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Demand Side Management Strategy for Alleviating Power Shortages in Nigerian Power System: A Case Study

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Abstract
This paper presents the simulation of demand side management (DSM) strategy for alleviating power shortages in Nigerian power system. The frequent power outages in the Nigerian power system especially in the distribution network which is caused by schedule and unscheduled outages in the system in which the schedule outages are predominant, is as a result of inadequate electricity generation and equipment limitations to meet the current ever-growing energy demand. The distribution network feeders' peak load and electricity supply was evaluated and data were collected from November 2017 to October 2018; to carry out the analysis of the network feeders' load and its management. Consequently, modeling of the proposed DSM strategy in Simulink environment and its optimization was done using the binary particle swarm optimization (BPSO) algorithm and, the simulations were carried out to test the efficacy of the model. The results of the simulations of the DSM strategy showed that the proposed method has the capacity to bring the load curve closer to an objective or desired load curve thereby reducing the blackout areas of the network per outage scheduling from 63.38% or 36.62% in the existing network to 14.08% in the proposed network and also, improved the 11 kV feeders' availability from twelve hours currently per day to twenty-four hours in the proposed network.

Keywords: BPSO algorithm, distribution network, demand side management, direct load control method, load shifting technique, outage scheduling

1.0 INTRODUCTION

Frequent power interruption in the distribution network of the Nigerian power system calls for serious attention of all stakeholders in the network. These is as a result of schedule and unscheduled outages occurring in the network with the schedule outages predominant in the system. The schedule outages in the network are caused by ever-growing energy demand by consumers which have outweighed the electricity supply today. This has created gap between electricity supply and energy demand currently. The electric energy demand in Nigeria currently far outweighs the electricity supply and, this has resulted to an increasing gap between electric energy demand and supply in the system. This has contributed to frequent power interruptions as a result of power shortages. A great margin has been created between electricity supply and demand due to ever-growing energy demand by consumers without commensurate growth in electricity generation in the Nigerian power sector. These create serious power issues such as frequent power outages which has hindered the socioeconomic and technological development. According to Akinbomi et al. [1] 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 Nigerian power system.

This huge gap has created power shortages in the network which has become a serious challenge in the Nigerian power sector in which engineers in the sector and affiliates are currently battling with for solution that will bridge or minimize the huge energy supply gap in order to meet the yearnings of consumers and forestall frequent power interruptions in the network. According to Sinha and De [2] energy demand and supply should be continuously balanced to avoid supply interruption. One of the ways to alleviate this power shortage in Nigerian power system is through demand side management. DSM is another option which is equally important and beneficial as that of distributed generation (DG) in improving the

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energy scenario [3]. DSM is defined by [4] as the implementation of policies and measures which serve to control, influence and generally reduce electric energy demand. Also, DSM was defined by [5] as an effective way of matching the demand for electric energy services with available central and distributed resources. Therefore, DSM is a veritable tool that can bridge the gap between ever-growing energy demand by consumers with the available electricity supply.

DSM has been recognized as one of the key enabler for cost-efficient energy transition. Especially, energy-intensive industries which contribute to energy transition by offering high potentials for grid stabilization and at the same time mitigate economic risks related to volatility in energy supply [6]. DSM depicts the technique used to monitor and control the efficient use of electric energy at the consumer side [2]. Generally, DSM strategies focus on the peak load demand, increasing efficiency and reduce operating cost in load scheduling [7-9]. DSM technologies is not new but recently, different approaches and algorithm are being explore in energy demand management activities to bring the electricity demand and supply closer to an objective shape or curve. Consequently, this paper focuses on demand side management strategy for alleviating power shortages in Nigerian power system as a case study of Ugbowo 2x15 MVA, 33/11 kV distribution network.

1.1 Brief History of Demand Side Management

Demand side management (DSM) programme 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 [7]. 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 [10]. It 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 important of energy management cannot be overemphasized in the present and even in the future grid since building new plants is capital intensive.

Therefore, DSM is a veritable technique for equalizing the ever-growing energy demand with electricity generated. Energy management is a structured management technique that enables an organization to identify and implement measures for reducing energy consumption and cost [11]. The overview of demand side management strategies is depicted in Figure 1.

