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The Role of Demand Side Management for Efficient Energy Management in Distribution Systems: A Case Study

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Abstract

The rate of growth of unserved load in the Nigerian power systems currently is as a result of the ever-growing gap created between the energy demand and available power supply, which is one of the major causes of frequent power interruptions in the network. Thus, stabilizing the network, efficient energy management is required on the consumers' side to equalize the available power supply with the ever-growing energy demand by the consumers; of which demand side management (DSM) is a veritable tool which can be deployed to match the ever-growing energy demand with the available power supply. Consequently, this paper presents the role of DSM for efficient energy management in the distribution system as a case study in the Nigerian power systems. The Ugbowo distribution network was used as a model; the shifting and switching techniques were adopted as a way of managing the ever-growing load demand by consumers in the network with the available power supply. The shifting technique was used as a direct load control (DLC) method in the network to shift the deferrable loads from peak period to off-peak or intermediate period and all these were carried out during the peak period to flatten the load spikes curve to an objective load curve in the network. The results showed that the techniques can match the available power supply with the ever-growing energy demand in the network, thereby improving the availability of the feeders and its associated power transformers in the system.

1.0. Introduction

A stable and reliable power supply is key to socioeconomic development and industrialization of a nation. A country's standard of living and degree of economic development is primarily determined by its energy use, generation and distribution; and its influences in productivity and overall economic growth [1]. Every developed nation has conquered inadequate and epileptic power supply in their national grid. Hence, efficient management of available energy in a nation is pivotal to stable and reliable power supply to consumers. But in recent times in Nigeria, the frequent power interruption at the distribution level became worrisome to consumers. According to [2] the frequent power interruption in the distribution network of the Nigeria power system calls for serious attention of all stakeholders in the network. This is because the energy demand in Nigeria currently far outweighs the electricity supply. This has created a huge gap between power supply and energy demanded currently and it is causing a high energy deficit in the National Grid today. The frequency of the National Grid collapse may not be unconnected to this huge energy deficit currently, but it is on record that the National Grid of Nigeria collapsed one hundred and five (105) times in ten (10) years [3]. This is astronomical for healthy power systems. According to [4] Nigeria as a country with population of over 200 million people should be targeting about 200,000 MW of electricity generation instead of 3500 to 5000 MW, if it aspires to attain industrialized nation status; this establish that there is huge energy supply gap in the Nigeria power system with the current load demand. From the aforementioned, the national grid has a lot of constraints ranging from poor generation to faults. According to [5] and [6] the Nigerian utility companies carried out energy management due to various reasons and limitations in the network namely:

a. Poor Generation in the system
b. Equipment limitation
c. Load shedding

These have affected the reliability of the system in terms of continuous electricity supply to consumers when it is needed, etc. especially in the distribution networks. According to [7] distribution network is a key part of power systems that facilitate the energy supply to consumers from the distribution network. Therefore, efficient management of the demand side of the network is key to the reliability of the distribution systems. The reliability of the distribution network is very significant to the continuous supply of electricity to customers in the network. Therefore, according to [8] applying demand side management to distribution systems makes it efficient, robust and reliable. Demand side management (DSM) is one of the most important features of smart grid that enables the electricity provider to manage high load demand within the available energy resources [7]. DSM helps to manage the available electricity with the ever-growing load demand from customers. According to [9] DSM alters customers' electricity consumption patterns to produce the desired changes in the load shapes of power distribution systems. Since generation of electricity in Nigeria currently is inadequate to meet the load or energy demand by its customers. Efficient energy management becomes a vital tool to bridge the energy gap created between the available electricity supply and the ever-growing energy demand by consumers, especially the demand side management. DSM is a method used in reducing electric energy usage through the promotion of activities that can enhance electric energy efficiency and conservation or more efficient management of electric load [10]. DSM reduces electricity consumption in homes, offices and factories by continually monitoring and actively managing how appliances consume energy. DSM is one of the new trending technologies which began modestly in the United State (US) with the view of playing a significant role in load management so as to bring the load curve to an objective load curve with the available electricity supply [10]. Also, according to [2] opined that DSM technologies is not new but recently, different approaches and algorithms are being explored in energy demand management activities to bring the electricity demand and supply closer to an objective shape or curve to manage the available power. DSM works to reduce electricity consumption in homes, offices, and factories by continually monitoring and actively managing how appliances consume energy [11]. It consists of demand response (DR) programmes, smart meters, dynamic electricity pricing, smart buildings with smart appliances, energy efficiency programmes and energy dashboards [11]. DSM is also referred to as a set of measures that allows the energy providers to reduce the peak load demand and to reshape the load curve of the system with the aim of bringing the final load curve closer to an objective load curve in order to improve the electric energy supply at the side of the customers.

