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A COMPREHENSIVE REVIEW OF OPTIMAL DEMAND SIDE MANAGEMENT AND ITS INFLUENCE ON ENHANCING DISTRIBUTION NETWORK CONGESTION MANAGEMENT

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Abstract

The aim of demand-side management (DSM) in the electric power distribution network is to manage congested systems and balance supply-demand at operating conditions thereby reducing systems losses, system reliability improvement and voltage stability. For the past fourteen (14) years, researchers have proposed various methodologies that include artificial intelligent-based techniques to implement DSM in the distribution network. This paper x-ray a comprehensive bibliographical study and general backgrounds of researches and developments in the areas of demand-side management (DSM) and optimization using modern heuristic tools in over thirty (30) published articles that were evaluated. The advantage of this comprehensive evaluation is to provide a reference point for educational development on the recently published articles in the areas of DSM and to stimulate research interest.

Keywords: *Artificial intelligent-based optimization techniques, Congestion management, Distribution network, Demand-side management.*

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1. INTRODUCTION

Optimal demand-side management (ODSM) is one of the best and cost-effective methods of energy management techniques deploy on the consumers' side meter. Nowadays the ever-increasing energy demand has necessitated the utility engineer to think of the best ways of supplying the inadequate electricity generated to customers more efficiently and reliably. This can be done by reducing losses in the transmission and distribution networks and also, the peak load demand through the demand-side management (DSM) techniques thereby increasing the systems' capacity. Energy management system (EMS) is an efficient and cost-effective way of meeting customers' energy demand, and the demand has become more variable in recent decades adding significant stress (congestion) to the grid [1]. Hence, DSM has been seen traditionally as a means of reducing peak electricity demand to manage the congested grid so that utilities can delay building further capacity [2]. Reducing the overall load on the electricity network, DSM has various beneficial effects, including mitigating electrical system emergencies, reducing the number of blackouts and increasing the system reliability; and also, DSM has a major role to play in deferring high investments in distribution network [2] and the congestion management side.

"DSM is a set of interconnected and flexible programmes which allow customers a greater role in shifting their own demand for electricity during peak periods and reducing their energy consumption overall. DSM programmes comprise of two principal activities: demand response programmes or "load shifting," on one hand and energy efficiency and conservation programmes on the other hand" [3]. In addition, DSM includes all measures, programmes, equipment and activities that are directed towards improving efficiency and cost-effectiveness of energy usage on the customer side of the meter.

In Nigeria today, the common energy management system carried out by the utilities is load shedding and they do this due to various reasons and limitations in the network namely:

a. Poor System Generation
b. Equipment Limitations:
   - Line Limitation
   - Circuit Breaker Limitation
   - Transformer Limitation
c. Management Load Shedding

This is done to manage the supply-demand and also to minimize system congestion. Indeed, numerous researches have been done with the aim of matching the supply-demand while maintaining the supply quality and reliability. DSM was also used in load balancing, increase in reliability of the network and most especially supply-demand balancing while focusing on the network stability and

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reliability. The concept of demand-side management (DSM) was invented and began modestly in the late 1970s [3]; it was originally referred to as demand-side load management, and over the decades, the DSM techniques have been explored and expanded relevantly in managing supply-demand and system congestion. This paper presents a holistic evaluation of the work done on demand-side management and its influence on enhancing system congestion management for the last fourteen (14) years.

