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Hybrid AC/DC Microgrid for Solar PV and Battery Storage Integration

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Abstract: The major advantage of the DC power systems over the AC system is that it can be integrated with new as well as existing load. The variability of the system allows to integrate and implement various DC systems into various system. The renewable generation and its effective collaboration with DC systems which makes it more efficient than the conventional AC systems. AC-DC hybrid micro grid has advantages of both AC –DC system and enables user to integrate each power source with one another. In this work the performance of hybrid micro grid with PV system integrated into it for lighting system [LED] for a small industrial site is investigated. Theoretical and experimental results are used for the design of micro grid. The major part of this study involves use of Arduino based bi-directional converter for conversion from AC-DC system.

Keywords: PV integration, AC-DC micro grid, Arduino based bidirectional converter, hybrid grid.

I. Introduction

There has been a numerous growth in the sector of Electrical and Electronics, since the 18th century. The battle between AC and DC power has been a major topic of debate since decades. The feasibility of conversion of AC power to various levels with the help of transformer and other basic converters has been one of its major advantage. On the contrary the DC power has its benefit of reduced loses over long distance transmission. The integration of AC-DC system together benefits user with the advantage of both the system individually.

With increasing modern electronics, the number of DC loads like inverters, lighting circuit, battery powered circuits involve complex converters which use the dc to dc conversion to obtain voltage at various levels. This conversion level reduce the quality of power induced in the circuits as the power factor increases. Similarly in AC circuits the quality of current supplied to the circuit varies based on the converters is varied and with a lot of noise. This noise in the circuit can reduce the efficiency of the operating circuit. Thus the combined operation of the AC-DC micro grid gives the advantage of improved efficiency as a common bi directional converter is used based on Arduino which reduces the losses in the DC to DC conversion as well as the noise in the AC circuit. Using individual power sources for the operation of various systems can lead to overloading of the power source and then powder failure. To avoid such situations it’s a better option to embed various power source into the grid.

With increased efficiency and effectiveness of the renewable sources various DC sources like PV modules, wind Turbines for the AC source as well as other renewable sources can be involved into the system operations. Thus the system reliability is also increased and the system becomes more efficient. Hybrid AC-DC micro grid uses and utilized the functions and advantage of both AC as well as DC systems. The system performance can be improved by integrating a battery storage system is the objective of the work mention here.
Research earlier has shown that the cost of such microgrids can be expensive and the system can be implemented in places that are small in size. A limited amount of load can be enforced upon such systems. The major focus of this work is to involve PV based systems along with Arduino based bi-directional converter to improve efficiency and reduce cost. A diagram is presented at the end for the hybrid grid at the end mentioning all the components and size involved.

II. Hybrid Building Microgrid

A. Microgrid Topology

Dc building microgrids promise significant efficiency improvements and cost reductions, in particular if implemented together with on-site PV generation and battery storage. Despite these advantages, there are several challenges, which hinder the adoption of dc microgrids in buildings. These challenges are related to lack of standardized equipment (dc network components are missing, end use appliances are lacking dc connectivity) and little industrial experience. Our approach therefore focuses on hybrid power networks, which consist of ac and dc networks connected by a bidirectional converter.

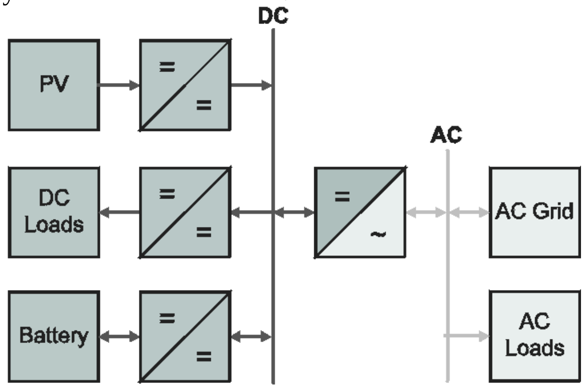

Fig.1. Hybrid ac/dc building microgrid model

Hence, both ac and dc loads can be connected. The system topology is designed as flexible as possible, in order to facilitate the successive integration of dc power technologies into existing ac systems. As illustrated in Fig. 1, PV modules are coupled to the dc network via a dc/dc maximum power point tracker (MPPT). The battery is coupled via a charge/discharge controller. A bidirectional converter connects dc and ac grid. Note that for some commercial PV applications, charge controller and bidirectional converter are integrated into a single device. Dc/dc converters supply dc loads at different voltage levels. Two dc distribution voltages may be used to supply high- and low-power loads. For example, a high (380V) and low-voltage (24V) standard for DC distribution in data centers and residential buildings is in preparation by the EMerge Alliance.

