Electrical Power and Energy Systems 78 (2016) 783–792

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Demand response governed swarm intelligent grid scheduling framework for social welfare

Sawan Sen [a,*], Sandip Chanda [b], S. Sengupta [c], A. De [d]

[a] Electrical Engineering Department, Kalyani Government Engineering College, Nadia, West Bengal, India
[b] Electrical Engineering Department, Budge Budge Institute of Technology, West Bengal, India
[c] Department of Applied Physics, University of Calcutta, Kolkata, India
[d] Electrical Engineering Department, Indian Institute of Engineering, Science & Technology, Shibpur, Howrah, West Bengal, India

ARTICLE INFO

Article history:
Received 14 February 2015
Received in revised form 2 December 2015
Accepted 9 December 2015
Available online 4 January 2016

Keywords:
Curtailment limiting index
Demand response
ISO
Social welfare
Smart grid
Swarm intelligence

ABSTRACT

Peak load defines the generation, transmission and distribution capacity of interconnected power network. As load changes throughout the day and the year, electricity systems must be able to deliver the maximum load at all times, which will be hard trade for a practical power network. Smart grid technologies show strong potential to optimize asset utilization by shifting peak load to off peak times, thereby decoupling the electricity growth from peak load growth. Under Smart grid trade regulation, with continuous varying demand pattern, electricity price will be uneven as well. On this view point, in order to obtain a flatten demand, without affecting the welfare of the market participants, this paper presents an on-going effort to develop Demand Response (DR) governed swarm intelligence based stochastic peak load modeling methodology capable of restoring the market equilibrium during price and demand oscillations of the real-time smart power networks. This proposed DR based methodology allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes and thereby minimizing erratic variations of price of electricity. For proper utilization of DR connectivity, a Curtailment Limiting Index (CLI) has been formulated, monitoring which in real time, for each of the Load Dispatch Centers (LDCs), the system operator can shape the electricity demand according to the available capacity of generation, transmission and distribution assets. The proposed methodology can also be highlighted for generating the most economical schedule for social welfare with standard operational status in terms of voltage profile, system loss and optimal load curtailment. The case study has been carried out in IEEE 30 bus scenario as well as on a practical 203 bus-265 line power network (Indian Eastern Grid) with both generator characteristics and price responsive demand characteristics or DR as inputs and illustrious Particle Swarm Optimization (PSO) technique has assisted the fusion of the proposed model and methodology. Encouraging simulation results suggest that, the effective deployment of this methodology may lead to an operating condition where an overall benefit of all the power market participants with standard operational status can be ensured and the misuse of electricity will be minimized.

Introduction

Power grid is a large interconnected infrastructure for generating and distributing electricity from different power plants to power consumers. Due to socio-economic reasons, the growth of electricity demands require reliability and quality of power supply and for that, the power industry is now facing unprecedented challenges and opportunities. Therefore a new kind of power networks that is environment friendly, economic, safe, reliable, flexible and has high-performance and low investment has been a motto of power engineers in the recent past. Thus the power world is proposing to modernize and make stride toward smart grids. A smart grid is a re-organized electrical grid that integrates the behaviors of suppliers and consumers by modern information and communications technology, to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity. In smart grid environment, the two-way communications enable the penetration of Demand Response (DR) into power grids, which leverage the information and communication technologies, to achieve efficient and economical

* Corresponding author.
E-mail addresses: sawansen@gmail.com (S. Sen), sandipee1978@gmail.com (S. Chanda), samarsgp@gmail.com (S. Sengupta), abhinandande@gmail.com (A. De).

http://dx.doi.org/10.1016/j.ijepes.2015.12.013
0142-0615/

power generation, transmission and distribution. Consequently, the price of electricity in modern power markets round the globe is greatly influenced by social and economic activities [1,2]. Thus smart grid technologies are currently undergoing a development in an effort to modernize legacy power grids to cope with the increasing energy demands without violating the power network constraints [3–5]. It has been shown by smart grid power researchers that the transmission, distribution and end users can be interconnected by high-speed bi-directional communication network to optimize the grid operation. Integration of automation, Supervisory Control and Data Acquisition (SCADA) and smart metering in power networks can enable the grid to rapidly self regulate and to improve system reliability and security. So far there has been a significant research, integrating consumer demand side management into smart grid to improve the system load profile and reduce peak demand [6]. DR allows the consumer to change demand pattern from their prescribed schedule in response to emergency and high price condition on the electricity grids. Such conditions are more prevalent during peak loads or congested operation. Non-emergency demand response in the range of 5–15% of system peak load can provide substantial benefits in reducing the need for additional resources and lowering real-time electricity prices. Demand response does not substantially change the total energy consumption since a large fraction of the energy saved during the load curtailment period is consumed at a more opportune time to flatten the consumption profile of the customers.

