Load Flow Analysis in Smart Grids

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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 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 volt-

ages remain within the given specifications and if any of the expensive equipment of the grid is overloaded. The results of load flow analysis are used to make key decisions and ensure a safe and reliable power distribution.

There are various uncertain and random elements associated with the load consumption in smart grids. For example, the usage of consumer appliances depends on weather conditions and the time of the day. The distributed generation and usage of storage cells also plays a key role in varying the electrical demand. Some of the key factors that influence the loads in smart grids and must be taken into consideration for load flow analysis of smart grids include weather conditions, time-of-day, arbitrary disturbances, electricity prices, demand response, storage cells and electric vehicles.

BACKGROUND

There are various uncertain and random elements associated with the load consumption in smart grids. For example, the usage of consumer appliances depends on weather conditions and the time of the day. The distributed generation and usage of storage cells also plays a key role in varying the electrical demand. The smart grid components may fail randomly and either self-repair or need manual repair to restore their operation. Some components may also have back-up protection. Similarly, the influence of electricity prices on the energy demand cannot be neglected as higher prices usually result in the reduction of energy consumption. Moreover, in smart grids, the consumers are more cautious about costs since they can get the real-time tariffs using smart meters. Time-of-Use (TOU) pricing scheme, which offers low off peak rates, encourages consumers to shift their loads to off peak hours. Moreover, electric vehicles (EVs) also greatly influence load profiles since their charging consumes a significant amount of energy and thus is recommended to be done in the off peak times.

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