B. Performance Simulation

In previous work, we developed a model for the evaluation of dc microgrid performance compared to conventional ac distribution in residential buildings . The model uses an electric load profile representative of a single-family home with a time resolution of 10 seconds and a detailed breakdown by appliance type. We find that in the case of a PV system sized to meet annual building demand (with an installed PV power of 7.4 kWpeak), a dc microgrid reduces power conversion losses by approximately 20% without and 30% with battery storage, corresponding to 2-4% of the total electricity demand of the building. Furthermore, the effect of PV and battery storage size on system performance is evaluated. Avoided losses of the dc system increase with PV system size. The increase of avoided losses is the highest up to an installed PV power of about 10 kWpeak and a battery capacity of 10 kWh. It levels off at higher values. Further analysis presented in Fig. 2b reveals that avoided losses and autarky, i.e. the share of the total building electrical demand which is covered by PV electricity generated on-site, are close to linearly dependent. Consequently, dc networks are most efficient for buildings with a high degree of autarky.

III. Prototype Setup

A prototype dc microgrid coupling PV electricity generation to building dc loads has been setup to test the technical feasibility and to measure its efficiency relative to a conventional system. The installation allows direct coupling of a central rectifier and PV modules to building loads on a dc bus. The main appliance tested in the prototype setup is LED lighting. The lighting control uses a standard DALI (Digital Addressable Lighting Interface) interface to facilitate building integration.

Fig. 3 illustrates the main components of the prototype setup. In the reference case (Fig. 3a), a standard LED lighting installation with an ac/dc power supply (75W nominal power) and 24V LED strips is tested. The light intensity is controlled with PWM dimmers. In the dc system (Fig. 3b), a central rectifier supplies multiple channels at 24 Vdc (95W nominal power). The output of the PV modules is coupled to the 24 Vdc bus via an MPPT. Compared to the ac system, two converter stages for the use of PV generated electricity can be avoided. A wireless control and monitoring interface enables LED dimming and measurement of dc power consumption. An additional data logger measures ac power consumption in 5 second intervals. In both cases, ac and dc system, the dimmers enable connection to most LED types (at constant voltage and constant current) for broad building implementation.

Experimental results showed that, depending on the dimming level and the amount of supplied dc power, the efficiency of ac/dc conversion is 4-8% higher for the central rectifier used in the dc system compared to the ac/dc power supply of the reference system. Depending on the type of electricity supply (ac power grid or PV), overall system efficiencies at full load of approximately 82-86% for the reference and 90-96% for the dc system are expected. System efficiency at full and partial loads will be further investigated in future measurements. In addition to LED lighting, other dc loads such as variable speed motors, can be powered from the 24 Vdc bus. System performance under these load conditions will be analysed.

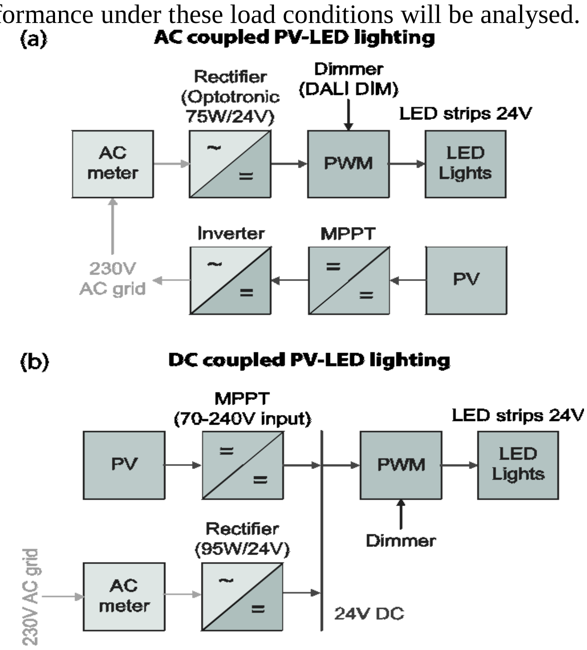

Fig. 3. Main components and power flows from PV supply to LED lighting in the reference ac system (a) and the dc prototype (b).

A limitation of the experimental implementation as shown in Fig. 3b, is that only a mono-directional converter from ac to dc could be used. Therefore, oversupply from PV modules cannot be transmitted to the ac grid.