2.0 RELATED WORK

In the existing literatures surveyed, several researchers have presented various assessments and investigations on the effectiveness of demand side management (DSM) to influence the energy consumption by consumers through load shifting and energy efficiency techniques for various networks. Some of these works examined the influence of load shifting in bringing the load curve closer to an objective load curve, while other assessed the potential benefits of energy efficiency in the network [12 – 18]. Specifically, [12] worked on the development of generic approach that enables devices to automatically determine their energy consumption using smart devices and electric vehicles (EV) in a park lot of the future grid. The results demonstrated the usefulness of the approach. In [13] clustering technique for grouping the time periods in DSM application was investigated. Model using the dynamic programming or greedy algorithm was developed. The results give time of use (TOU) segment that utility may use for selective pricing for peak and off periods to influence demand for purpose of load leveling. [14] evaluated the impacts of DSM on reliability of automated distribution system. The load shifting method was implemented in real-time and the results through sensitivity analysis may improve, worsen or have no significant effect on the system reliability. [15] studied home energy management in smart grid using BPSO algorithm. The load shifting method was implemented in Matlab/Simulink environment and the results showed that peak load shaving can be achieved by the proposed method. [16] carried out optimal residential demand response using IEEE test distribution system. The load shifting technique was simulated in the IEEE test system and the results showed two interesting effects such as the rebound and location effects. [17] investigated the techno economic and environmental effect of DSM technique on rural loads before design and sizing hybrid energy system.

The load shifting method was simulated using HOMER software and the results proved to be more economical and environmental friendly. Also, in [18] the difference between load management (LM) and demand side management (DSM) was evaluated. The LM was used for load shifting in peak periods to prevent tripping in the model using DigSILENT power factory software. The results showed improve economic status, stable and balanced system.

The literatures surveyed revealed that the demand side management has been applied for supply-demand balancing in abstract ways without taking into account the underlying power distribution network and its associated feeders. In the distribution network, the load and supply balancing is carried out to increase the availability of the feeders and service hour to consumers which has not been given adequate coverage. Therefore, this study aims to fill this gap. The goal is to initiate optimal switching technique in real-time scenario for load shaving and stability of the network feeders.

