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Optimization Approaches for Demand Side Management in Smart Grids

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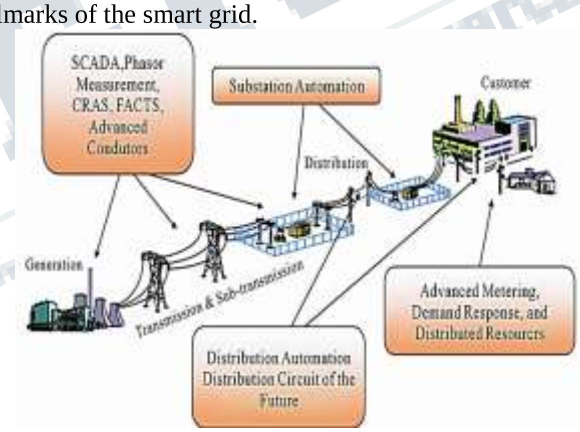
***Abstract*: -- This paper describes the novel simulation and optimization approaches for demand-side management (DSM) in smart grids. Over the past two decades, power systems have witnessed significant changes in the use of renewable and distributed energy resources, energy control technologies, and technical advances in communication and computation, which has led to the development of smart grids. Smart grids provide sustainable power grids with the capabilities of self-healing and automatic execution in an isolated mode, but the operation and control planning of smart grids are challenging procedures. The main challenges arise from energy load scheduling of customers using interruption load management (ILM) and load shifting strategies; communication between customers and utility companies or third-party aggregators to increase customer satisfaction and decrease costs; and the need to provide reliable and high-quality energy to customers to address the main challenges in the operation and control planning of smart grid threshold values.**

***Keywords:* — Demand side management (DSM), Interruption load management (ILM), Smart Grid, RRED, load shifting strategies, DSM programs.**

I. INTRODUCTION

The traditional electrical power grid is unidirectional in nature, where the electricity flows from power generation facilities to end users. Modern society demands this system to be more reliable, scalable, and manageable while also being cost effective, secure, and interoperable[1].The next-generation electric power system, known as the "smart grid" [2], is a promising solution to the long-term industry evolution. The smart grid is expected to revolutionize electricity generation, transmission, and distribution by allowing two-way flows for both electrical power and information "A smart grid is a modern electric system. It uses communications, sensors, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system. It offers consumers increased choice by facilitating opportunities to control their electricity use and respond to electricity price changes by adjusting their consumption. A smart grid includes diverse and dispersed energy resources and accommodates electric vehicle charging. It facilitates connection and integrated operation. In short, it brings all elements of the electricity system production, delivery and consumption closer together to improve overall system operation for the benefit of consumers and the environment"[3]. In general, a smart grid is the combination of a traditional distribution network and a two-way communication network for sensing, monitoring, and dispersion of information on energy consumptions. An example of communication architecture in a smart grid is shown in Figure1. A typical smart grid consists of numerous power generating entities and power consuming entities, all connected through a network. The generators feed the energy into the grid and consumers draw energy from the grid. The ad hoc, dynamic and decentralized energy distribution are hallmarks of the smart grid.



Demand side management programs are mainly used to avoid potential instabilities in power networks, providing economic benefits by utilizing only the least-expensive sources of generation and eliminating the need for constructing additional power plants to satisfy increasing peak demand [4]. Demand side management has become a significant function in energy management due to its potential to reduce the cost of peak demand satisfaction.

Demand Response Applications

One main component of the smart grid is the possibility of customer participation in the overall grid energy management. This participation is done via the notion of demand response or demand side management, in which

(a) The power company provides incentives for customers to shift their load over time, and

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(b) Customers are provided with partial autonomy to participate in buying/selling energy from/to the grid. Thus, in any smart grid mechanism, it is imperative to factor in demand response models and their associated challenge.

In power networks that include smart grids, the total power supplied from traditional and renewable energy sources must be greater or equal to customer demand. However, there are times when power generation may not sufficiently satisfy demand, which can be significantly higher than its predicted value. During these times, the power network is at risk due to severe voltage oscillations that may cause minor or major (even permanent) failures. To prevent such failures, utilities commonly plan for their total installed electricity generation capacity to satisfy the forecasted peak demand, considering a margin of error. Most power systems are also supported by contingency energy sources in an idle state in the grid but ready to be used in case of power outages. These systems are typically managed in a way such that demand is satisfied at a minimum possible cost with the least expensive generation sources being utilized first, followed by other more expensive sources. In order to increase reliability in smart grids and decrease blackout and brownout periods, demand side management (DSM) is used to control and reduce peak demand. In energy management literature, there are six main groups of DSM: 1) peak clipping, which reduces peak load demand by using time-based incentives for interrupted customers;(2) load shifting, which shifts loads from on-peak to off-peak time periods;(3) valley filling, which shifts peak demand usage to low demand periods, but the term can refer to any program or strategy aimed at filling the usage valley between peak uasage times;(4)flexible load shape, which provides control over customers during critical periods in exchange for various incentives;

(5) strategic conservation, which reduces energy demands directly on customers' premises; and

(6) strategic load building (load growth), which optimizes daily response in case of large demand [5-12]. Load shifting and peak clipping, also known as interruption load management (ILM), are the most popular DSM programs due to their ease of application and efficiency.