2. LITERATURE REVIEW

Padhy (2002) presented technology development and progress made in the field of distribution automation system (DAS) and demand-side management (DSM) in Indian utilities by the technical institutions/industries/research laboratories. The urgent need and importance of DAS and DSM to meet up with energy demand, cost-effectiveness and the technical feasibility were surveyed in the Indian utilities. The results showed that the influence of DAS and DSM in load control, feeder automation and the automatic meter readings (AMR) which were found to be very much useful in curtailing the misuse of power and provides power quality to customers compared to other functions [4]. Gabaldon, Molina, Roldan, Fuentes, Gomez, Ramirez-Rosado, Lara, Dominguez, Garrido and Tarancon (2003) presented a stochastic state-space model for loads and a simulated typical urban power system. The results showed savings both in costs and transport losses [5]. Yang, Zhang and Tong (2006) presented a system dynamics approach for designing energy for demand-side management (DSM). The price was split into capacity and a quantity part, and also a government-driven policy was derived [6]. De-Ridder, Hommelberg and Peeters (2009) reported the business impacts of demand-side management (DSM). Four business models were analyzed in a region of three hundred (300) households with three various types of electric devices simulated: load with storage (e.g boiler), deferrable loads (e.g, dishwasher) and real electric storages (e.g; batteries). They focus on the area level, i.e., making an area or region more self-sustainable with regards to power consumption, and it was entirely market-based. It results shown that flexible loads can be very attractive for distribution system operators (DSOs) when used for substation peak load shaving [7]. Panchal (2010) presented load rationing as a new concept for the effective way forward for demand-side management (DSM) to combat power shortage especially at peak demand in the distribution network. He reviewed the energy demand profile of the Indian utilities and the current load shedding method or way of managing power shortage as a drawback and disadvantage to the common man and the reliability of the network due to frequent power interruptions. A load rationing concepts were proposed which can be achieved by installing a smart meter with load limits disconnect switches at the consumer premises that will aid the reliability and smartness of the distribution system [8]. Shanthi and Rajalakshi (2011) presented the current advancements and technologies used in demand-side management (DSM) for the smart grid. They suggested two important DSM technologies: Power factor correction and co-generation; and the ways to implement the techniques in smart grid to achieve energy security, grid reliability, economic growth and national competitiveness. The benefits of implementing DSM was highlighted and the challenges of timely development of a smart grid system [9]. Palensky and Dietrich (2011) presented the overview, taxonomy and various types of demand-side management (DSM) that is currently been developed. The report gives the outlook on the current demonstration of projects in DSM achievements, drawbacks, and areas of operation today. They concluded that open ADR and IEC61850 DSM program has received broad acceptance and that when designing ICI-based DSM, all security requirements are important and need to be taken into consideration [10]. Diskin and Fallon (2012) presented the investigation of demand-side management (DSM) resource and network measurements. The ESB Networks were used as a test system and the measurements were analyzed and applied in advanced simulation and modeling so that loss reduction achievable could be quantified and the reliability of the load response can be evaluated. The advanced simulations and modeling were carried out and the results showed that all the DSM resources investigated maximally influence the ESB Networks in terms of peak load reduction, increase in reliability, cost-saving, local voltage management and operability of the resources [11].

Raabe and Ullmer (2013) suggested the legal aspects concerning the future market of demand-side management (DSM) services and the underlying information and communication technology (ICT) infrastructure necessary to handle the DSM services. The report further pointed out where the legislator and regulatory bodies should adapt or extend the existing regulatory framework in Germany grids. Conclusively, the report stated that the regulatory framework necessary to create and regulate a functioning competitive market for local demand-side management and necessary ICT – based DSM infrastructure are barely in existence now, especially binding standardization of communication ways and protocols as well as the definition of market roles, which needs further research from legal point of view and further detailed regulations [12]. Recently, Heussen, You, Biegel, Hansen and Andersen (n.d) presented a conceptual understanding of classification analysis of indirect control strategies in demand-side management (DSM). The control concepts and the analysis of indirectness to create a framework for systematic classification of indirect control strategies was reviewed. The developed concept enables the control performance and evaluation of direct and the indirect control strategies on active DSM, but they didn't address the integration and evaluation of mixed portfolios of direct and indirect control [13].

Omorogiuwa and Elechi (2014) presented how a smart grid system on demand-side management (DSM) can help in ensuring constant power supply, optimum use of supplied power and implementation of appropriate fault finding technologies with the benefits of DSM. A case study was

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carried out on 11kV power distribution network on Abuja Campus, University of Port Harcourt, River State, Nigeria with and without DSM application during peak and off-peak periods. With the DSM application, smart meters and smart distribution board were installed to implement DSM on the consumer side for effective energy management. The results showed that with DSM 27.4% energy saved during the peak period and 37.3% energy saved during the off-peak period but there was no real implementation of DSM programme and there were many assumptions in the work [14]. Atasie (n.d) developed a mathematical model approach using the steepest ascent method to evaluate the impact of demand-side management (DSM) on power system operation and planning in terms of daily peak demand and cost of electricity consumed for a typical residential building in Lagos State, Nigeria. The developed method was applied to a residential building with and without DSM during peak demand. The results showed that the peak demand was reduced from 11.23kW to 3.19kW which is 71.95% decrease and the cost of electricity consumption was also reduced from ₦68.64 to ₦18.97 which is 72.36% decrease [15]. Harish and Kumar (n.d) presented the approach and concept used for demand-side management (DSM) in India. A comprehensive methodology for implementing DSM programmes in India was outlined with detailed stepwise action plan formulated for planning and implementing DSM programmes in India but the cost of implementing DSM and the energy saved by DSM programme were not holistically evaluated [16]. Shi, Li, Xie, Chu and Gadh (2014) proposed a distributed demand response (DR) scheme for load service entity (LSE) and home energy management system (HEMs) operation to jointly compute the optimal demand schedule. The DR scheme was modeled as an optimal power flow (OPF-r) problem to solve using the predictor-corrector proximal multiplier (PCPM) algorithm and the performance of the DR scheme was evaluated by simulating the scheme using the modified IEEE 13 node distribution system. The simulations results shown that the scheme can actually or effectively manage the appliances of the homes in the distribution network to keep the system demand under the demand limit and to maintain the bus voltage levels within the allowed range during the DR event with location and rebound effects noticed during the scheme which were not addressed [17].