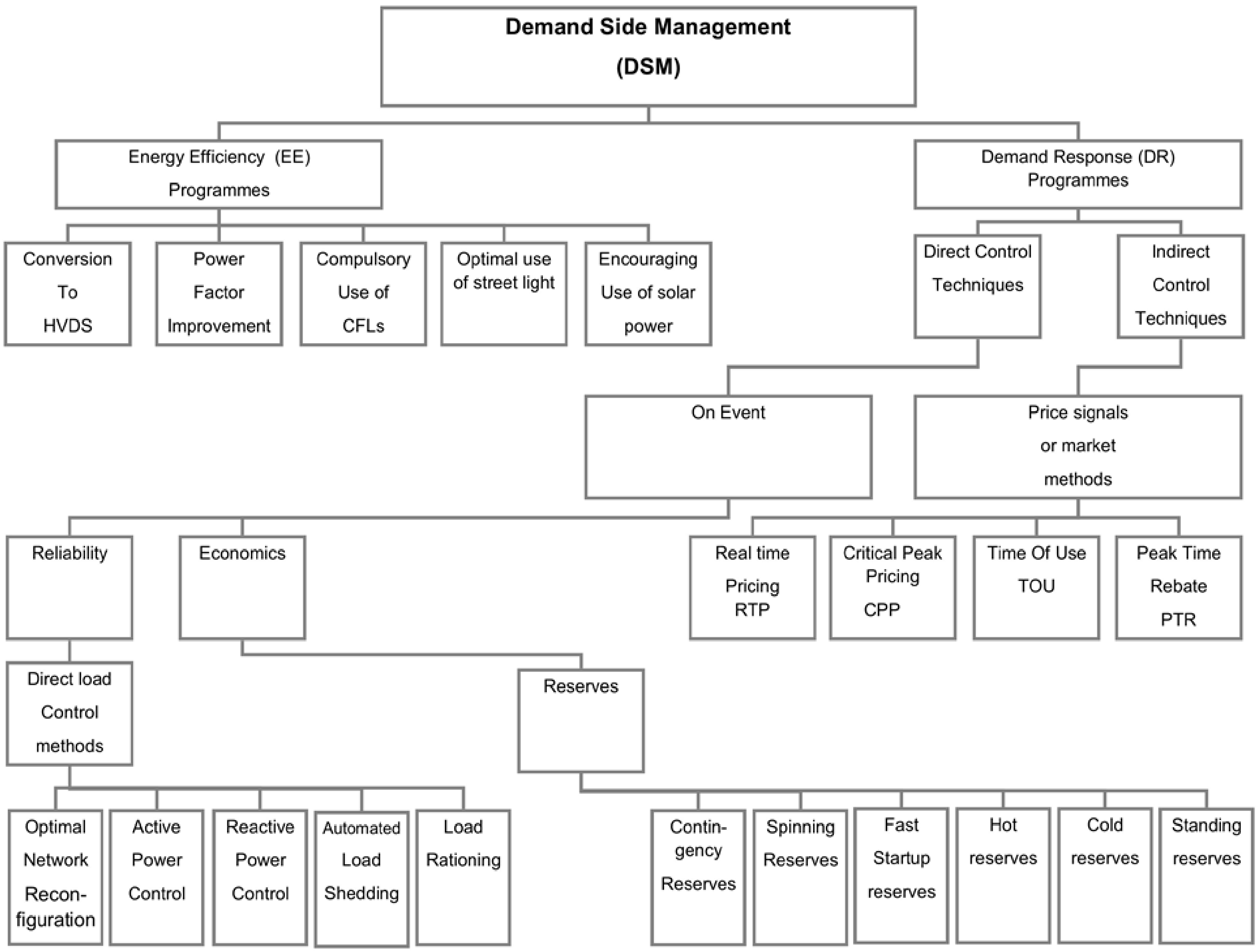

Figure 1: Overview of Energy Management Strategies

3.0 MATERIALS AND METHOD

The materials and method used in this paper are presented in this section. The materials are presented in section 3.1 and the method adopted is described in section 3.2

3.1 Materials

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

3.1.1 Input Data

The data required for this study include the transformer names and their ratings, peak load of the transformers in the four feeders of the network, the peak load of each feeder and peak supply to the distribution network. The peak demand and supply of the network was collected from November 2017 to October 2018 from the Ugbowo 2x15 MVA, 33/11 kV distribution network. Table 1 presented the peak demand of the four feeder and the peak supply with energy deficit in the network for the period under study.

Table 1: Peak Demand-Supply from November 2017 – October 2018

S/N	Time (Months)	Peak Supply (MW)	Peak Demand for Four Feeders (MW)	Energy Deficit (MW)
1	Nov. 2017	15.6	19.4	- 3.8
2	Dec. 2017	15.9	19.07	- 3.17
3	Jan. 2018	15.9	20.61	- 4.71
4	Feb. 2018	15.7	20.31	- 4.61
5	Mar. 2018	16.5	20.44	- 3.94
6	Apr. 2018	15.5	20.21	- 4.71
7	May 2018	15	19.6	- 4.60
8	June 2018	15.6	19.58	- 3.98
9	July 2018	14.7	16.39	- 1.69
10	Aug. 2018	14.7	15.26	- 0.56
11	Sept. 2018	15.2	15.17	0.03
12	Oct. 2018	15.8	16.95	- 1.15

3.2 Method

The optimal load shifting technique is proposed for the four feeders' associated transformers using the discrete binary particle swarm optimization (BPSO) algorithm. The objective of the algorithm is to initiate and optimally select the remote controlled switches (RCS) introduce in the network using the direct load control (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 demand side management is realized.

