Ain Shams University
Faculty of Engineering
Electrical Power and Machines Department

Electrical Energy Management in Power Delivery Systems Using Virtual Power Plant Concept

Ph.D. thesis

By:
Eng. Mahmoud Mohamed Othman Ahmed

A thesis submitted to the Faculty of Engineering-Ain Shams University
in partial fulfillments of the requirements for the Ph.D. degree in
Electrical Power and Machines Engineering

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Approval Sheet

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Statement

This thesis is submitted to the Faculty of Engineering, Ain Shams University in Partial Fulfillment of the requirements for Ph.D. degree in Electrical Power and Machines Engineering

The included work in this thesis has been carried out by the author at the Electrical Power and Machines Department, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Signature:

Date: 29/12/2014

Acknowledgment

First of all, I wish to offer my great thanks to Allah and I hope that God would bless this research.

Although my next few words couldn't express my deep feelings and respect towards my supervisors, but it may at least indicates some of those feelings.

I would like to present my deep thanks to Professor Dr. **Almoataz Y. Abdelaziz** for his excellent supervision, encouragement and endless support during the research period.

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Dedication

This work is dedicated to my **late brother**, **father**, **mother**, **wife**, **sisters** and **my lovely son**.

I would like to thank and appreciate my **wife** for her support and patience.

ABSTRACT

The electricity market liberalization allows proliferated integration of distributed energy resources (DER) that include distributed generation (DG) and controllable loads with the distribution network. However, increasing DER penetration without amity between them may lead to undesired impacts. In addition, relying on renewable energy based DGs may cause unreliable operation of the power system due to their stochastic nature. Thus, energy storage elements are needed to bridge the gap between the stochastic generation and demand.

In order to control and manage the operation of the distributed energy resources and the energy storage elements, the virtual power plant (VPP) concept is introduced. VPP can be defined as "A concourse of dispatchable and non dispatchable DGs, energy storage elements and controllable loads accompanied by information and communication technologies to form a single imaginary power plant that plans, monitors the operation, and coordinates the power flows between its component to minimize the generation costs, minimize the production of green house gases, maximize the profits, and enhance the trade inside the electricity market".

This dissertation utilizes the VPP concept for managing the electrical energy in the power delivery networks. The work presented in this thesis can be grouped into three phases; the first

phase includes the studies concerned with the optimal sizing and siting of DG units. The second phase aims to support the renewable based DG units operation via the optimal sizing of the energy storage elements. While, the third phase proposes load control study in order to manage the electrical energy not only in the distribution network but also in exchange with the main grid.

In the first phase, two novel optimization techniques, named supervised Big-Bang Big-Crunch and supervised Firefly, have been developed and implemented in order to accurately select the optimal size and location of voltage controlled DG units in order to minimize system power loss. The developed techniques have been applied to balanced and unbalanced distribution feeders and their results have been compared to published results for validation of the proposed techniques. Several related studies have been presented include optimal sizing and siting of DG units for daily energy losses minimization, multiobjective performance index minimization through optimal choice of capacity and location of DG units, and optimal planning of DG units for achieving a planned power loss. In addition, a novel strategy for modeling renewable energy based DG units has been presented. The proposed strategy, that utilizes diagonal band Copula and Monte Carlo methods, is capable of considering the stochastic nature of the renewable sources as well as the dependence between the renewable sources and the system demand. The

results of the modeling strategy have been integrated with the supervised Big-Bang Big-Crunch optimization technique for optimal allocation of renewable based DG units with and without dispatchable DGs.

In the second phase, an innovative algorithm for determining the optimal size and operation schedule of energy storage elements has been introduced. The proposed algorithm allows the distribution system operator to choose the optimal charging and discharging rates and optimal capacity of the energy storage element connected with the renewable energy based DG unit. Through the introduced algorithm, the energy storage element manages the renewable based DG power schedule in order to minimize the annual energy losses.

In the third phase, a Big-Bang Big-Crunch based optimization algorithm is developed for determining the optimal load control schedule. All of the aforementioned optimization techniques are integrated with the load control technique for the realization of the VPP concept. Two studies are performed to manage the electrical energy using the VPP concept; the first aims to minimize the energy purchased from main grid and the second minimizes the cost of energy purchased from main grid by enhancing the energy trade.

The presented studies and the subsequent results and discussions emphasize the prominence of the VPP concept in

handling the electrical energy management problem as it is used to ensure that the power system is operated in an optimized and secure way taking technical constraints into account.

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