Chapter 14
Load Flow Analysis in Smart Grids

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ABSTRACT

Load flow analysis is widely used to estimate the flow of various electrical parameters such as the voltage, current, and power in power grids. These estimates allow us to effectively and reliably manage the given grid under random and uncertain conditions. Given the enormous amount of randomness and uncertainties in the factors that affect the smart grids, compared to traditional power grids, a complete and rigorous load flow analysis holds a vital role in ensuring the reliability of this safety-critical domain. In this chapter, the authors describe smart grids in terms of their basic components and then categorize the factors that affect the loads in smart grids. This is followed by a comprehensive survey of various existing load flow analysis techniques (i.e., numerical, computational intelligence, and probabilistic).

INTRODUCTION

With 19320 TW-hr/yr consumption of electrical energy in the entire world nowadays, the traditional unidirectional power transmission grids are struggling to survive as the number of fluctuations, blackouts and outages is tremendously growing since the last decade (Gao et al., 2012). More reliable and safe distribution networks have become a dire requirement due to the safety and financial-critical nature of electricity these days. For example, a blackout per minute across Silicon Valley costs 75 million and 1 million dollars for Sun Microsystems alone. There are numerous environmental concerns with the present-age power generation methods as well since these methods are largely dependent on fossil fuels, which result in global warming and carbon-dioxide emissions. For example, the United States power system

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alone is responsible for 40 percent of carbon emission nationwide (Hledik, 2009). Thus renewable energy resources, like solar and wind based solutions, are extensively being advocated throughout the world but the traditional grid does not facilitate their integration in the national grids. Moreover, the traditional power grids are not very efficient in terms of distribution loss management as well. For example, about 17 percent of electrical energy generated in the year 2011 by Pakistan was wasted in distribution systems. Similarly, the problem of electricity theft is also a growing concern in traditional grids.

Smart grids can overcome the above mentioned shortcomings by providing an alternative electric power transmission framework that comprises of Intelligence based Electronic Devices (IED) (Momoh, 2012) for detecting and correcting faults, and advanced metering infrastructure (AMI), to facilitate the integration of multiple renewable energy sources. Some of the distinguishing characteristics of smart girds compared to traditional power grids include:

- **Safety and Reliability:** Smart grids can predict unforeseen situations and autonomously react accordingly to prevent them (e.g., isolating the faulty component of the grid from the entire system (Farhangi, 2010)) and hence improve the safety and reliability (Moslehi and Kumar, 2010) of power distribution and save millions of dollars.
- **Cost-Effectiveness:** Smart grids provide real-time tariff information to the consumers so that they can manage their loads to save energy and costs (Li et al., 2010).
- **Efficiency:** Smart grids allow optional usage of the assets to maximize the efficiency of the grid and thus can have a major performance impact. For example, according to the US Department of Energy (DOE), just a 5% increase in grid efficiency can have the same impact as if fuel and greenhouse gas emissions are eliminated from 53 million cars.
- **Security:** Smart grids allow more secure electrical networks, by using tools like smart meters, and thus electricity theft can be minimized (Khurana et al., 2010, Metke and Ekl, 2010).
- **Environmental Friendliness:** Smart grid allows the integration of environmental friendly generation methods and is inline with the recent advancements in renewable energy research (RER) (Ipakchi and Albuyeh, 2009).

Based on above-mentioned capabilities, the National Academy of Engineering listed "electrification as made possible by the grid" as the most significant engineering achievement of the 20th Century.

Due to the inherent randomness of smart grids, including variable loads, peak consumption times and renewable energy sources with generation capacity depending on varying weather conditions, there is a lot of interest in rigorously analyzing the voltages and load profiles for resilient and effective power delivery to the users. Besides providing means for effectively managing the energy distribution, these profiles can be used by the consumers to change their loads by a smart device from anywhere as per their requirements. Load flow analysis (Van Benthem and Doets, 2001) fulfills the above-mentioned requirements and allows us to find the magnitude and phase angle of the voltage and the real and reactive power flowing in each bus of the smart grid and the optimal parameters for various components, like inductors, conductors, transformers, and shunt capacitors. It also provides statistics about the behavior of the system during on-peak and off-peak loads in order to identify and plan the contingencies. Moreover, load flow studies help us in conducting short-circuit fault analysis and in finding the stability and the steady-state operating state of an electric power system by calculating the voltage drop on each feeder, the power flow in all branches and feeder circuits, X/R ratio in line impedances and the voltage at each bus. Finally, load flow studies can determine if system voltages remain within the given specifications

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