RENEWABLE SOURCES BASED DC MICROGRID: DESIGN, OPERATION, ANALYSIS AND APPLICATION

ABSTRACT

A microgrid can consist of several power generators (renewable and/or non-renewable), possibly with an energy storage system. The microgrid can work independently or in-conjunction with utility grid. Hence, it can be configured in two modes: (i) AC microgrid, (ii) DC microgrid. However, DC microgrid can be more advantageous in being more energy efficient and less complex, due involvement of lesser number of power conversion stages.

Present study deals with the design, analysis and application of renewable generators based DC microgrid for low voltage load applications. Solar photovoltaic (SPV) system is used as primary power generator to cater the load demand while fuel cell (FC) and battery bank function as auxiliary power source.

A feasibility study considering techno-economic is conducted for the system component sizing (power rating of generators and energy storage mediums) according to a given load requirement. In this study, battery and hydrogen storages are used as energy storage mediums. Lead-acid and lithium-ion are considered for battery storages, while high-pressure cylinder and solid (metal hydride) storages are considered for hydrogen storage. Techno-economic analysis shows that battery storage is more cost-effective compared to hydrogen storage in the present microgrid. The levelized cost of electricity is found to be 0.144 $/kWh and 1.61 $/kWh for battery storage (lithium-ion) and hydrogen storage (metal hydride), respectively. However, high-pressure hydrogen storage is more economical as compared to solid hydrogen storage for the microgrid application.

Based on the feasibility analysis of the proposed DC microgrid system, a hardware implementation of the proposed system has been done. In hardware realization of DC microgrid, different voltage levels are selected for the microgrid according to the available DC load voltages. Design and analysis of different voltage levels 24, 48 and 110 V DC microgrids is performed to evaluate the most appropriate voltage level for DC system in terms of voltage regulation, efficiency, losses and cable size. For creating different voltage levels DC buses using the

renewable sources, suitable DC-DC converters (24/48/110 V output voltages) are designed using appropriate topologies. The converters can use a wide range of DC voltage at the input allowing the use of PV generator, battery storage system and FC, each of which has a different voltage characteristics for the operating load. The performance of the DC-DC converters has been studied using all these sources and found to be commensurate with the design. The 24/48 V DC-DC converter efficiency is found to be ≈ 87%. A higher converter efficiency (≈ 95.7%) is found for 110 V DC-DC converter which is obviously due to a lower current required for the given load.

The energy efficiency of the DC system can be enhanced using the power semiconductor devices based on wide band gap semiconductors like silicon carbide in the DC-DC converter. A comparative study between the usage of insulated gate bipolar transistor, silicon and silicon carbide devices in the DC-DC converter has provided the data for a detailed analysis of the power losses for different devices. It is found that the DC/DC converter efficiency is increased by ≈ 2% with the use of silicon carbide device.

A control strategy for integration of PV-FC-battery system is also proposed which addresses the issues related to the integration of system components, stability of DC bus voltage, demand-supply balance, and load dynamics involved in the system. The proposed control strategy shows that integration of the PV, FC and battery is suitable to meet the load demand in the transient operating conditions such as low and high PV power generation; and abrupt increase and decrease in the load demand.

A 110 V DC system can be very suitable in the Railways with most of the lighting and electric fans operating at 110V. The efforts being made by Indian Railways to use roof mounted SPV modules can then be supported by this study of an 110V DC microgrid operating such loads. 24/48 V DC system have been used in the country for solar homes etc. and also for off-grid sensor load applications. The design and implementation of such a system for a practical load demand provides a complete insight into the SPV based microgrid.