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Voltage Regulation Planning Based on Optimal Grid-Connected Renewable Energy Allocation Using Nature-Inspired Algorithms to Reduce Switching Cycles of On-Load Tap Changing Transformer

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CONTENTS

Keywords: optimal voltage regulation, renewable energy resources, on-load tap changer, multi-objective optimization, genetic algorithm, Cuckoo Search Algorithm

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Abstract—Due to the non-deterministic and probabilistic qualities of renewable energy resources (RER), integrating these resources has posed a challenge for energy companies and government policy planners. Hybrid power systems require frequent voltage regulation to address the changes in renewable generation and facilitate voltage management. This leads to an increment in the operating time of the tap changer in the power transformer, thus resulting in accelerated degradation of the on-load tap changer (OLTC) device. The primary focus of this paper is to optimally manage the penetration level of renewable generation while maintaining the minimum time for proper operation of voltage regulation devices. Accordingly, the major contribution of this paper is to address the switching cycle issues of the on-load tap-changing transformer. Initially, a framework is proposed to optimize the location and size of renewable power generation using a multi-objective cuckoo search optimization algorithm. The main goal here is to reduce power losses and tap changer operations while improving the system voltage profile under different levels of renewable energy penetration. The optimization problem takes into consideration the fluctuating nature of wind speed and solar irradiance for sunny and cloudy days over 24 h. The framework has been applied to the IEEE 57-bus and 118-bus systems with different load levels. The performance of the proposed approach has been benchmarked by comparing it with the genetic optimization algorithm to identify the higher potential buses for renewable generation allocation. The cuckoo search algorithm (CSA) shows outstanding results in reducing the number of switching cycles to about (37 – 43) % whereas the genetic algorithm (GA) only (17 – 18). In this sense, the number of changes in tap position when using the CSA is 1956 for sunny days and 1763 for cloudy days compared to GA 2558 for sunny days and 2547 for cloudy days. The voltage profiles for both algorithms are maintained in the range of (1.06 and 0.94) per unit. The results affirm the effectiveness of the proposed approach in determining the optimal placement and size of RER with voltage profile improvement and reduction in the switching cycles of OLTC.

1. INTRODUCTION

The depletion and environmental concerns raised by conventional energy resources in recent years have resulted in the development and integration of RER into the existing power grid. An optimal approach for locating and sizing these units is critical for both system planning and growth efforts. The adaptation strategies of RER have gained attention more precisely when renewable generation systems engage in voltage regulation. The implications involve boosting the share of renewable energy in the supply mix and generation to fulfill the increase in load while delaying expenditures and decreasing power system losses [1]. The ensuing improvements often include enhanced capacity for hosting RER on transmission networks, decreased energy consumption of constant-impedance loads, and reduced transmission network voltage variations. The role of RER in voltage regulation could be regarded in several ways, for instance, engagement of RER in voltage control can indeed be utilized to minimize the load on the power grid. It is achieved by keeping the bus voltage magnitude level as close as feasible to the voltage limit. From the technical standpoint, the continuous changes in renewable generation outputs have a detrimental effect on the lifespan of on-load tap changers. Many types of voltage regulators are used to normalize node voltage in the current power grid. These devices include but are not limited to, OLTC, shunt capacitors, and induction generators that are used to provide the required reactive power. In most distribution feeders, the voltage regulators are controlled based on local signals. In this conventional control method, all devices operate autonomously in a non-coordinated manner and at the unity power factor of renewable generation, thus, impacting the operations of OLTC and leading to wear and tear of the tap changer due to the fluctuation of RER. The study in [2] presents different scenarios for significant power injection by RER, it was found that under certain operational conditions, the voltage regulator failed to control voltage at the buses and reached the lowest or highest tap limits. Such a phenomenon is widely known as reverse power tap changer runaway conditions. This highlights the fact that when renewable resources are incorporated into voltage regulation schemes, coordination challenges with the voltage regulators in the existing system may arise. Therefore, in some grid-connected renewable generation systems, distributed generation units are typically not authorized to engage in voltage regulation systems; instead, they are run at a set power factor and classified as a negative load [3].

1.1. General Context and Motivation

Renewable generation needs to be placed at optimal locations in the electrical networks to reduce the consumption of fossil fuels. Given the expense of voltage regulation devices, coordinating the penetration of renewable generation units, and maximizing their placement can optimize resources both technically and economically such as installation and maintenance costs of regulating devices. Pollution from fossil fuels (known as a key greenhouse gas) remains a major issue worldwide which led many countries including Malaysia to sign the Paris Climate Agreement. The Malaysian government is no stranger to this concern and started a rapid transformation toward the maximum utilization of RER. In this respect, the Energy Commission of Malaysia agreed to build large-scale solar power plants in Peninsular Malaysia and Sabah/Labuan with a total capacity of 460 MW connected to the national power grid [4].

The standard autonomous tap control of OLTC provides a steady voltage on the transformer's secondary side depending on local busbar voltage readings, line-drop compensation, or remote voltage information. Since OLTCs are often constructed with a power dissipation along the feeder, a voltage spike induced by reverse power draw during non-peak hours and high photovoltaic (PV) feed-in can create over-voltages. Furthermore, when the PV penetration level increases, high-frequency solar ramping caused by fast-moving clouds result in excessive tap changer operations. It is worth noting that the change in the network topology impacts the placements of RER, which have been previously determined based on using limited factors such as power loss or voltage tolerance indices. Therefore, optimization of the placement and size of RER can result in both, the maximization of renewable generation benefits and the minimization of potential problems associated with renewable energy penetration. In this context, penetration of renewable generation is usually represented as an optimization problem with constraints and can be solved using a variety of analytical and heuristic methods. Owing to the fact that the majority of formulations involve both discrete and continuous sizing factors, heuristic approaches are gaining popularity in favor of analytical solutions.

1.2. Literature Survey

Optimal integration of renewable resources can result in multiple gains for services, users, and investors, whereas unplanned allocations of these resources might result in counterproductive solutions. Various research studies have