform

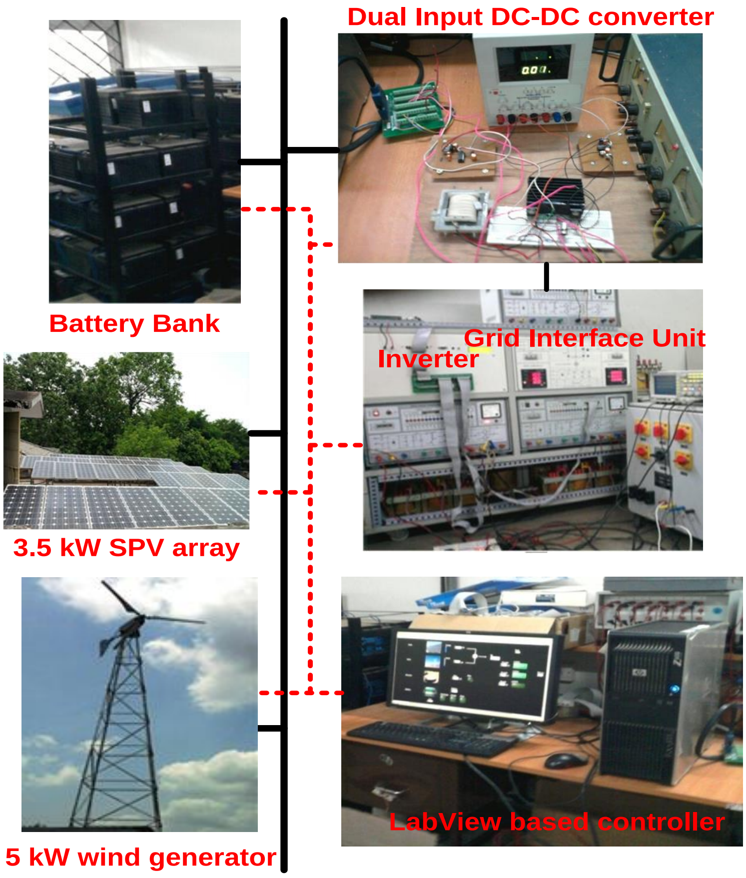
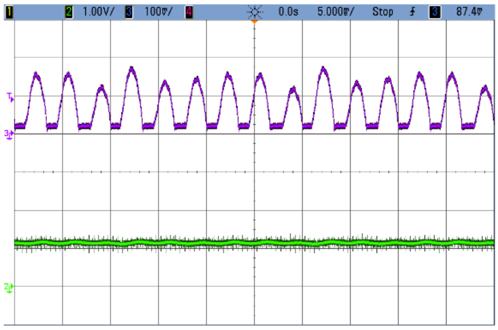
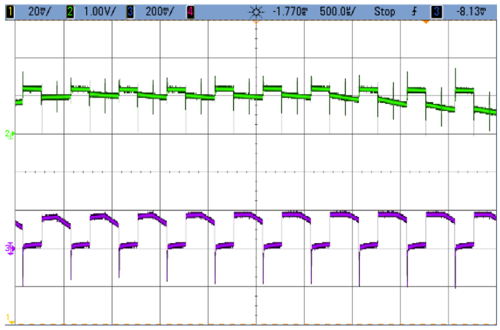


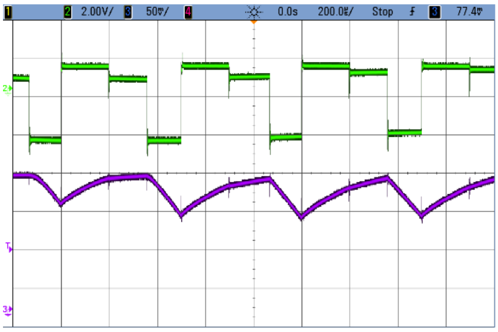
Figure 3. Laboratory Scale Model of the Microgrid Developed at NITC



