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LOW-VOLTAGE DC MICROGRID SYSTEM FOR RURAL ELECTRIFICATION

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ABSTRACT

This paper discusses the current state of DC distribution systems, how it can be beneficial to isolate solar-based Micro-Grid (MG) systems in rural areas, and how the priority-based approach can help the MGs to operate in cost-effective and reliable ways. DC distribution system holds many advantages over AC systems in such areas, where the load demand is not so high and the electricity supply through grid extension is not feasible. A direct load control-based approach can ensure a continuous supply of power to the loads with various priorities. In this paper, an experimental analysis of the DC MGs has been presented with the help of priority-based algorithms.

Keywords: Demand Side Management, Distributed generation, Energy Resource, SCADA

1. INTRODUCTION

With the increasing integration of distributed renewable energy resources (RESs) like wind turbines and photovoltaic (PV) arrays to the grid, the trend moves away from the large centralized to distributed power generation. However, due to the intermittent characteristic of renewable energy, energy storage devices such as batteries are usually used to buffer the weather-dependent unstable power generation. Microgrids have emerged as a promising way of organizing and coordinating the operation of distributed energy resources (DER). The organization of DERs into a microgrid before connecting to the existing grid has several advantages. First, using different energy sources can mitigate the uncertainties of renewable energy, e.g., wind and solar energy are complementary with each other. Second, the power management within a microgrid makes it a better power generation profile than a standalone renewable energy system. To manage power flow in the micro grid as well as the energy sources, power converters are desired to absorb the surplus power generated by RESs or supply deficient power to the micro grid. Generally, there are mainly two ways to integrate multiple energy sources into the grid. One is to use multiple converters, e.g., an independent converter for each source; the other is to use an integrated converter with the capability of interfacing multiple sources, namely a multiport converter. Compared to the former method, using a multiport converter can achieve a more compact structure and higher power density since some components can be shared. Besides, it does not require board-to-board communications, and a centralized controller can manage power flow. Therefore, the latter solution is preferable. Most of the existing multiport converters that interface an energy source, battery, and the load (or DC-link) are three-port. A lot of multiport DC-DC converters with different topologies reported, including interleaved buck-boost and boost topologies, dual active bridge, full bridges, Z-source converter, the

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three-phase structure, and LLC resonant configuration. However, these multiport converters cannot be directly used for interfacing more than three sources, and an extra port needs to be extended. In addition, the majority of three-port converters (TPCs) cannot be simply extended for four-port applications; only a few four-port topologies can be derived from the TPC without adding too many components. Moreover, in most of the bidirectional TPCs, only the battery has the bidirectional port, and the battery can be charged by the RES only. Compared to the TPC, less research work has been done for the four-port bidirectional converter. Many papers contribute to the design of four-port bidirectional converters to connect storage. The bidirectional port in most of the existing four-port converters is only designed for the battery, i.e., the battery is charged by the RES and discharged to the DC-link. Furthermore, the polarity of the battery current is changed within a switching period, e.g., the current is fluctuated at a high frequency. Such a high-frequency charge/discharge hurts the battery lifetime. Due to the lack of a bidirectional port at the DC-Link, the energy in the microgrid cannot be stored in the battery. The 'use or waste' issue cannot be solved when the micro grid works in the island mode. Therefore, these four-port converters are suitable for standalone applications, e.g., satellite applications, electric vehicles, PV-battery systems, and hybrid renewable energy systems. When the micro grid works in the island mode, both the battery and DC-link are desired to be bidirectional ports to solve the 'use or waste' issue at the system level. Some units generate more renewable energy and their battery are fully charged, while some units generate less power and the state of the charge (SOC) of the battery is low. The surplus power in the micro grid can then be stored in the battery with the reversed power flow.

2. PROBLEM STATEMENT:

This research put up an idea to shed the loads in terms of priorities. For a healthy operation, the proposed method traces the working pattern of each appliance in each household. The individual smart controller is adjusted for the consumption characteristics of the appliances, which might spread over a few hours. In this context, this paper presents a framework to control and operate the rural DC-MGs via a priority-based concept.

A significant portion of the global rural population. In developing countries, still a lack of access to reliable and affordable electricity. Conventional grid infrastructure in remote and sparsely populated areas is often not economical. Moreover, traditional AC-based,systems complex and inefficient for low-demand Settings where power requirements are minimal.

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3. PROPOSED METHOD

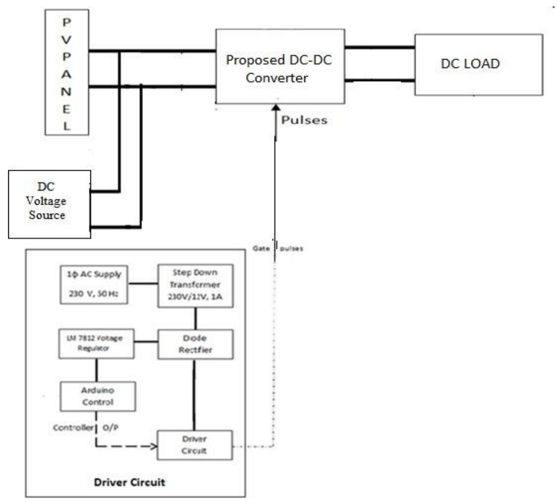

Figure 1: Block diagram

In this the PV panel and dc voltage source is providing power which is provided to the load so that the panel directly powers the load and when the irradiation reduces and the panel power generation is reduced below the required level, the dc voltage source such as battery starts supplying the load and the control is transferred to second dc-dc converter. During the unavailability time period of solar and the battery starts to discharge i.e provides energy to dc link.