1.1 Brief History of Demand Side of Management

Demand side management (DSM) programmes began modestly in the 1970s in response to growing concerns about dependence on foreign sources of oil and environmental consequences of electricity generation, especially nuclear power [12]. From then, DSM programmes grew rapidly during the

1980s as a regulatory measure that provides incentives for utilities to pursue least cost or as an integrated resource for planning [13]. Its function encompasses the systematic activities of utility and governmental policies designed to influence the amount and or/timing of the customers' use of electricity for the collective benefit of the society, utility and its consumers. The importance of energy management cannot be overemphasized presently and even in the future grid since building new plants is capital intensive. DSM is a veritable technique for equalizing the ever-growing energy demand with electricity generated. According to [14] DSM is an integral part of smart grid and it includes all activities that aim to reshape the consumer's load profile, resulting in reduction in the peak load demand. Energy management is a structured management technique that enables an organization to identify and implement measures for reducing energy consumption and cost. The overview of energy management strategies is depicted in Figure 1 [2]. The role of DSM in managing the available energy with the ever-growing energy demand is system wide and encompassing in nature. Consequently, the research aims at evaluating the role of demand side management for efficient energy management in distribution systems using Ugbowo distribution network as a case study.

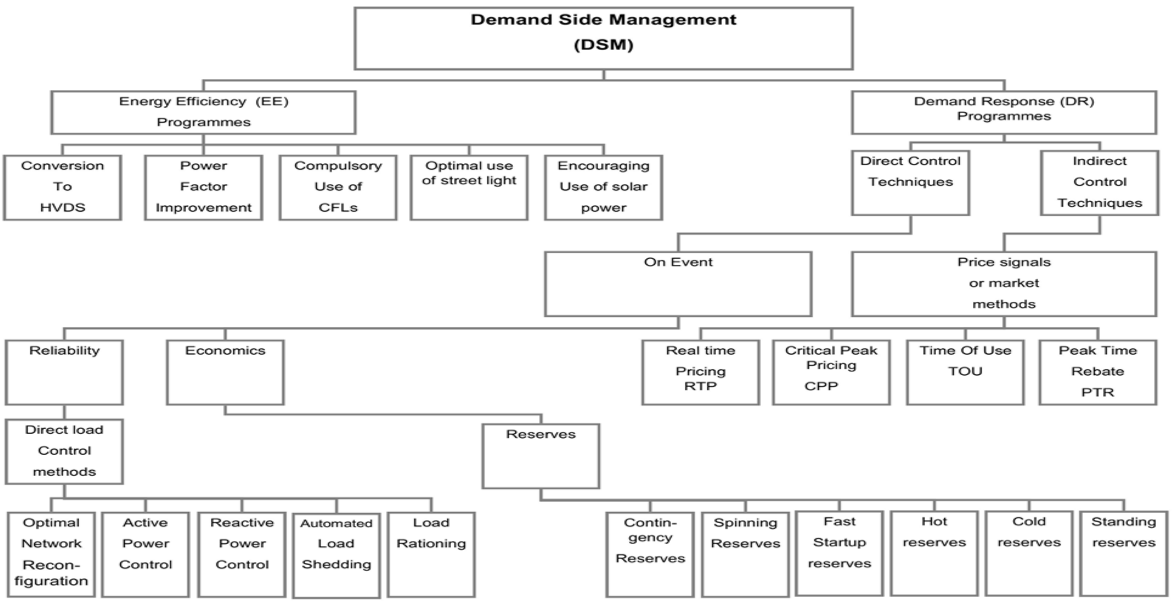

Figure 1: Overview of Energy Management Strategies

1.2 Types of Demand Side Management

DSM is a broad concept encompassing energy efficiency (EE) measures, behavior-based energy conservation (EC) and demand response (DR) measures. But DSM programmes can be majorly classified into [11]:

1) **Energy Efficiency (EE) Programmes:** "refers to programmes that aim at reducing the energy used by specific end-use devices and systems, typically without affecting the services provided. These programmes reduce overall electricity consumption, often without explicit consideration for the timing of programmer-induced savings" [15]. EE is also known as energy efficiency measures, it consists of actions taken to improve the efficiency of the entire distribution system by the adoption of energy efficient technologies, energy conservation measures and having an energy accounting and energy audit system [16]. The goal of EE is to reduce the amount of energy required to provide products and services [17]. The

improvements in energy efficiency are generally achieved by adopting a more efficient technology or production process [18] or by application of commonly accepted methods to reduce energy losses [17]. According to the International Energy Agency (IEA), improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gasses [19]. Energy efficiency and renewable energy are said to be the twin pillars of sustainable energy policy [20] and they are high priorities in the sustainable energy hierarchy [21].