Meiling, Steinbach and Schemidt (n.d) presented an approach for scalable demand-side management (DSM) using multicast technique over public internet service providers (ISPs) networks. The concept was achieved by the implantation of prototype HVMcast architecture and their aim was that the DSM mechanism balances the variable energy output from the renewable resources and energy usage to level the load on the power grid. The results of the model shown that using the multicast, energy consumers can easily be controlled in a scalable manner by pooling device into groups [19]. Ramanathan (2014) examined the problems of demand-side management (DSM), effective implementation of the smart energy system and their roles in alleviating peak load and sub-optimal energy saving in households. Ramanathan argued that the solution to the problems was the application of information and communication technology (ICT), application modeling and behavioural understanding of DSM approach. The DSM approach comprised of parallel application of energy efficiency and demand response (DR) to manage peak load; the use ICT to energy management as the cornerstone of turning Smart Grids to result in smart energy infrastructure was evaluated. The core achievements of the DSM for households were to obtain granular consumption data and utilize it for meaningful feedback and DR but without a carefully designed system, there is a risk that the investment in the infrastructure will not fetch any benefit [19]. Galvan-Lopez, Taylor, Clarke and Cahill (2014) proposed a stochastic evolutionary-based optimal or near-optimal solutions that schedule the number of electric vehicles (EVs) charging in the grid at the same and to be fully charged at the time of departure. A single source scenario was considered and simulations were carried out using the well-developed GridLab – D. The simulations results obtained by the techniques were highly encouraging in both: EVs being almost fully charged at time of departure and the transformer load being reduced as result of avoiding turning on the EVs at the same time, but the state of charge (SOC) achieved by the approach was not reported [20]. Zheng, Wu, Zhang and Sheng (n.d) presented residential direct load control (DLC) scheme that enables load service entity (LSE) to adjust electricity usage by consumers at home. The scheme jointly maximizes LSE and households with the consideration of their operational constraints in an unbalanced three-phase distribution network with the extension of residential demand response model to a more elaborate and realistic formulation. The optimization package CPLEX was used to solve the model and the scheme was implemented in MATLAB environment with simulations using the modified IEEE standard distribution system. The simulations result showed that the suggested scheme can effectively shave peak load in the unbalanced distribution network, but the scheme didn't address the privacy issues of the system or customers [21].

Sinha (n.d) presented power scenario of India and ways to improve the current power situation through sectoral reforms driven by energy efficiency (EE) and demand-side management (DSM). The report carried out a realistic review of the India power sector and suggested comprehensive and integrated strategies of supply-side imperatives with DSM and EE of a 25 – 35% energy saving potential through EE and DSM as estimated but implementation of the programmes were not carried out [22]. Ghicajanu (n.d) presented the world energy efficiency policies and demand-side management (DSM) benefits. The report explores the integrated resource planning (IRP) and demand-side management (DSM) processes for meeting future electricity demands and selects the optimal mix of resources that minimize the cost of electricity supply while meeting reliability needs and other objectives as well as DSM date of initiation. It was shown from the report that DSM studies in China and other countries can reduce