IV. Building Integration

The results of the model and the experimental prototype are used for the design of a hybrid ac/dc network which will be implemented at the HiLo unit (www.hilo.arch.ethz.ch) in the modular building NEST at EMPA (www.nest.empa.ch). HiLo is a two bedroom apartment which features several innovations in the domains of lightweight construction and smart adaptive building systems [11]. The energy concept of HiLo targets net-plus energy in operation. This is achieved using efficient heating, cooling and ventilation systems together with thin-film CIGS (copper indium gallium selenide) PV modules on the roof and façade. Non-uniform irradiance of PV modules due to curvature of the HiLo roof can lead to electrical mismatch losses. One approach to mitigate these losses are power optimizers, i.e. dc/dc converters for distributed maximum power point tracking at the subarray level.

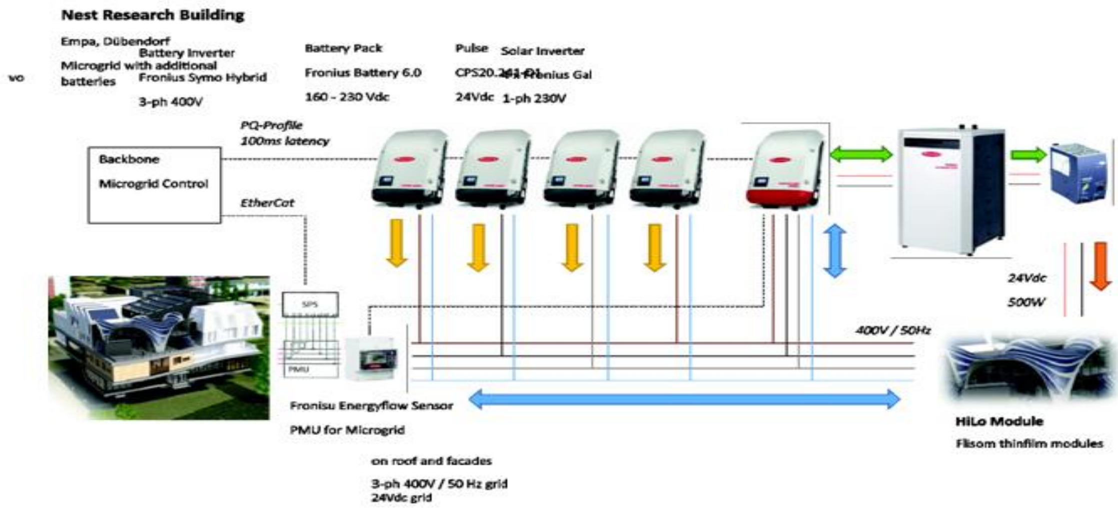

Fig. 4. PV system with hybrid ac/dc microgrid planned to be implemented at the NEST/HiLo building

A schematic of the hybrid ac/dc microgrid planned to be implemented together with the PV system of the NEST/HiLo building is shown in Fig. 4. Due to the use of thin-film PV modules, galvanic isolation of the inverter is required. Therefore the range of possible commercial products is limited. The proposed system consists of four single-phase inverters and one three-phase bidirectional inverter/charger. The inverter/charger enables multiple and parallel energy flows between PV, battery, and ac grid. One possible operation mode is charging the battery from the ac power grid or a local ac source, such as a micro-CHP (combined heat and power) or wind generator. The latter operation mode is important for cost optimal control of the battery at variable electricity tariffs as well as for the provision of ancillary grid services. It is also important if the battery should be used for emergency supply in case of power outage. The battery of HiLo consists of several LFP (lithium iron phosphate) modules stacked in series. An elevated battery voltage is beneficial in terms of system efficiency. A dc/dc converter connects the battery and a 24 Vdc network, supplying LED lighting and electronic appliances in the HiLo building. An additional dc/dc converter can be installed to connect dc loads at higher voltage.

V. Conclusions

This paper presented research on hybrid ac/dc microgrids for improved integration of PV and battery storage in buildings. Simulation results showed that power conversion losses can be reduced by 20-30% for residential buildings with a net-zero energy balance. The benefits of hybrid microgrids may be even larger for commercial and office buildings with integrated PV, due to a higher share of dc internal loads and increased self-consumption of PV electricity. PV and battery size are important parameters for the evaluation of hybrid microgrid performance. We find that dc networks are most efficient for buildings with a high degree of autarky enabled by a high share of dc renewable sources. Initial results of an experimental prototype indicate that dc microgrid coupling of PV and LED lighting leads to significant efficiency improvements compared to a conventional system. Finally, the current design of a hybrid microgrid implemented with a PV system at the NEST HiLo building has been presented. HiLo will provide several years operational phase research.

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