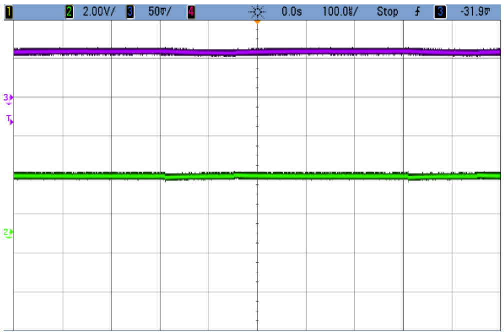
(a) Source 1 - Voltage and Current



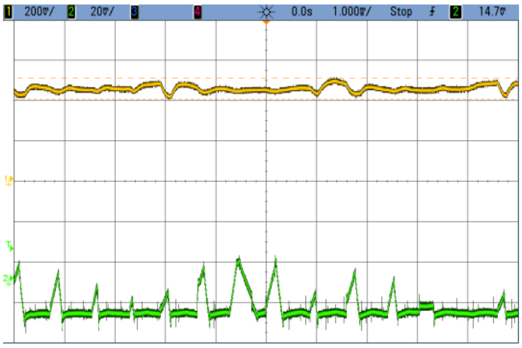
(b) Source 2 - Voltage and Current



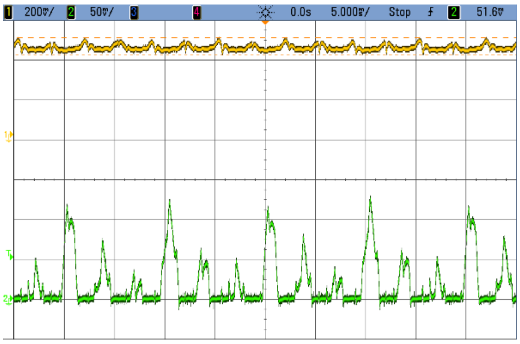
(c) Inductor Voltage and Current



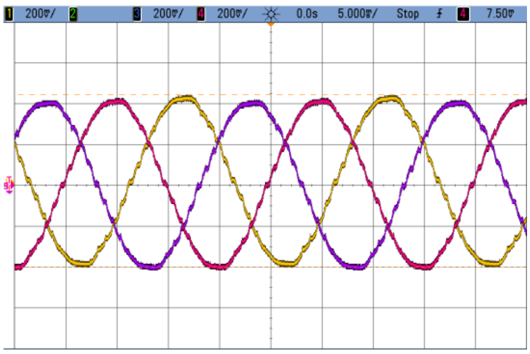
(d) DC bus Voltage and Current



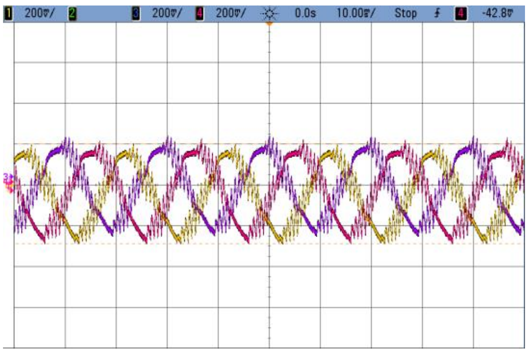
(d) Voltage and Current of Battery While Charging



(e) Voltage and Current of Battery While Discharging



(f) Voltage at the PCC



(g) Current Injected into Grid

Figure 4. Voltage and Current Waveform of the Lab Scale Microgrid

Test results show that the designed controller is effectively managing the power available with the SPV and wind sources under different scenarios. Loads are scheduled appropriately by the controller with respect to the status of renewable sources, battery and utility grid. During the islanded mode of operation of the microgrid, dump load is used effectively by the controller. Modes of operation of the microgrid are selected with respect to the status of the grid and control signal for the static switch is generated properly as given in Table 1. Excess energy available in the SPV and wind sources is injected to the utility grid. The developed microgrid structure with the controller has the flexibility to accommodate any number of sources and loads according to the requirement.