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electricity usage and peak demand approximately by 20 – to – 40% [23]. Dethlefs, Preisler and Rens (2014) presented demand-side management (DSM) oriented Multi-Agent System (MAS) paradigm for distributed optimization of consumers. Their approach focuses on the automated use of flexibility potentials on the consumer side and the Ant Colony System (ACS) algorithm was used as an efficient distributed optimization tool with generic software architecture to solve the operation of the Large-scale distributed demand side and it was integrated into the electricity market. A use-case study of 100 active domestic households was simulated and the results showed that the ACS finds very good solutions and a better performance to effectively optimize consumers in a nature-inspired and self-organizing way compared to Ant System (AS) and Greedy algorithm [24]. Zhao, Wang, Zhao, Lin, Zhou and Wang (2014) presented a review of recent advancements and identify emerging technologies and future development trends to support active distribution management (ADM). Various management framework, active voltage and energy management methods, active protection and fault location techniques, demand-side management and agent-based management strategies for ADM were critically reviewed. Finally, the future trends of energy storage, customer participation and the concept of virtual micro-grid for active management of distribution network were highlighted [25].

Dhend and Chile (2015) proposed the smart distribution management system (DMS) using the smart meters that can be implemented for real-time distribution system automation and monitoring in context to the deployment of today's smart grid scenario. The report reviews the existing distribution monitoring system of Indian, the necessity of smart distribution system and the features of smart distribution management system (DMS). Finally, the report highlighted the benefits of implementing smart DMS but the challenges of insecurity of data collections were not addressed [26]. Hungerford, Bruce and MacGill (2015) presented modeling software tools used to examine DSM for renewables integration in large power systems. The report reviews the suitable approaches to modeling of DSM for renewables integration in the Australian National Electricity Market (NEM) and DSM methods. They suggested that the effect on the market of real-time pricing (RTP) schemes in the presence of price-responsive load are important to explore and the DSM modeling within energy system simulation software is highly desirable to enable more realistic assessment of the likely costs, benefits and risks associated with the increased implementation of DSM [27]. EI Safty, EI Zonkoly and Hebala (2015) presented the utilization of demand-side management (DSM) in order to minimize the peak demand within each of the residential, commercial and industrial sectors. Load shifting DSM technique was used to schedule controllable devices of different types at various hours of the day bringing the final load curve closer to an objective load curve or shape. Both utility and customer benefits were taken into consideration using particle swarm optimization (PSO). The suggested algorithm was applied to Alexandria power grid and the simulations result show that the proposed DSM technique comprehends reasonable savings to both utility and consumers simultaneously while reducing the system peak load better when compared with the genetic algorithm (GAs) [28]. Engr. Okhumeode (2016) presented the description of demand-side management (DSM); energy efficiency (EE) and various load shape objectives. The report exposes various barriers to DSM and EE, and provided ways to ameliorate the barriers and efficiently actualizing the DSM and energy efficiency with their benefits [29]. Recently, Iranmanesh and Rashidi - Nejad (n.d) presented a heuristic approach to reducing losses of congested distribution line via FACTS devices. The method employed real genetic algorithm (RGA) for optimization process while analytical hierarchy process (AHP) with dimensional serialization valuing mechanism was implemented to evaluate RGA fitness function in congestion management, and the effectiveness of the method was tested with a 33-bus radial distribution system which is simulated using MATLAB 2008 software. The simulations result showed that TCSC and SVC that are the main commercially available FACTs controllers, support system congestion relief while voltage profile was improved simultaneously [30]. Hang, Wu, Liu and Nielsen (n.d) carried out reviews of the existing congestion management methods for distribution networks with high penetration of distributed energy resources (DERs) documented in the recent research literature. In the report, congestion management is grouped into two categories: 1. Market methods and 2. Direct control methods which are the dynamic tariff, distribution capacity market, shadow price etc., and network reconfiguration, reactive power control and active power control respectively. Finally, the report concluded that the market methods should be used for congestion management but it is important to have the direct methods as a backup for the indirect methods (Market methods) in the congestion management system [31]. Manikandan, Raja, Venkatech and Mandela (2011) presented a comparative study of two congestion management methods for power systems. The cluster/zone and the relative electrical distance (RED) methods for congestion management were simulated in MATLAB 7.3 environment using the sample 6-bus system, IEEE 30-bus system and the Indian 69-bus utility system. The simulations results of the two methods for the various cases study were compared and the results show that the RED method has better results in terms of time taken for congestion relief process was much less, rescheduling and generating costs were also significantly less for the RED method compared to cluster/zone method [32]. Ogujor, Omoruyi and Idiagi (2013) presented congestion management in the Nigerian 330kV transmission ring network. The electric power demand and the capacity of the network were critically reviewed, and simulations were carried out with and without a thyristor controlled series capacitor (TCSC) to evaluate the effectiveness of the device in reducing losses in the line. The TCSC was optimally placed using the line utilization factor (LUF) to determine the best location and the simulations result showed that the TCSC has the capacity in reducing power losses in the

