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Demonstration study of hybrid solar power generation/storage micro-grid system under Qatar climate conditions

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ABSTRACT

The ultra-strong solar irradiance conditions in Qatar area have natural benefits for large-scale solar photovoltaic (PV) farm deployment. However, climate issues such as soiling, extremely high temperatures and sand storms are real challenges for stable performances of solar PV farms. The integration of an energy storage system to the solar farm can be used to smooth the intermittency of the PV power generation. A 500 kW/500 kWh hybrid solar power generation/storage micro-grid system has been installed in the Solar Test Facility (STF) near Doha, Qatar. In this work, we describe the main elements that constitute the hybrid micro-grid, and the Supervisory Control and Data Acquisition (SCADA) system that has been developed to monitor the different elements of the micro-grid. We give a brief summary of the solar PV performance, analyze the impact of power fluctuations on the quality of the grid and present the data generated from the micro-grid system. We demonstrated a significant improvement of the power quality of the grid with the introduction of an energy storage system to the micro-grid.

1. Introduction

Renewable energy technologies such as photovoltaic (PV) and wind power backed by energy storage systems will play key roles in the near future in global energy market and economics. According to the 2015 renewable energy medium-term market report from the International Energy Agency (IEA), renewable electricity expanded at its fastest rate to date (130 GW in 2014 and accounted for more than 45% of net additions to world capacity in the power sector) [1]. Currently, it is estimated that between 100 and 200 remote micro-grids in the globe are fully functional, providing power in the absence of traditional grid infrastructure [2–11]. For instance, remote micro-grids such as those in rural Alaska or in islands, do not have the benefit of using the larger grid for backup, and as such, provide all the energy the consumer needs [12]. However, a few micro-grids have advanced capabilities such as connecting multiple unaffiliated end-users with multiple types of generation, storage, and smart devices [13]. Also, although a lot of solar farms or wind farms based micro-grid projects have been developed in recent years, but just a few of them have integrated large-scale Energy Storage System (ESS) due to the high cost of batteries.

The need for storage is now widely recognized as part of a complete solution for energy. As an essential element of renewable energy integration, the ESS is perceived as the missing other half of the equation for solar PV or wind power [14,15]. In this context, Li-ion batteries are an excellent choice as stationary energy storage [16,17] and they are dominating the ESS market together with thermal storage [18,19]. Most of the energy storage systems are used for peak-shaving and grid regulation together with large solar PV and wind farms, and their storage capacity varies from 10 MW to 60 MW for Li-ion systems while thermal storage is considered for bigger installation (more than 100 MW).

Nowadays Qatars economy relies heavily on oil and gas industry's income. However, with the volatility of oil prices and hydrocarbons being a finite resource, sustainable and cleaner alternative means of energy production are much needed. Therefore, Qatar has strong demand on diversifying the nations economy and promoting renewable energy applications under desert environment. However, significant local climate conditions such as dust soiling, ultra-hot temperatures and sand storms are real challenges to be addressed before adopting existing renewable technologies in an efficient way. Dust is a real challenge because of its heavy effects on the PV modules efficiency and surface accumulation that requires regular cleaning [20–22]. Moreover, dust can be detrimental to mechanics and electronics making them sensitive to fatigue and failure. Weather factors such as cloud, sand storm and winds have also impact on PV fluctuations which can range from hour to second levels. So, without peak-shaving or smoothing technologies ensured by storage systems, the power generated from the PV farm

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cannot be qualified for grid feeding because of power quality and demand response issues. Finally, the ultra-high temperature and strong irradiance in Qatar make it very difficult for technicians to monitor and manage the solar facilities in outdoor environment. Thus, a remote Supervisory Control and Data Acquisition (SCADA) system based on advanced industry automation technologies to monitor and control the overall site is much needed.

The purpose of this paper is to investigate the performance of a 500 kW/500 kWh hybrid micro-grid system, encompassing a lithium-ion battery storage system, built in the area of Doha, Qatar under the challenging local climate conditions. To the best of our knowledge this type of micro-grid demo is currently the only one in the Gulf Cooperation Council (GCC) area. Therefore the data taken from these facilities could be a valuable reference for stakeholders in the GCC. In this paper, we first present an overview of the complete system and its components. Then, we focus on the optimization of the SCADA control profile. Finally we introduce and discuss the solutions developed for an optimal use of the micro-grid under the challenging desert climate of Qatar.

2. System overview

The hybrid solar power generation/storage micro-grid system has a power/energy capacity of 500 kW/500 kWh, the power management system and layout of the plant are shown in Fig. 1. This hybrid micro-grid system includes an 250 kW solar PV array, 250 kW/500 kWh lithium-ion battery storage system, a control room, and a grid connection to an office building which is also connected to the local utility grid.

