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A review of technical challenges in planning and operation of remote area power supply systems

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ABSTRACT

Remote area power supply (RAPS) systems are being used for many years to supply power to rural or remote communities where the utility grid is not accessible. In order to avoid the high operating cost and environmental impact caused by conventional generators, renewable energy resources are currently being utilised in RAPS systems. However, the intermittency of such renewable energy resources greatly impacts on planning and operation of RAPS systems. This paper aims to present a comprehensive review with regard to the RAPS system planning and operation techniques published in the literature. This paper summarises different modelling approaches associated with the RAPS system architectures, pre-feasibility studies for energy potential analysis, component modelling, unit size optimisation approaches, and system control aspects. In addition, technical challenges associated with RAPS systems, such as system sizing, voltage and frequency control and coordination of different system components are also highlighted in the paper. Moreover, further research avenues with regard to various different aspects of RAPS systems are also delineated in the paper.

Contents

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1. Introduction

Remote area power supply (RAPS) system is a standalone power system that usually supplies power to small rural or remote communities. These communities do not have access to the utility grid, and it is technically and economically infeasible to extend the utility grid to remote regions. According to the International Energy Agency report, 1.3 billion people worldwide do not have access to electricity [1]. RAPS systems are considered to be a feasible option for electrification and highly promoted by the Energy Access Practitioner Network launched by the United Nations Foundation to ensure universal access to modern energy service [2]. Conventional generators such as diesel generator sets are widely being used in RAPS systems. However, due to the decreasing fossil fuel reserves, increasing fuel prices, as well as environmental issues, renewable energy resources are becoming more popular in RAPS systems.

The RAPS system can be defined as a small electricity network which serves a single property owner with very simple loads or several communities with complex and interconnected power stations [3]. However, different terminologies have been used in the literature to define RAPS systems, such as ‘standalone power systems’ [4], ‘off-grid power systems’ [5], ‘isolated power systems’ [6], ‘electrification power systems’ [7], ‘household power system’ [8], ‘mini-grids’ [9], ‘autonomous power systems’ [10], and in certain cases it is defined as a ‘microgrid’ [5,11]. The typical feature of a RAPS system is being isolated from the main utility grid. The generators in a RAPS system supply power to a cluster of loads, and the system balances generation and demand autonomously. From this perspective, the terms like ‘standalone power systems’, ‘off-grid power systems’, and ‘isolated power systems’ are used due to the fact that RAPS systems are isolated from the main grid, whereas the term ‘electrification power system’ is used due to the fact that RAPS system are used for the rural electrification schemes. As defined in [12], mini-grids are centralised generation systems to provide electricity to small towns or large villages. Therefore, mini-grid is also another form of a RAPS system with a higher capacity. Similarly, ‘household power system’ is a kind of RAPS system with smaller capacity serving a single residential user. The ‘autonomous power systems’ are also designed for electrification of regions without large transmission networks. Their capacity can be ranging from a few hundred Watts to tens or hundreds of mega-Watts [13]. It can be seen that the definition of autonomous power systems is also similar to that of the RAPS system.

The Consortium for Electric Reliability Technology Solutions explored the potential of generation by locally available smaller distributed energy resources (DER) to meet customers' needs with the emphasis on reliability and power quality, and developed the concept of ‘Microgrid’, i.e. an aggregation of load and micro-sources operating as a single system providing both power and heat and presenting itself to the bulk power system as a single controlled unit [14]. Microgrids can operate in two modes: grid-connected mode, and islanded mode. Contrarily, RAPS systems always operate in standalone mode and do not inject or absorb any energy from the utility grid. Additionally, energy storage devices are commonly used in both microgrid and the RAPS system to mitigate the impact of fluctuation of non-dispatchable energy resources and improve system reliability, and utility grid can also be regarded as a storage system with an infinite capacity. Hence, storage devices may have relatively smaller capacity compared to the RAPS system of comparable size [15]. In microgrids, advanced communication infrastructures are usually applied to realise centralised control schemes [16,17], which can be costly and impractical for RAPS systems considering the budget limitation as well as geographical constraints. As the microgrids are connected to the utility grid, certain power quality requirements such as voltage, frequency and harmonic emission must be maintained according to the utility grid-code standards at the point of common coupling (PCC). However, RAPS systems are not obliged to maintain such rigorous grid-code standards [15,18]. Moreover, voltage and frequency at the PCC is commonly used as the reference for the microgrid, whereas a RAPS system has to establish its own voltage and frequency references. Therefore, it is inappropriate to use the same terminology to represent both the RAPS system and the microgrid. The aforementioned differences between microgrids and RAPS systems are summarised in Table 1.

Nevertheless, microgrids and RAPS systems share some similarities. For example, in microgrids and RAPS systems, both conventional energy resources and renewable energy resources with smaller capacity are utilised. Energy resources are located at close proximity to the end-user and system voltages are at the low voltage level, so tie-lines are usually resistive rather than inductive as in the high voltage systems [19]. Therefore, some control strategies used in islanded microgrids can be readily applicable to RAPS systems and vice versa.

RAPS systems are becoming increasingly popular as a rural electrification option; hence it is a timely requirement to review the planning and operation techniques feasible for RAPS systems. Therefore, the main emphasis of this paper is to present a review on various planning and operational techniques, such as system architecture, renewable generator sizing and control techniques associated with RAPS systems. Ultimately, this will enable RAPS

Table 1
A comparison between RAPS systems and microgrids.

Items	Microgrids	RAPS systems
Utility grid availability	Yes	No
Energy storage devices	Storage systems and grid	Storage systems
Communication infrastructure	Costly advanced techniques	No or normal techniques
Performance requirement	Specific utility grid standards	Flexible
Voltage and frequency reference	Yield from PCC	Self-established