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network of about 17.24%, thereby relieving the congested system [33]. Sheba, Kumari, Shanthi and Maheswari (2014) presented recent reviews on computational intelligence techniques for efficient power distribution and consumption. The clustering and classification techniques that were used to cluster load curves which assisted in formulating tariff policies, theft identification that is of great use to power distribution companies; dimensionality reduction techniques; regression techniques; supervised and unsupervised techniques that are used for load analysis and control; long, medium and short terms load forecasting and price forecasting that helps market participants were critically surveyed. Finally, the report sum-up that there is a clear move towards hybrid methods which combine two or more of the techniques which offer to develop and rapidly changing computational intelligence field in power distribution network [34].

3. ARTIFICIAL INTELLIGENT BASED OPTIMIZATION TECHNIQUES

Distribution system supply-demand management, system congestion and loss minimization are dealt with effectively using Evolutionary algorithms and swarm intelligence techniques [34]. Modern heuristics or artificial intelligent-based optimization techniques try to simulate living organisms (human) behaviour. These intelligent-based tools present a better, faster and accurate solution to an optimization problem than the existing conventional (classical or traditional) optimization techniques [35]. The mimicking behaviour of living organisms by the algorithms when simulated on a computer environment is known as artificial intelligent. These artificial intelligent-based tools provide the utilities' engineers with innovative solutions for efficient analysis, optimal operation and control, and intelligent decision making [34]. Hence, some artificial intelligent-based optimization techniques used recently for optimal demand-side management and system congestion; and optimal decision making problems in DSM are briefly explained below:

3.1 Genetic Algorithm (GA)

"Genetic algorithm (GA) is a search algorithm that based on the conjecture of natural selection and genetics. The features of a genetic algorithm are different from other search techniques in several aspects. Firstly, the algorithm is a multipath that searches many peaks in parallel, hence reducing the possibility of local minimum trapping. Secondly, the GA works with a coding of parameters instead of the parameters themselves. The coding of the parameter will help the genetic operator to evolve the current state with minimum computations. Thirdly, the GA evaluates the fitness of each string to guide its search instead of the optimization function" [36]. The GA work with a population of individuals represented by bit strings and modifies the population with random search and competition [37].

3.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is an exciting new methodology in evolutionary computation that is somewhat similar to the genetic algorithm in that the system is initialized with a population of random solutions [36]. PSO is a population-based search algorithm, which solely depends on the behavior of the flock of birds or schooling of fish. "In PSO, a number of particles are randomly generated to form a population and are discarded, like in GA. The search behavior of a particle is therefore influenced by that of other particles within the swarm. PSO can be said to be a kind of symbiotic cooperative algorithm" [37]. PSO has been found to be extremely effective in solving a wide range of engineering problems [36].

3.3 Ant Colony Optimization (ACO)

Ant Colony Optimization (ACO) is based on foraging techniques of real ant colonies. ACO tool mimic the behavior of real ants. "Real ants are capable of finding the shortest path from food sources to the nest without using visual cues. They are also capable of adapting to changes in the environment, e.g, finding a new shortest path once the old one is no longer feasible because of a new obstacle. Studies by ethnologists reveal these, such capabilities are essentially due to what is called "Pheromone trails," which ants use to communicate information among individuals regarding the path and to decide where to go" [36]. ACO algorithm is a tool that tries to find the shortest path from point A to point B by mimicking real ants' situation that finds the shortest path between the food source and nest without any visual, central and active coordination mechanism.

4. CONCLUSION

The importance of optimal demand-side management in managing or matching supply-demand and its influence in relieving systems congestion has been comprehensively highlighted in this literature evaluation. The crucial part of the article is the review of the use of modern heuristics or artificial intelligent-based optimization techniques on the demand-side management in selecting the best ways of energy management and capacitor bank placement for the system. Furthermore, the evaluation shown that much work has not been done on optimal demand-side management on the Nigerian distribution networks using optimal DSM and demand-side management tools, hence, the need for the comprehensive literature survey. The paper is based on many research published since last fourteen (14) years on the application of DSM to distribution network and grid congestion management and also, the paper will serve as eye opener to power system researchers, distribution station operators, utility managers, practitioners; and in addition, it will provides a formidable ground for further research in the area of DSM.

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