2.1. Solar farm

The solar farm is rated as 250 kW power capacity, and the practical power output runs at 200 kW. In order to test, compare and study various PV panels from different manufactures and their performances under local environment, a mixed solar PV array with different brands and technologies are built in the solar test facility (STF) site. The novel solutions and technologies applied in this solar farm mainly address two problems: dust and power harvesting efficiency.

A. Anti-dust
To address the soiling problem in the STF facility, two types of technologies are utilized. One is anti-soiling coating technology and the other is robotic cleaner technology. Generally, soiling decreases PV power by 10–20% per month under local conditions. Module efficiency can be improved by the incorporation of super-hydrophobic coatings in the PV panels or by using a robotic cleaner to remove dust. However, the later has not proven to be cost-effective so far.

B. Power harvesting efficiency
To improve PV module efficiency due to azimuth and elevation angles impact, one-axis and 2-axis solar tracking systems are both introduced. The one-axis solar tracking only changes elevation angle, and two-axis solar tracking changes both azimuth and elevation angle, depending on the position of the sun.

For monitoring and recording PV power generation performance, data acquisition is available in the field. The PV generated power is time-variant under different irradiance conditions. To understand the effect of this power generation profile information at the cell, string and array levels is necessary. Enabled by the self-metering capability with solar inverters, the PV panel power data is recorded by its own converters and communicated with Ethernet gateways via wireless communications. The wireless data communication has the advantage that it avoids wiring and powering of communication devices. Also, because the solar inverter is grid-connected, the power devices are always powered by either solar panel or grid.

2.2. Energy storage system

The energy storage system in the solar test facility is a 500 kWh/250 kW Li-ion battery based on $LiFePO_4$/graphite technology which is one of the most promising technologies for long cycle life and enhanced safety for transportation and stationary applications [23]. The whole system consists in power conversion system (PCS), Li-ion battery, battery management units (BMU), fire protection system, lighting system, ventilation and air-conditioning system, and grounding system. The full ESS stack includes 7 strings in parallel and each string has 42 modules in series, each module has 4 cells in series with a capacity of 195 Ah and a nominal voltage of 3.2 V. The total calculated energy is therefore 722 kWh which is much higher than the nominal rated capacity of 500 kWh. The oversize of the battery allows protection against overcharge and over-discharge, and therefore ensures high safety and long lifetime.

The data communication is based on Modbus/CAN industry communication protocols and therefore, this system cannot support high-speed measurement of thousands of cells or specified cell-level battery parameters such as voltage and temperature. To address this technical challenge, a Time Division Multiple Measurement (TDMM) based measurement scheme (Fig. 2) is proposed. As can be seen from Fig. 2, the measurement time slot is divided into pieces to maximize measurement efficiency. In order to synchronize the time slot for each full stack measurement, the one-time interval is set as 5 min. Data

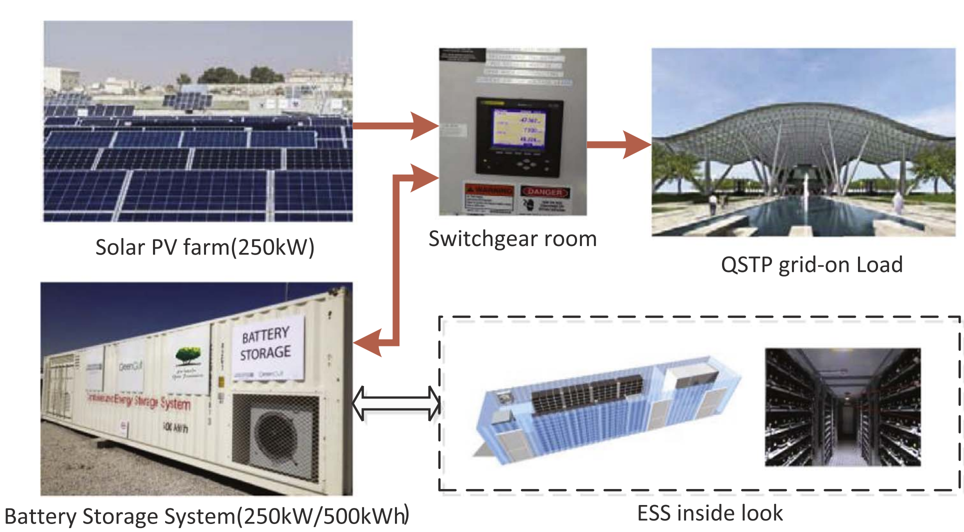

Fig. 1. layout of the hybrid solar/ESS micro-grid.