On the other side, priority-based logic has been implemented in the demand side to maximize the distribution of the electricity supply. The conventional DSM techniques like peak clipping, valley filling, load shifting etc. are theoretically effective, but the grid operating system fails to control the system effectively, since these techniques mainly depend on the consumer's actions. Hence, the system needs to go for load shedding mode; cutting off supplies to certain parts of the loads. In such cases, the priority-based DSM techniques can be applied. In this study, loads of each household has been divided into essential and non-essential categories.

4. WORKING MODEL

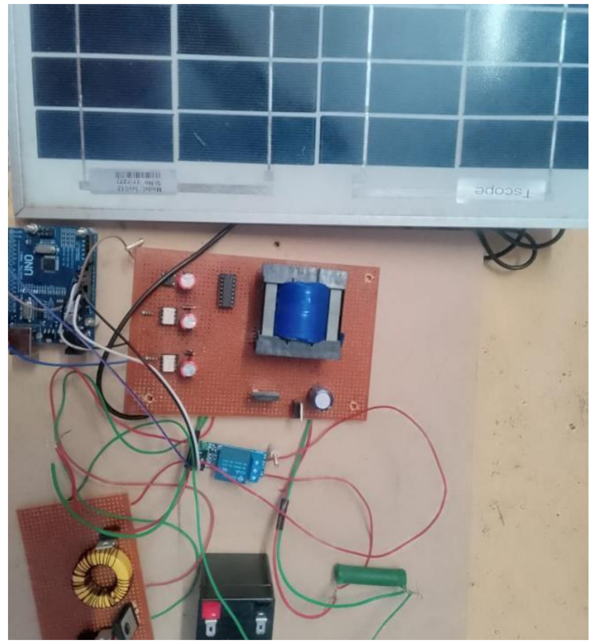

Fig.2 Hardware model

DC-MG may consist of multiple energy sources like solar, wind, biomass, battery etc., and one may hold higher preference over others due to the factors like price and reliability. In such a case, there is a need for a logic that can draw power from multiple energy sources according to the level of preference. Priority-based parallel operation of boost converter may be a suitable one to perform required operation in such situations. In priority-based parallel operation of boost converters, the sources are divided into different priorities according to the demand. The converters are connected in parallel. The converters with lower priority act as an extension of the converter with preceding higher priority. To implement the strategy, all of the converters are controlled with a single regulator. As discussed in Section 2.1, a change in the duty cycle is required to balance the system's voltage level. If the required duty cycle is more than the upper limit for the first converter, the controller

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starts giving additional pulse to the next controller. Similarly, if the power requirement decreases, the duty cycle starts to decrease from the lowest priority converter.

5. RESULT

As the system faces fluctuations in both the demand and supply sides, the supply side is considered to have two different sources: solar (Source A) and battery (Source B). The sources are connected so that the solar generation holds higher priority and the battery is used as a backup. To test the system in realistic conditions, the sample for the demand of a scale-downed load at the rural community has been taken, and the loads are divided into three categories depending upon their level of necessity, as in these loads are provided with different levels of priorities in the power system. The main objective of the proposed algorithm is to ensure the continuous supply to the essential loads while increasing the demand from the non-essential loads. For this, loads are operated in such a manner that each of the loads will be cut off automatically after crossing the threshold value of the battery assigned to each load. The threshold value for each load is dynamic and changes every day as per a piece of information obtained from the optimization processes of the available power and energy.

6. CONCLUSION

This paper aimed to present a new approach to designing PV/wind microgrid considering load uncertainty for the city of Yanbu, Saudi Arabia. In the developed approach, four primary methods are combined to form the MOEA/D, which is capable of providing a wide range of solutions. At first, each of the basic approaches has been run separately, then the proposed method (by combining all four basic approaches) has been run to show its superiority. To establish the robustness of the approach, two case studies, consisting of 5 houses and 10 houses, were investigated. The uncertainty of the load has been modelled using a stochastic method. The obtained Pareto front or the set of solutions exploited by the designer/engineer to select the best solution, considering other constraints that are not feasible to model mathematically.

Furthermore, this work can help researchers by using the proposed method for their own microgrid design process. It can also be as a reference for comparing their results to the ones obtained in this paper in order to design more efficient algorithms. As part of future work, the effects of the loss of one of the primary sources of energy and the associated recovery strategies can be investigated. Another perspective is to study the effect of the ageing of equipment on the overall performance of the microgrid.

7. FUTURE SCOPE

- Integration Smart Energy Management Systems.
- Future microgrids can incorporate intelligent control systems for real-time monitoring, load forecasting, and automated energy distribution, improving efficiency and reliability.
- Hybrid Renewable Energy Sources.
  Combining solar with other renewable sources like wind or micro-hydro can enhance energy availability and grid stability, especially in regions with variable weather conditions.
- Development:DC-Compatible Appliances.
  Expansion of the market for efficient, affordable DC appliances (TVs, refrigerators, pumps) will make DC microgrids more practical and attractive for end users.
- Advanced technologies Innovations in energy storage—such as lithium-ion, flow batteries, and supercapacitors—can increase system lifespan, reduce maintenance, and improve energy reliability.
- Scalability,Community-Level Expansion.
  Modular DC microgrids can be scaled to support schools, clinics, and small enterprises, promoting broader community development and economic growth.
- Policy and Business Model Innovation new models (like pay-as-you-go) and supportive government policies can accelerate adoption and make microgrid solutions sustainable and inclusive.
- Integration with National Grid
  In the long term, DC microgrids can be designed to integrate with the main grid, enabling energy trade and grid resilience through distributed generation.

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