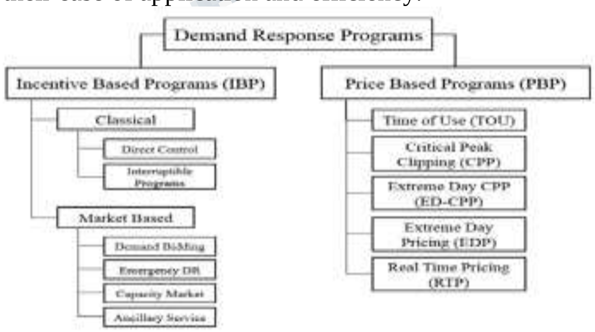

Fig. 2: Classification of demand response programs:

Different DSM programs, shown in Fig. 2, can be divided into two main categories: incentive-based programs (IBPs) and price-based programs (PBPs) . Classical IBPs can either be direct load control (DLC) programs or interruptible/ curtailable load programs. Market-based IBPs include emergency demand response (DR) programs, demand bidding, the capacity market, and the ancillary services market. In a classical IBP, which forms the core of this doctoral research, participating customers receive participation payments, usually as a bill credit or discount rate, for their involvement. In DLC programs, utilities can remotely shut down participant equipment on short notice. Typical remotely controlled equipment includes air conditioners and water heaters. This kind of program is of interest mainly to residential customers and small commercial customers.

A Deterministic Multi-Objective Optimization Framework for DSM in Smart Grids.

Increasing populations, growing electrical energy consumption, and the integration of renewable energy sources into electricity grids over the last few decades has made maintaining grid power balance a major challenge for energy providers [13]. Due to the deployment of renewable energies and the need for high reliability, traditional power grids will move toward becoming intelligent modern power grids known as smart grids in the near future [14]. Smart grids play a critical role in transforming the traditional power grid system into one that provides a user-oriented service and guarantees high security, quality, and economic efficiency. However, to maintain sustainability in smart grids, the total capacity of installed generation in the system must be larger than the maximum load demand to ensure the security of supply in the face of uncertainty (e.g. generation breakdowns and interruptions to primary fuel sources) and variations in energy supply due to adverse weather [15]. DSM programs have been proposed as a major dimension of future power supply and control to prevent blackouts and brownouts during load variation and uncertain energy generation. DSM programs are typically a set of programs that harmonize the activities of energy providers and consumers to control energy consumption. These programs monitor and influence load profiles during peak load demand and are used to avoid installing new generation infrastructure.

Despite the progress achieved in the field of DSM, a simultaneous consideration of cost minimization and customer satisfaction maximization has not yet been addressed. The proposed deterministic multi-objective optimization framework for DSM in this dissertation attempts to minimize cost and greenhouse gas (GHG) emissions while maximizing customer satisfaction. Fig. 3 represents the proposed mixed-integer multi objective optimization framework for

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implementing load shifting and ILM programs in smart grids to satisfy desired demand.

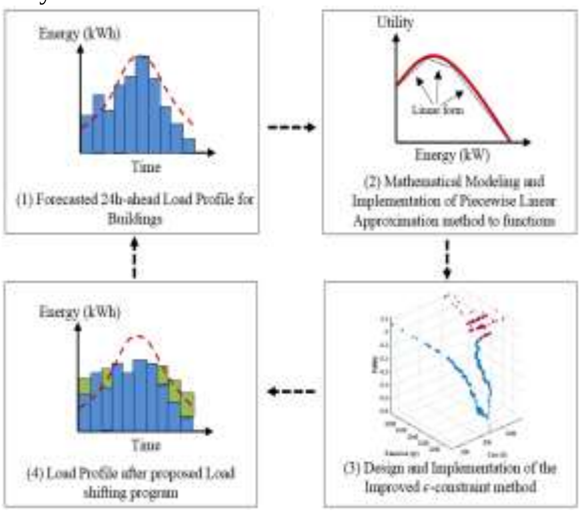

Fig.3:Proposed multi-objective optimization DSM framework

The proposed framework includes four main components: (1) a forecasting model that creates a 24-hour-ahead load profile using historical data about renewable energy sources in smart grids, (2) a mathematical model of the load shifting and ILM problem and implementation of a piecewise linear approximation method to achieve the mixed-integer multi-objective optimization model, (3) an advanced ϵ-constraint model for the mixed integer multi-objective optimization problem that acquires Pareto frontier solutions with a higher number of non-dominated solutions and less computational time, and (4) mathematical scheduling for load profile construction based on the results of the framework. This proposed framework is implemented for a small case study of smart grids for efficiency and effectiveness purposes.

II. CONCLUSION

This paper describes simulation and optimization framework to determine (near-) optimal 24-hour-ahead load scheduling for loads and buildings in smart Grids. This paper provides simulation and optimization tools for energy providers and third-party aggregators to schedule energy loads in smart grids to satisfy desired load demand. The main capability of the proposed framework is the consideration of deterministic loads provides flexibility for users. The aim of this research was to examine how the invention of smart meters (ECCs) and integration of multiple renewable energies can satisfy customer loads in day-ahead scheduling.

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