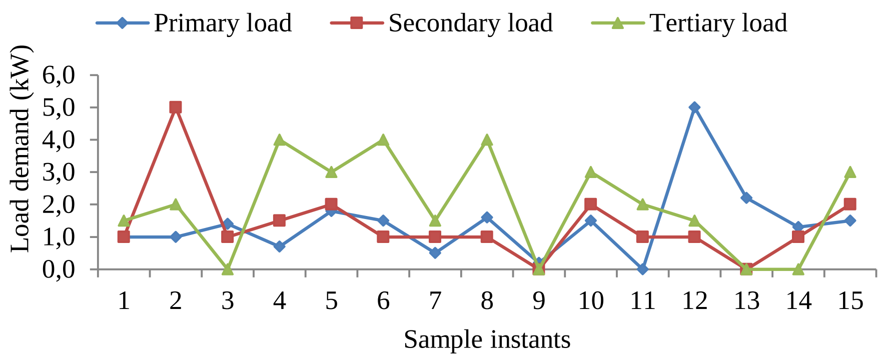


Figure 5. Load Profiles Considered for The Testing of the Controller

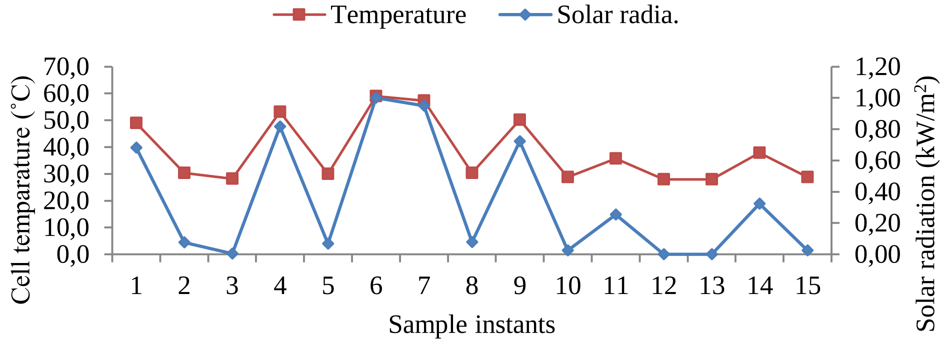


Figure 6. Solar Radiation and Cell Temperature Considered for the Testing of the Controller

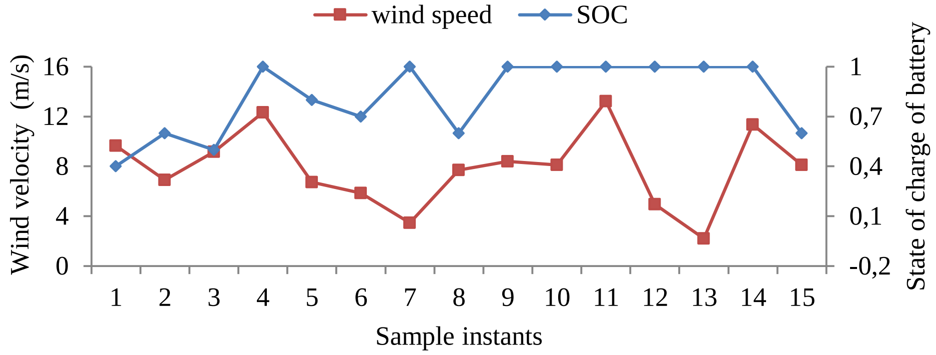


Figure 7. Wind velocity and state of charge considered for the testing of the controller

Table 1. Performance of the Developed Controller in the Laboratory Environment

Static switch	Operating time	P_{PV} (kW)	P_{Wind} (kW)	Battery	Grid status	Load 1	Load 2	Load 3	Dump Load
Open	Off-peak	1.95	3.16	Charging	OFF	ON	ON	ON	ON
Open	Off-peak	0.24	0.88	Charging	OFF	ON	OFF	OFF	OFF
Open	Peak	0.01	2.72	Charging	OFF	ON	ON	OFF	OFF
Open	Off-peak	2.29	4.71	Floating	OFF	ON	ON	ON	ON
Open	Peak	0.21	0.79	Discharging	OFF	ON	OFF	OFF	OFF
Open	Off-peak	2.72	0.42	Charging	OFF	ON	ON	OFF	ON
Closed	Off-peak	2.60	0.05	Floating	Drawing	ON	ON	ON	OFF
Closed	Off-peak	0.24	1.43	Charging	Drawing	ON	ON	O N	OFF
Closed	Off-peak	2.05	2.01	Floating	Injecting	ON	OFF	OFF	OFF
Closed	Off-peak	0.08	1.76	Floating	Drawing	ON	ON	ON	OFF
Closed	Peak	0.77	4.86	Floating	Injecting	ON	ON	ON	OFF
Closed	Off-peak	0.00	0.18	Floating	Drawing	ON	ON	ON	OFF
Closed	Off-peak	0.00	0.00	Floating	Drawing	ON	OFF	OFF	OFF
Closed	Off-peak	0.98	4.35	Floating	Injecting	ON	ON	OFF	OFF
Open	Peak	0.08	1.76	Charging	OFF	ON	OFF	OFF	OFF

6. CONCLUSION

LabVIEW based controller for the hybrid renewable energy system operated AC-DC microgrid is presented in this paper. A control strategy is developed for the efficient utilization of SPV and wind sources connected to the microgrid. A feed forward ANN is used to predict the output power of the SPV and wind generators. Laboratory scale model of the microgrid has been set up. A control strategy for the effective power management of the HES operated microgrid is implemented in the LabVIEW platform and tested successfully for the practical load and source data. Test results prove that the SPV and wind sources integrated in the microgrid along with the battery storage are used effectively by the controller. Developed controller for microgrid can be applied to meet the large demand of industry/community loads for improving the reliability and reducing the energy cost of the HES.

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