2) **Demand Response (DR) Programmes:** It refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period, network congestion or high price) [22]. DR is a change in the power consumption of an electric utility customer to match the demand for power with the electricity supply. Electric energy cannot be easily stored in bulk form, so utilities have traditionally matched energy demand and supply by throttling the production rate of their power plants, taking generating units on or offline, or importing power from other utilities. There are limits to what can be achieved on the supply side because some generating units can take a longer time to come up to full power or capacity, some units may be very expensive to operate, and demand can at times be greater than the capacity of all the available power plants put together. Demand response seeks to adjust the demand for power instead of adjusting the supply" [23]. "If enough consumers comply with this approach, utility companies will not need to dispatch an additional power plant on the most expensive asset they operate. To increase the number of consumers who comply, utility companies may offer cash payments or reduced billing. In principle, DR initiatives can bring about significant reductions in electricity prices as shifts of demand during peak period, and it could reduce the need for higher marginal cost generation, offer lower cost system balancing and decrease grid reinforcement investment" [11].

2.0 Materials and Methods

The materials and methods used in this paper are presented in this section. The materials are presented in section 2.1 and the methods adopted are described in section 2.2

2.1 Materials

The materials used for this study include simulation software, remote controlled switches (RCS), input data and optimization tools.

2.2 Methods

The load shifting technique is proposed for the four feeders and its associated transformers using the direct load control (DLC) method. The objective of the technique is to initiate and optimally select the remote-controlled switches (RCS) introduced in the distribution network using the DLC method to bring the current load curve closer to an objective load curve that matches the available electricity supply, so that the objective of the DSM is realized. DLC is a way to reduce the demand for electric energy by consumers using various techniques. It is also a way customers allow the utility to control the manner at which electric energy consumption is consumed by customers during peak hours of the day by giving some incentive. The proposed DSM scheme is based on direct load shifting operation which is implemented on MATLAB Simulink with the associated power transformers grouped into a cluster and the DLC technique was adopted for the scheme operation using the Binary Particle Swarm Optimization (BPSO) Algorithm.

2.3 Binary Particle Swarm Optimization Algorithm for the Optimal Switching Technique DSM Scheme

Figure 2 showed the binary particle swarm optimization (BPSO) algorithm flow chart used for the optimal load switching operations to carried out the switching on/off of controllable loads in the distribution network to match the available electricity supply with ever-growing energy demand.

