Electrical Power and Energy Systems 32 (2010) 1125–1134

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal voltage control in distribution systems with coordination of distribution installations

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ARTICLE INFO

Article history:
Received 18 September 2009
Accepted 7 June 2010

Keywords:
Centralized control
Distributed generation
Distribution system
Distribution voltage/reactive power control
Genetic algorithm
Tabu search

ABSTRACT

In recent years, distributed generations based on natural energy or co-generation systems are increasing due to global warming and reduction of fossil fuels. Many of the distributed generations are set up in the vicinity of customers, with the advantage that this decreases transmission losses and transmission capacity. However, output power generated from renewable energy such as wind power and photovoltaics, is influenced by weather conditions. Therefore if the distributed generation increases with conventional control schemes, the voltage variation in a distribution system becomes a serious problem.

In this paper, an optimal control method of distribution voltage with coordination of distributed installations, such as On Load Tap Changer (OLTC), Step Voltage Regulator (SVR), Shunt Capacitor (SC), Shunt Reactor (ShR), and Static Var Compensator (SVC), is proposed. In this research, the communication infrastructure is assumed to be widespread in the distribution network. The proposed technique combines genetic algorithm (GA) and Tabu search (TS) to determine the control operation. In order to confirm the validity of the proposed method, simulation results are presented for a distribution network model with distributed (photovoltaic) generation.

1. Introduction

Due to global warming and reduction of fossil fuels, use of distributed generation such as renewable energy generation or co-generation system which has high thermal efficiency has been increasing. Many of the distributed generations are set up in the vicinity of customers, because this offers advantages such as reduction of transmission loss and transmission capacity, short-period of construction and low investment risk. However, the output power of natural energy based distributed generation, such as wind power or photovoltaic generations, is influenced by meteorological conditions. Therefore the distributed generation connected to the downstream distribution system may produce backward power flow that is not assumed in conventional distribution systems. The electric power flow is unidirectional, from the upstream to the downstream in the conventional distribution system. Thus voltage control of a distribution system postulates the condition of the power flow as an unidirectional flow. When the number of distributed generation increases with the conventional control schemes, voltage variation in a distribution system becomes a serious problem. In order to protect equipments from voltage variation, voltage at the consumer side should be regulated within the statutory range defined in the Japanese Electricity Business Act. Several methods have been proposed to address the above given issue. A control scheme for Shunt Capacitor (SC) is proposed in [1], where the on–off switching is operated using the average value of voltage at connecting point in order to avoid frequent operation. However, only local information is used for operation. Optimal voltage profile of overall system is not considered. With centralized control, voltage control considering the entire power system is possible. Some on-line control methods for SCs in a distribution system have been proposed in [2–4]. Other suggested methods include coordinated control, such as SCs and On Load Tap Changers (OLTCs) [5–7] and combined Heuristic-algorithmic approach for reactive power optimization [8].

In the distribution system with photovoltaic generation, the minimum inverter capacities of FACTS devices which can regulate voltage within restricted condition can be determined by the method proposed in [9]. Although various controllers (OLTCs, Step Voltage Regulators (SVRs), SCs, Shunt Reactors (ShRs), and Static Var Compensators (SVCs)) exist in the real distribution system, the coordinated control considering various controllers has not been considered sufficiently. Moreover, the optimal control

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doi:10.1016/j.ijepes.2010.06.010

method of voltage profile in a distribution system with various controllers has not been proposed.

This paper proposes the optimal control of distribution voltage profile with coordination of distribution installations such as OLTCs, SVRs, SCs, ShRs and SVCs. In this study, the communication infrastructures of the distribution system, such as optical fibers, are assumed to be widespread along feeders. The concept of communication infrastructures is shown in Fig. 1. The proposed method considered that the control center send the optimal tap information to the local controller of the OLTC, SVC and SVR. This proposed method acts as a scheduling technique for control of the distribution installations in distribution system. Besides, the proposed method is an off-line centralized control method based on the predicted values of load demand and photovoltaic generations, and the control performance of the proposed method depends on the accuracy of the prediction. Studies about the prediction of load demand and generation are presented in [10,11]. Thus, prediction is possible with certain accuracy.

