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Coordinated control of automated devices and photovoltaic generators for voltage rise mitigation in power distribution circuits

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ABSTRACT

A coordinating, model-centric control strategy for mitigating voltage rise problems due to photovoltaic (PV) penetration into power distribution circuits is presented. The coordinating control objective is to maintain an optimum circuit voltage distribution and voltage schedule, where the optimum circuit operation is determined without PV generation on the circuit. In determining the optimum circuit voltage distribution and voltage schedule, the control strategy schedules utility controls, such as switched capacitor banks and voltage regulators, separate from PV inverter controls. Optimization addresses minimizing circuit losses and motion of utility controls. The coordinating control action provides control set-points to the PV inverters that are a function of the circuit loading or time-of-day and also the location of the PV inverter. Three PV penetration scenarios are considered, 10%, 20%, and 30%. Baselines with and without coordinating controls for circuit performance without PV generation are established, and these baselines are compared against the three PV penetration scenarios with and without coordinating control. Simulation results are compared and differences in voltage variations and circuit losses are considered along with differences in utility control motion. Results show that the coordinating control can solve the voltage rise problem while minimizing circuit losses and reducing utility control motion. The coordinating control will work with existing PV inverter controls that accept control set-points without having to modify the inverter controls.

1. Introduction

Photovoltaic (PV) power generation is a rapidly growing renewable energy source, and is regarded as an appealing alternative to conventional power generated from fossil fuel. This has led to efforts to increase PV generation levels in the U.S. [1]. Although the integration of PV brings many advantages, high penetration of PV provides challenges in power system operations, mainly due to its uncertain and intermittent nature.

Among the various technical challenges under high PV penetration, voltage rise problems caused by reverse power flows are one of the foremost concerns [2]. The voltage rises due to the PV generation. Furthermore, the need to limit the voltage rise problem limits PV generators from injecting more active power into the distribution network. This can be one of the obstacles to high penetration of PVs into circuits.

Voltage control of PVs is studied in Refs. [3,4]. These papers demonstrate the voltage control capability of the PV. PVs can use both active and reactive power injection for control. Based on this capability, many PV control strategies are presented in Refs. [5–13]. In Refs. [5–7], the reactive power injection of the PV is used to reduce voltage deviations caused by large PV penetrations. The control strategy minimizes circuit losses while maintaining the voltage within limits in Refs. [8–11]. An active curtailment strategy to reduce PV power injection is used to prevent voltage violations in Refs. [12,13].

It is important to coordinate PV control with other controllable, automated devices, such as capacitor banks and voltage regulators. Optimal control of the automated devices is able to not only reduce circuit loss, but also improve the voltage profile [14–16]. In these papers, different automated devices are coordinated to find optimal dispatch schedules.

This paper introduces a control algorithm for maintaining the average customer voltage profile obtained before introducing the PV into the circuit. The control of automated devices, such as voltage regulators and switched capacitor banks, defines the optimal operating point or schedule by minimizing the circuit loss

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while simultaneously reducing the motion of the automated devices without considering the PV. Then, the PV is controlled to maintain this operating point by controlling the active and reactive power. This is implemented with a centralized control algorithm which provides set-points to both the automated devices and PVs that need to be adjusted [17,18].

To evaluate the performance of the control algorithm, three penetration scenarios are considered, 10%, 20%, and 30% PV penetration into the distribution circuit. First, system effects due to the addition of PV are analyzed without the proposed coordinated control. Then, these effects are compared with those of using the coordinated control to show the effectiveness of the control.

The paper is organized as follows. Section 2 presents the control strategy of the automated devices and the PV. In Section 3 the system effects due to the addition of large PV are analyzed for baseline conditions. In Section 4 the proposed control is analyzed. Its effectiveness is shown by comparing the results with the baseline conditions of Section 3. Finally, findings of the study are summarized in Section 5.