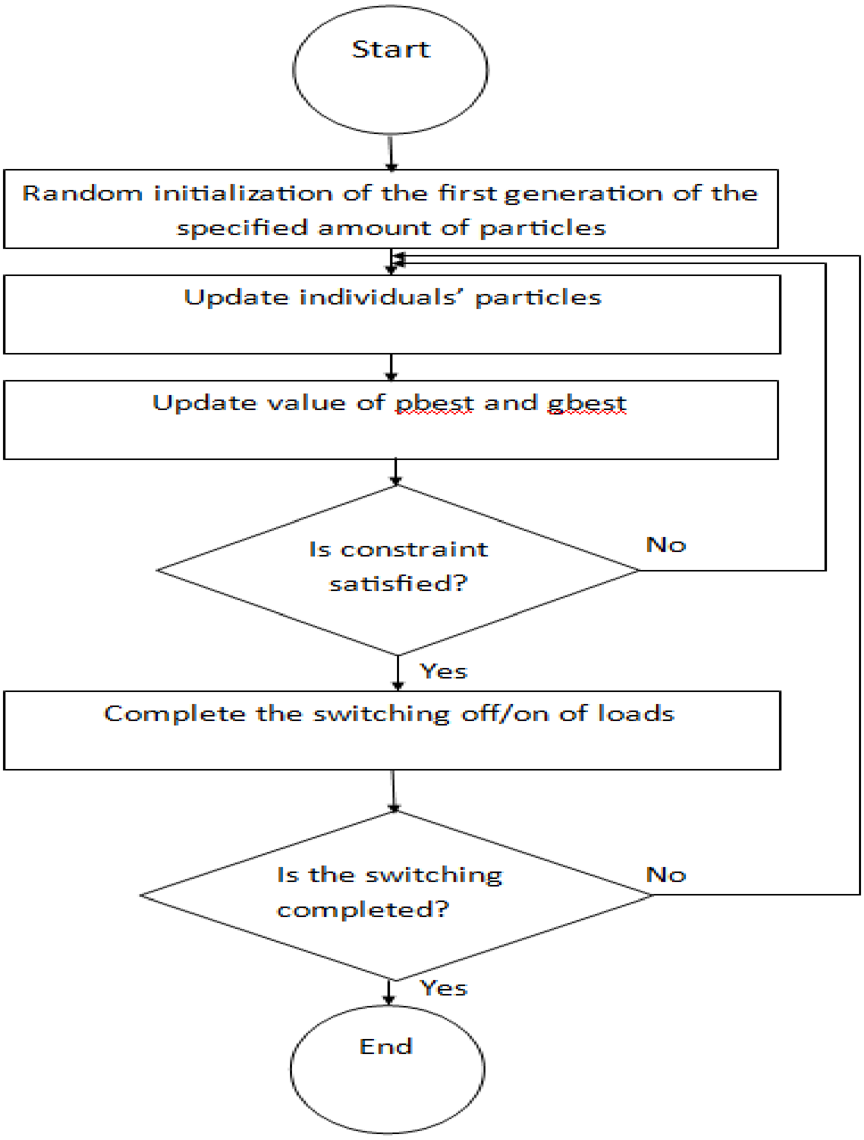

Figure 2: Flow Chart of BPSO Algorithm for DSM Model [10]

3.0. Results and Discussions

The results and discussions of this paper are presented in this section. The results are presented in section 3.1 and the discussions adopted are described in section 3.2.

3.1 Results

The results of the research are presented in Figure 3 and 4, Table 1 and 2 respectively.

