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Placement of Remote-Controlled Switches to Enhance Distribution System Restoration Capability

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***Abstract*—A smart distribution system should restore service to interrupted customers as quickly as possible after an outage. Upgrading manual switches to remote-controlled switches (RCSs) enhances restoration capability. The placement of RCSs should consider both functional and economic requirements. This paper presents a systematic method to determine the set of switches to be upgraded for an existing distribution system. The maximum restoration capability is achieved by upgrading a near-minimum number of manual switches to RCSs. The RCS placement problem is formulated as a weighed set cover (WSC) problem. A greedy algorithm with a polynomial-time computational efficiency is designed to generate a near-optimal solution for the WSC problem. A 3-feeder 9-node test system and a 4-feeder 1069-node unbalanced test system with microgrids are used to validate the effectiveness of the proposed method.**

***Index Terms*—Distribution automation (DA), reliability, remote-controlled switch, self-healing, service restoration.**

I. INTRODUCTION

DISTRIBUTION system reliability is essential for both customers and utilities. The U.S. Department of Energy (DOE), in collaboration with the power industry, has implemented 99 Smart Grid Investment Grant (SGIG) projects since 2009, 48 out of which are intended to improve distribution system reliability [1]. Generally, reliability can be enhanced by reducing failure rates of individual devices, shortening restoration and repair time, and reducing outage management costs [2]. This paper is concerned with enhancement of restoration capability through distribution automation (DA). Remote monitoring enables near-real-time detection of disturbances, while remote control enables efficient implementation of feeder restoration commands [3].

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Distribution system restoration (DSR) is aimed at restoring the maximum amount of load by a sequence of switching operations after the isolation of a fault [4]. An efficient DSR strategy significantly reduces the customer interruption duration and enhances reliability [5]. The time to implement a DSR plan depends on the number of switching operations and the time to implement switching actions.

A remote-controlled switch (RCS) can be operated by a distribution system operator in the distribution operating center, which is much faster than operating a manual switch by field crew. Therefore, installing RCSs enhances restoration capability. In practice, the placement of RCSs must take into account functional requirements and the cost benefit. It can be formulated as a single/multiple-objective optimization problem [6]–[12]. Since RCS placement is an investment decision, minimizing the total cost, i.e., the sum of RCS-investment cost and customer interruption cost, is used as the objective in some studies [6], [7]. Algorithms proposed in these studies include optimization with decomposition [7], analytic hierarchical process (AHP) [8], and heuristic techniques, such as particle swarm optimization (PSO) [9], [10], genetic algorithm (GA) [11], and immune algorithm (IA) [6].

The RCS placement problem can be formulated for two scenarios. One assumes that the topology of the distribution system is given but there is no switch in the system. This is the case for planning of a new distribution network. RCSs can be located anywhere in the distribution network, and their status, i.e., open or closed, is determined based on system requirements [12]. The other scenario is for enhancement of an existing distribution system. A number of manual switches are upgraded to RCSs to meet desired objectives [7]. This paper is focused on the latter scenario.

The RCS placement plan is associated with the fault scenarios of interest as well as the DSR strategy for each fault scenario. In this paper, the universe of single fault scenarios are considered. DSR strategies determine the utilization patterns of switches in service restoration and consequently affect the placement of RCSs. For example, the DSR strategy in [8] is to open a normally closed sectionalizing switch and close a normally open tie switch to pick up interrupted load. So switches are upgraded in pairs, i.e., a sectionalizing switch and a tie switch.

Various algorithms have been proposed for development of efficient DSR strategies, including expert system approach [13], fuzzy evaluation [14], mixed-integer programming [15],