Summary Report

Project Title: Design and Operation of Utility Integrated Photovoltaic (PV) System as Supercapacitor Energy Storage.

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Summary: This research was conducted as an undergraduate design project, where two undergraduate students registered for design courses (EECE 4991 and EECE 4992) in 2020 at the University of Memphis. The goal of the project was to design and operate a grid-connected photovoltaic (PV) system as a supercapacitor energy storage (SES) during night time or intermittent cloud insolation conditions as well as during day time. Among renewable energy sources, the PV system has been considered to be the most promising due to its inherent features such as no presence of moving parts, low maintenance and operation cost, etc. Typically, a grid-connected PV system consists of a PV array/panel, a DC-DC boost converter with a maximum power point tracking (MPPT) controller, a DC-link capacitor, a battery energy storage (BES) system, an inverter, and a step-up transformer. Since at night or a cloudy day, the PV panel does not produce any real power, the BES provides power to the grid at that time. In recent years, due to its cost-effectiveness, the SES has been extensively used for dynamic performance enhancement of power grids. The SES can control both active and reactive powers quickly and simultaneously. The SES unit consists of a supercapacitor, a DC-DC buck/boost converter, a DC-link capacitor, a voltage source converter (VSC), an inverter, and a step-down transformer. However, a close similarity is found between the PV system and the SES unit in terms of their components. Except the PV panel, MPPT controller, the BES and the supercapacitor, both systems have the same type and number of components. Based on this fact, the proposed approach considers utilizing the existing PV system components as a SES unit during both night time and day time.

According to the proposed approach, a supercapacitor to be connected at the PV panel terminal through a switch will be charged during day time. At night time, the PV panel will be disconnected naturally. Consequently, the charged supercapacitor connected as the input to the DC-DC converter and the rest of the components (except the MPPT controller and BES) will constitute the SES unit that can be used for dynamic performance improvement of the grid-connected network that may have other distributed energy resources (DER) such as wind generator, diesel generator, etc., and various flexible loads. During daytime, following any disturbances like any faults in the network, the PV panel will be disconnected for a very short

time, and the SES unit will control both reactive and active powers, thereby providing both voltage and frequency support to the grid. Once the power grid stability is maintained, the PV panel will be connected to the SES system and operate properly. Thus, the proposed approach can provide a seamless and robust operation of the grid-connected PV system. Importantly, this technology will achieve significant cost savings due to use of existing PV system components as the SES unit.

For modeling and simulating the PV system alongwith the SES, the Matlab/Simulink software has been used.

Results: Simulation results obtained show the effectiveness of the proposed system to maintain voltage stability during the main grid's voltage sags and swells. In this case, it is considered that a voltage disruption in 1s intervals takes place in the main grid voltage magnitude. The proposed PV system together with the supercapacitor (SC) is termed as 'PVSC'. Figure 1 compares the performance of the proposed PVSC system and basic PV system (BPS) for voltage and frequency at voltage VSC terminal in response to this disruption. As it can be shown, the SC remains connected after the system returns to normal condition to charge the SC and gets prepared for the next event. Although in case of PVSC the frequency at VSC terminal has transients during the voltage disturbances and SC operations, the voltage is maintained properly at its nominal value guaranteeing the power quality for the local load. Moreover, it is considered that a step load disruption (both active and reactive power) occurrence at the local load causes some transients. As shown in Figure 2, since the BPS does not control the voltage and frequency, the load variation causes voltage excursions from its nominal value and a low magnitude frequency swing is observed in BPS's terminal. In contrast, the proposed PVSC damps the load variation transients by controlling voltage and frequency.