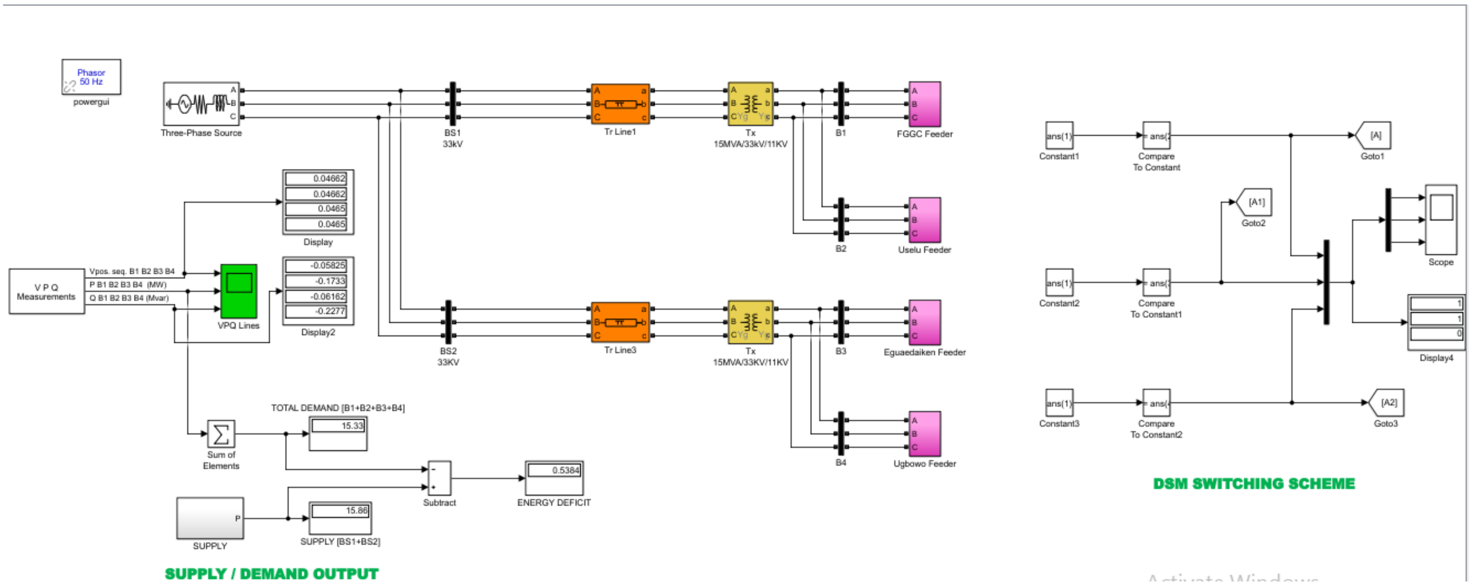

Figure 3: Simulink Model of DSM for the Distribution Network

Table 1: Existing and Proposed Switching Technique for the Distribution Network

<table>
<tr><th colspan="4">Existing Switching Technique</th><th colspan="2">Proposed Switching Technique</th></tr>
<tr><td>FGGC Feeder</td><td>Uselu Feeder</td><td>Eguaedaiken Feeder</td><td>Ugbowo Feeder</td><td colspan="2">All Four (4) Feeders</td></tr>
<tr><td>ON</td><td>ON</td><td>OFF</td><td>OFF</td><td colspan="2">All Four Feeders ON</td></tr>
<tr><td colspan="2">36.62% of the area of the network supplied with electric power</td><td colspan="2">63.38% of the area of the network is on blackout</td><td>85.92% of the area of the network supplied with electric power</td><td>14.08% of the area of the network is on blackout</td></tr>
<tr><td>OFF</td><td>OFF</td><td>ON</td><td>ON</td><td colspan="2">All Four Feeders ON</td></tr>
<tr><td colspan="2">36.62% of the area of the network is on blackout</td><td colspan="2">63.38% of the area of the network supplied</td><td>85.92% of the area of the network supplied</td><td>14.08% of the area of the network is on blackout</td></tr>
</table>

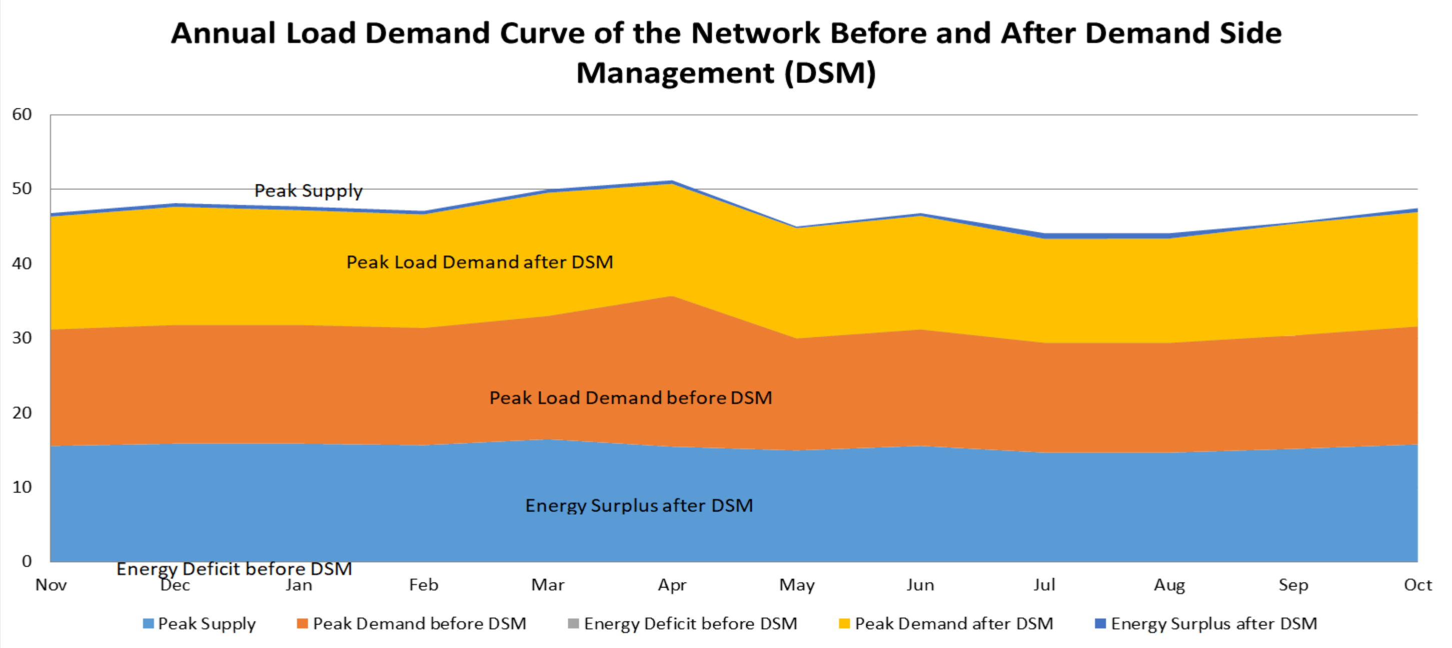

Figure 4: Load Curve before and after Deployment of Demand Side Management

Table 2: DSM Proposed Switching Pattern of the Feeders' Associated Power Transformers in the Distribution Network