The objective of this study is the development of a control method which can achieve optimal voltage profile by determining the control schedule of OLTCs, SVRs, SCs, ShRs and SVCs in a day. Tap changing of OLTCs and SVRs, on–off switching of SCs and ShRs, and operation of SVC accompany mechanical attrition. Therefore, the life of the voltage control device is shortened and higher maintenance cost is incurred if the control device is operated frequently. To resolve this problem, the maximum number of allowable operations in a day for the control device is considered in this study. The proposed method combines genetic algorithm (GA) and Tabu search (TS) to determine the schedule for the operation of the voltage control devices in a day. GA is an excellent technique with high-speed approximation of solution and works efficiently when a feasible area is discretely set in a large-scale optimization problem. TS is an extended local search algorithm and has both advantages of high search efficiency of local search algorithm and global search ability of intelligent algorithm. By application of the proposed method, the schedule for the operation of the voltage control devices can be determined relatively in short time. In order to confirm the validity of the proposed method, simulation results are presented for a distribution network model with a distributed (photovoltaic) generation.

2. SVC/OLTC/SVR

2.1. SVC device

An SVC comprises a bank of mechanically switched capacitors and a thyristor-controlled reactor. An SVC can inject and absorb reactive power continuously by mechanical switching of capacitors and electronic switching of a thyristor-controlled reactor. Fig. 2 shows the fundamental configuration and the equivalent circuit of an SVC. The proposed method assumes the SVC operates same speed with OLTC and SVR, and also with ShR and SC because the proposed method assumes that there is few delay between SVC and other distribution installations.

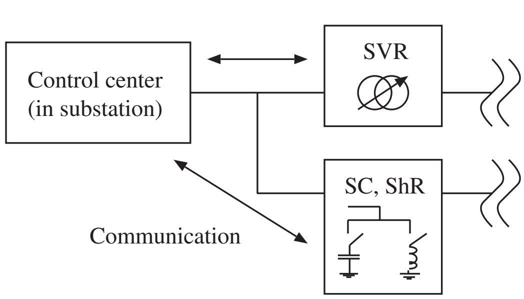

Fig. 1. Concept of communication.

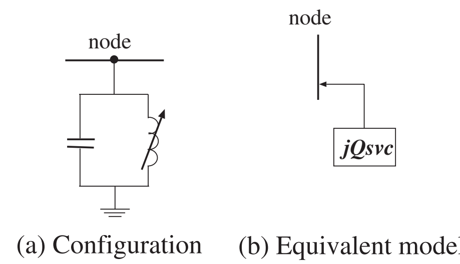

Fig. 2. Model of SVC.

Generally, an SVC is controlled to regulate the voltage at the setting point to the reference value. However, only static voltage profile is evaluated in this study. Additionally, from perspective of determination of the device capacity, an SVC is modeled as a simple source of reactive power in the simulation.

2.2. The problem of SVR, OLTC

In the present control scheme, voltage profile in a distribution system is controlled by changing the tap position of the OLTC and the SVRs based on local information [6].

Voltage at the central load point in the secondary side of the transformer is estimated from voltage and current measured at the setting point of the transformer. If the estimated voltage deviates from predetermined value, the tap position of the transformer is changed according to the voltage variation. However, the following problems arise in the present control scheme:

- Voltage profile of each feeder gets complicated from the reverse power flow by distributed generation and non-uniformity of load distribution. Consequently, it becomes difficult to estimate the voltage at the particular point accurately, and unexpected voltage deviations may occur.
- OLTCs and SVRs are coordinated by time period and voltage sensitivity for tap changing, but the optimal voltage profile in the entire system is not considered exactly.

Therefore, tap changing of OLTCs and SVRs in this study is operated by centralized control considering optimal voltage profile over the entire system.

3. Operation technique of the controller

3.1. Set up of objective function

In this research, the operation of each device is determined by calculating the objective function and optimization of the voltage

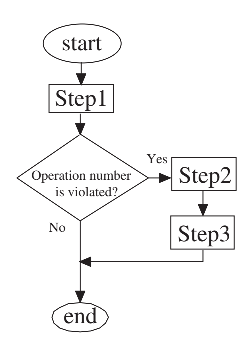

Fig. 3. Flow chart of the proposed algorithm.