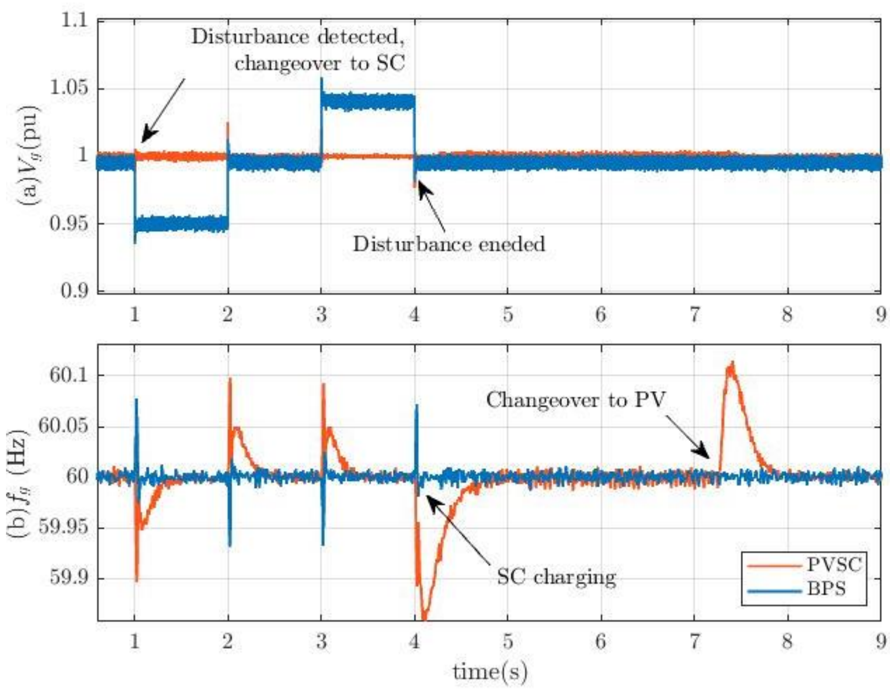

Figure 1. Performance evaluation of proposed PVSC compared to basic PV system during voltage disruption in main grid; (a) VSC output voltage, (b) VSC output frequency.

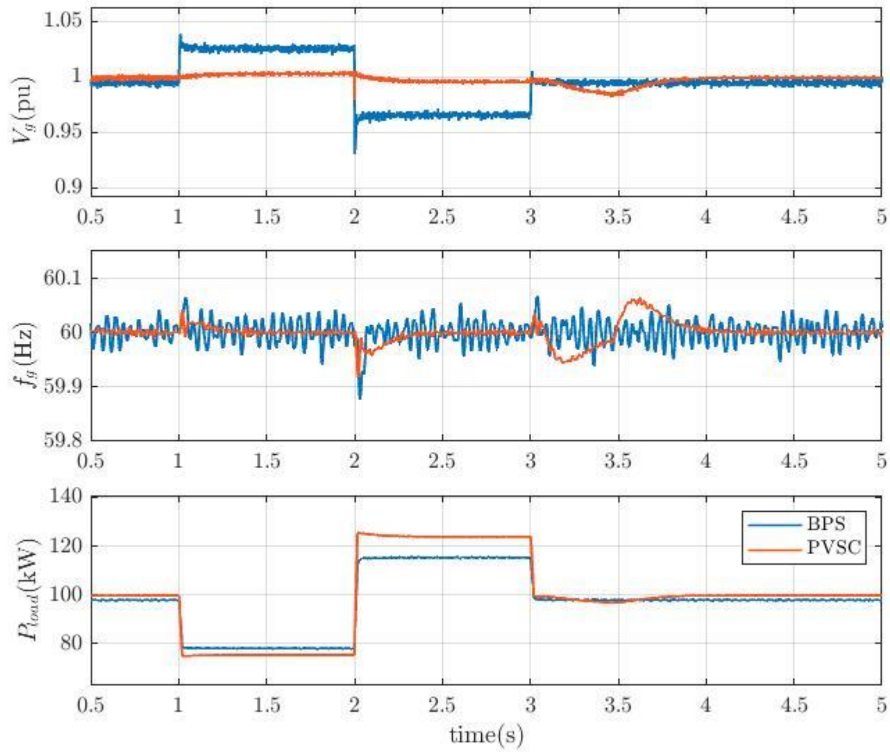

Figure 2. Stepwise load variation and weak integration to grid.

Conclusion: The proposed method is effective in improving the dynamic performance of the connected power grid system. The proposed project has a potential impact on the relevant field and application. The major advantage of this novel and unique approach is that a significant cost saving will be achieved due to use of existing PV system components as the SES unit. Moreover, no additional SES unit or any flexible ac transmission systems (FACTS) devices will be needed for connection at the grid point. The proposed project has a great relevance to solar industry, as the proposed solution can advance the widespread adoption of solar power while securely integrating it into the nation's energy grid.

Reference: M. D. Keshavarzi and M. H. Ali, "Dynamic Performance Enhancement of Power Grids by Operating Solar Photovoltaic (PV) System as Supercapacitor Energy Storage," *MDPI journal of Energies*, 2021, *14*(14), 4277.