Cases	00:00 – 03:00	03:00 – 06:00	06:00 – 09:00	09:00 – 012:00	12:00 – 15:00	15:00 – 18:00	18:00 – 21:00	21:00 – 00:00	Total Time of Service per Day
Case 1	OFF	ON	ON	ON	ON	ON	ON	ON	21 Hrs
Case 2	ON	OFF	ON	ON	ON	ON	ON	ON	21 Hrs
Case 3	ON	ON	OFF	ON	ON	ON	ON	ON	21 Hrs
Case 4	ON	ON	ON	OFF	ON	ON	ON	ON	21 Hrs
Case 5	ON	ON	ON	ON	OFF	ON	ON	ON	21 Hrs
Case 6	ON	ON	ON	ON	ON	OFF	ON	ON	21 Hrs
Case 7	ON	ON	ON	ON	ON	ON	OFF	ON	21 Hrs
Case 8	ON	ON	ON	ON	ON	ON	ON	OFF	21 Hrs

3.2 Discussion

If the energy gap created in the network is not addressed, the frequent outages of the 11 kV feeders due to overload or regimented scheduled outages because of the energy supply gap created will further lower the availability of the 11 kV feeders in the network. This is because of equipment limitations and inadequate energy generating capacity currently witnessed in the National Grid. In order to bridge this gap that has been created with these limitations in the distribution network under study and to increase the availability of the 11 kV feeders and also, the associated outdoor power transformers; the proposed DSM scheme was deployed to bring the load curve closer to the objective load curve that balances the ever-growing load demand with the available electricity supply. The associated power transformers (outdoor) were grouped into clusters and a discrete format was adopted in the automated switching method in the DSM scheme as shown in Figure 3. Optimal load shifting technique was initiated by the proposed method to reduce the blackout areas of the network from 63.38% or 36.62% in the existing switching technique to 14.08% in the proposed switching technique and also, to improve the availability of the four (4) 11 kV feeders from twelve hours per day to twenty-four hours as shown in Table 1. Each feeder associated power transformers availability was increased from twelve hours in the existing network to twenty-one hours in the proposed network using the DSM switching technique as shown in Table 2. Table 1 also shows a better energy management technique that improves the availability of the network feeders that feds the consumers from twelve (12) hours in the existing network to twenty-four (24) hours in the proposed network; and its associated substations (outdoor power transformers) availability from 50% to 87.5% per day in the proposed network which is twenty-one hours from the twelve hours in the existing network. The active power losses of the network were reduced by 75.96% for peak period and off-peak period by 69.99% in the proposed network with DSM implementation. This minimizes the excessive power losses witnessed in the existing network. The aim of the DSM strategy is to reduce the peak load demand and to reshape the load curve of the system to bring the final load curve closer to an objective load curve as shown in Figure 4 and also, to improve the electric energy supply at the consumer side thereby improving the efficiency of the network and availability of power supply.

4.0 Conclusion

The study highlighted the role of DSM scheme for efficient energy management in the distribution network of the power systems using the load shifting technique. The switching technique was deployed in the distribution network using the RCS which plays a vital role in the systems switching and the distribution network been the last section of the power systems, it plays a vital role in transferring energy to the consumer's premises in which each outdoor substation can be efficiently managed using the RCS. The stability of the distribution network and its continuous functionality ensure continuous power supply to the consumers. And if energy is to be manage, a better energy management technique that improves the availability of the network feeders that feds the consumers from twelve (12) hours currently to twenty-four (24) hours and its associated substations' (outdoor power transformers) availability from 50% to 87.5% per day which is twenty-one hours from the twelve hours currently is needed in the network. The proposed system had the capacity to reduce the blackout area of the network during the outage scheduling from 63.38% or 36.62% in the existing to 14.08% in the proposed network with power or loads rerouting capability that achieved objective load curve in the network as seen from Table 1.

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