Literature reviews suggest that several methods of load management governed by DR have been reported. In [7], a model of adaptive control strategy for interruptible load management that handles load variation is presented. But, the model could not maintain a flat DR as required. A fully decentralized grid-scheduling framework has been reported in [8] but the model is unable to utilize the DR data for optimization of grid operation. A cellular technology based demand side energy management has been proposed in [9] but the framework is only capable of operating in distribution networks rather than optimizing the whole grid operation. In [10], an optimization algorithm to schedule direct load control as a part of virtual power plant is presented but the participation of the loads in scheduling the plants are nominal in the cases cited. Different opportunities and challenges for DR and distribution grid operations have been discussed in [11], but a specific solution algorithm is required for proper smart grid operations. A harmonic distortion and transformer derating based load management in smart grid has been proposed in [12], but the algorithm proposed in this work does not incorporate the cost factors of the DR. Load reduction realization has been proposed in [13] by aperiodic switching, but the involvement of distribution networks has not been shown in this work. A DR based market resource planning strategy has been shown in [14] but the model proposed only shows the DR connectivity in the network rather than enlightening the optimization scheme to be harnessed in utilizing DR for optimal operation of smart grids. A DR based distribution grid operation model is shown in [15], but its inclusion in the transmission part of the grid has not been shown. An optimal real time pricing algorithm has been depicted in [16,17] for utility maximization in smart grid. In this case also the authors could not utilize the DR effectively for load management. All these methods are basically based on some proposed architectures, which considers DR but could not maximize the utilization profit through dynamic price equilibrium in smart grid environment governed by deregulation and distributed generation.

In view of this above literature survey, necessitate of an algorithm can be felt which can ensure a standard parametric operational condition with an objective of both maximizing social and individual welfare with optimal load distribution without violating the price equilibrium of the market by optimum utilization of DR. In this pursuit this work has developed, demonstrated and recommended the following contributions with a novel model and methodology in reinforcing quantifiable and substantial social welfare in the modern and future smart power grids:

- A flexible DR based peak load modeling methodology applicable to restore the market conditions during alterations in demand profile as well as price volatility.
- Segregation of the loads according to their willingness to pay for sustainability of power supply with the help of the proposed Curtailment Limiting Index (CLI).
- An optimal load schedule with optimal generation for limiting peak load with market price variation to maintain social welfare.
- Load tracing in real time and update the status of the end user/ power consumer to retain equilibrium in power market and to limit market price variation.
- An improvement of resource-efficiency of electricity production due to closer alignment between customers' electricity prices and the value they place on electricity.

The convex nature of solution algorithm with nonlinear working surface was compelling in the selection of a stochastic optimization technique like Particle Swarm Optimization (PSO). In the proposed methodology the swarm intelligence based optimizer generates random solution particles in the workspace bounded by the maximum and minimum limit set by the GENCOs and the LDCs. In each step the optimizer generates an optimum generation, load schedule with an objective of maximizing DR governed social welfare. The global best solution is selected as optimal solution for the given set of operating constraints. A benchmark system (IEEE 30 bus system) and a practical system (Eastern Grid of India) with smart metering have been preferred to test the applicability of the projected algorithm and the obtained results looked quite promising.

The next section of this paper covers the background issues of DR governed smart grid network, which includes defining the different types of demand response resources and the services they can provide. Subsequently, the newly proposed index named as CLI also has been discussed. A detailed description of the proposed methodology and implementation of the same using PSO has been depicted in the next section, forming a strong background for the simulation work. Simulation results convincingly demonstrate that the implementation the proposed model and methodology mitigate network constraints while catering higher demand levels and effectively improve the reliability of the system by maximizing the social welfare.

Theory

Demand response governed smart grid network

DR management is the process of self-controlling of power consumers from unnecessary and excessive use of power. More precisely, DR based programs offer incentives to electricity users to change their power use in response to a utility's need for power due to a high, system-wide demand for electricity or emergencies that could affect the transmission grid. In electricity grids, DR is similar to dynamic demand mechanisms to manage end users' consumption of electricity in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. In Smart grid environment, the change in demand pattern may be shifting of load to a better time, may be intended to match the load with available generation, may be a hard instruction to change demand by a specified amount