2. Control strategy

The main objective of the control is to maintain the optimum operating profiles of the circuit established by automated devices without PV generation. Automated devices considered here are voltage regulators and switched capacitor banks. Then, the voltage profile of the circuit should not change when PV generation is introduced into the circuit. Thus, the PVs are controlled to maintain the optimal operating schedule established by the automated devices.

2.1. Control of automated devices

The objectives of the automated device control are to reduce the customer level voltage deviation from the desired value while minimizing the steps of the automated devices, and then to minimize the circuit loss. The control of the automated devices uses an iterative approach which involves adjusting the controllable single-step devices (switched shunt capacitors) and multiple-step devices (voltage regulators) to find the best operating point, as illustrated in Fig. 1.

The total steps of the automated devices (M_n) are calculated by:

$$M_n = \sum_{k=1}^{K} m_{n,k} \tag{1}$$

where K is the total number of controllable automated devices and $m_{n,k}$ are the steps of device k at time n with the following constraint:

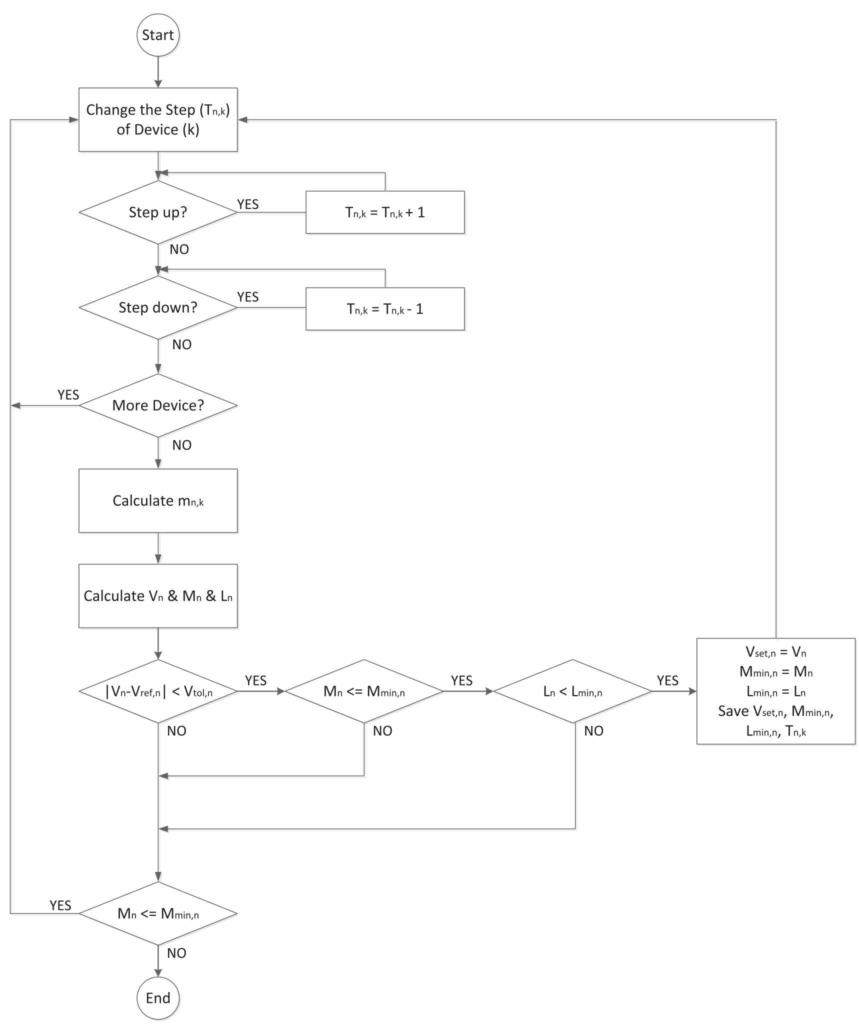

Fig. 1. Flowchart of automated device control.