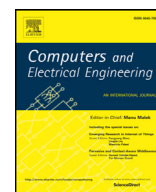




Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Congestion management in restructured power systems for smart cities in India[☆]

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ARTICLE INFO

Article history:

Received 31 January 2017

Revised 19 April 2017

Accepted 19 April 2017

Available online xxx

Keywords:

Smart cities

Smart grid

Restructured power systems

Congestion management

FACTS and microgrid

ABSTRACT

The development of smart cities in India will require a smart grid for power generation, transmission and distribution systems with a continuous power supply. The transmission line is one of the major elements to supply continuous power to the smart cities via a smart grid. Transmission line congestion is a major technical problem, which must be relieved in order to maintain the system in a secure state. The present work proposes a combined FACTS device and a microgrid based congestion management (CM) method for relieving transmission line congestion. The optimal placements of the FACTS device and microgrid are obtained by using real power flow (RPF) and transmission line relief (TLR) sensitivity indices. The proposed method has been demonstrated on an IEEE 14 bus test system. The FACTS and MG based CM approached when combined were found to be superior to the performance when the methods are carried out individually.

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1. Introduction

The development of smart cities results in a positive impact on the environment, yielding a reduction in social costs due to effective energy utilization while increasing the capacity of renewable sources. A model for energy-related operations and planning of a smart city was presented in [1], where the focus was on the power generation, infrastructure, storage, and transport system in a smart city. However, in the present work, the analysis is limited to, the power supply system of smart cities via the smart grid, which supplies power by utilizing renewable energy sources along with conventional sources. The power supply and load control technology for smart cities have been described in [2], in which an advanced demand response (ADR) technique was used to control the balance between power supply and electricity demand. The global electrical power industry is undergoing a radical change in both its business and operational mode, whereby, vertically integrated utilities are being restructured and competition is being introduced among power producers [3].

In the competitive power market, power producers and customers are demanding forms of electrical energy potion and consumption that could lead to congestion in some of the transmission lines in the system. Congestion problems of this kind represent a frequently occurring phenomenon in a restructured power system environment, which take place when the power of the transmission line reaches its maximum power flow limit [4,5]. Congestion management (CM) is a mechanism by which to relieve transmission congestion by keeping all line transactions and schedules within limits. A bibliographical survey of CM methods in which different schemes are presented can be found [6,7]. The power production costs are minimized by the optimal power flow (OPF) solution for real power generation scheduling. The OPF is required to distribute the

[☆] Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. S. Smys.

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power in order to optimally meet load demand, while managing all equality and inequality constraints of the system, such that the total fuel costs of the generating units are minimized [8,9].

In the literature, different optimization methods are used to solve OPF solutions for various test systems. In the present work, two approaches are used: one is a classical method (primal linear programming (PLP)), and other is the heuristic search method (genetic algorithm (GA)). The OPF solution involving the 14 bus test system is obtained, when the system is under normal as well as congested operating conditions. The fundamentals of linear programming (LP) and PLP methods and their application to optimization problems in the power system have been described in [10,11]. The application of the GA method to power systems in order to solve different optimization problems has been presented in [12,13]. The heuristic method has been found to result in rapid convergence, thereby proving that an optimal OPF solution is meeting all system constraints. The comparative work of OPF solutions with classical and intelligent methods has been presented by the authors in [14].

The thyristor controlled series capacitor (TCSC) is one of a series controlled of FACTS devices used in the present work, as the work mainly concentrates on the power transfer capacity (PTC) of transmission lines. The modeling and simulation of a TCSC based controller design for PTC and power system stability were presented in [15,16]. The real power flow sensitivity index (RPFSI) determines the severity of transmission line loading under normal and congested system operating conditions [17]. The TCSC is used for relieving transmission line congestion by increasing the PTC of transmission lines, while its optimal placement is determined by RPFSI values. The microgrid (MG) is a small local power network, which can work in two modes: the autonomous mode and the grid-connected mode have been presented in [18,19]. The distributed generators (DGs) are the power generating units in the MG, which can generate electricity from renewable energy sources. In the present work, a voltage source converter (VSC) based DG unit is used in relieving transmission line congestion, along with minimizing the power production costs of systems. The modeling of the VSC based DG unit and its power flow (active and reactive) control has been presented by the authors in [20]. In the present work, optimal locations of DG unit are determined by transmission line relief sensitivity index (TLRSI) values.

In the present work, the coordinated FACTS device and MG based CM method are proposed to relieve congestion with the objective of minimizing system total production costs and increasing the reliability. This high-performance transmission line support system creates a better smart grid system so that it is better equipped to supply uninterrupted power to smart cities from the grid. The proposed method of relieving congestion has been demonstrated on IEEE 14 bus test systems, while the required data have been taken from [21]. The paper has been organized as follows: Section 2 deals with the OPF problem formulation of test systems, while Section 3 presents various optimization techniques such as PLP and GA methods, which are used to solve the OPF problem. The modeling and optimal placement of FACTS and MGs have been presented in Section 4. Section 5 reveals the simulation results of an IEEE 14 bus test system with FACTS and MGs under various system operating conditions. Finally, Section 6 sets out the conclusions and the future scope of this work.

2. OPF problem formulation of the test system

Conventionally, the optimal planning and operation of power system networks have been made according to economic criteria. Worldwide, most power utilities have changed how they exploit the restructuring mode. The restructured power system has introduced a new open market pricing structure and made changes to the transmission network, in turn forcing the optimal operation philosophy of electricity generation. The OPF is offering broad applications in restructured electricity market operations and bid management [8,9], in which the main goal is to minimize the costs of production in a system load that needs to be distributed among different generating units while satisfying all the system constraints. In general, the OPF problem is formulated as a nonlinear and non-convex optimization problem, which is used to minimize objective functions.

The OPF problem in a pool based market is formulated as in (1) below:

$$\text{Min } f(x, u) = \text{Min} \left(\sum_{i=1}^{N_G} C_{Gi}(P_{Gi}) - \sum_{i=1}^{N_D} D_{Di}(P_{Di}) \right) \quad (1)$$

where $f(x, u)$ is the main objective function of the test system, x and u are configured to state and controlled variables, P_{Gi} & P_{Di} represents the real power generation and demand at the i th bus, and C_{Gi} & D_{Di} represents the total real power generation and demand cost at the i th bus, and N_G & N_D are the total number of generating units and load demands.

When subjected to system equality constraints (usually the power balance equations),

$$h(x, u) = 0 \quad (2)$$

As such, the set of inequality constraints are followed:

$$g(x, u) \leq 0 \quad (3)$$

where h and g are configured as equality and inequality constraints. The conventional OPF provides the measured values of the disturbance variables, which are usually the system's active (P) and reactive (Q) power demands. These P & Q values at the load bus are assumed to be constant during the optimization. The OPF solutions provide optimum settings for the control variables u . In this work, the economic load dispatch on real power (P) generation has been analyzed.

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