3.2.1 Mathematical Formulation of Demand Side Management (DSM) Strategy

The mathematical formulation of the DSM strategy was designed for the system feeders under consideration for ever-growing load in the network and the available electricity supply balancing. It explains how the available electricity supply and energy demand by consumers in the network feeders are balance by reducing the load on each feeder through direct load control (DLC) method. The DLC method employed the optimal load shifting technique which combines the benefits of peak load clipping and load valley filling methods to achieved the desired or objective of the demand side management using simple linear algebraic technique as [2, 19]:

For Feeder One (FGGC Feeder) Model

$$D_{FGGC(\max)}(t) = \sum_{t=1}^{T(d)} [E_{FGGC}(t) - (W_1 * \frac{P_{FGGC}^{C}}{x}(t) + W_2 * \frac{P_{FGGC}^{U}}{g}(t))]^2 \quad (1)$$

For Feeder Two (Uselu Feeder) Model

$$D_{Uselu}(t) = \sum_{t=1}^{T(d)} [E_{Uselu}(t) - (W_1 * \frac{P_{Uselu}^{C}}{x}(t) + W_2 * \frac{P_{Uselu}^{U}}{g}(t))]^2 \quad (2)$$

For Feeder Three (Eguaedaiken Feeder) Model

$$D_{Eg(\max)}(t) = \sum_{t=1}^{T(d)} [E_{Eg}(t) - (W_1 * \frac{P_{Eg}^{C}}{x}(t) + W_2 * \frac{P_{Eg}^{U}}{g}(t))]^2 \quad (3)$$

For Feeder Four (Ugbowo Feeder) Model

$$D_{Ug(\max)}(t) = \sum_{t=1}^{T(d)} [E_{Ug}(t) - (W_1 * \frac{P_{Ug}^{C}}{x}(t) + W_2 * \frac{P_{Ug}^{U}}{g}(t))]^2 \quad (4)$$

$$D_{T(\max)}(t) = W_{FGGC} * D_{FGGC}(t) + W_{Uselu} * D_{Uselu}(t) + W_{Eg} * D_{Eg}(t) + W_{Ug} * D_{Ug}(t) \quad (5)$$

$$DSM_{Curt}^{\max}(t) = [E_{FGGC}(t) + E_{Uselu}(t) + E_{Eg}(t) + E_{Ug}(t)]^2 \quad (6)$$

$$DSM_{Sh}^{\max}(t) = [\frac{W_1}{x}(P_{FGGC}^{C}(t) + P_{Uselu}^{C}(t) + P_{Eg}^{C}(t) + P_{Ug}^{C}(t)) + \frac{W_2}{g}(P_{FGGC}^{U}(t) + P_{Uselu}^{U}(t) + P_{Eg}^{U}(t) + P_{Ug}^{U}(t))]^2 \quad (7)$$

$$\Rightarrow D_{T\max}(t) = DSM_{Curtl}(t) - DSM_{Shl}(t) \quad (8)$$

Where:

$E_{FGGC}(t)$, $E_{Uselu}(t)$, $E_{Eg}(t)$, $E_{Ug}(t)$ are the energy consumption after load shifting at time, t for the various feeders of the network.

$P_{FGGC}^{C}(t)$, $P_{Uselu}^{C}(t)$, $P_{Eg}^{C}(t)$, $P_{Ug}^{C}(t)$ are the customers' objective consumption at time, t that was chosen to be inversely proportional to the time of day (TOD) tariff x in the network which aim to benefit the costumers.

$P_{FGGC}^{U}(t)$, $P_{Uselu}^{U}(t)$, $P_{Eg}^{U}(t)$, $P_{Ug}^{U}(t)$ are the utility objective consumption at time, t that was chosen to be inversely proportional to pool or spot electricity market price g which aim to benefit the Utility.

W_1 and W_2 are the weights that achieve either the customer or utility objective load curve. The weights were made equal for it to benefit both costumers and utility such that $W_1 = W_2 = 0.5$

3.3.2 Objective Function of Demand Side Management

The objective function of the DSM strategy is designed based on the load shifting technique using the binary particle swarm optimization (BPSO) algorithm that optimally shift the load in the network during peak period around in time that causes the load demand curve to come closer to an objective load curve. The DSM strategy fitness is given mathematically as:

$$\text{Minimize} \quad Fitness = D(t) - DSM_{Curt}(t) - DSM_{Sh}(t) \quad (9)$$

Subject to the following constraints:

$$D(t) - DSM_{Curtl}(t) - DSM_{Shl}(t) \le \sum_{t=1}^{T(d)} A_S(t); \forall t \in d, T \quad (10)$$

$$-DSM_{Shl}^{\max}(t) \le DSM_{Shl}(t) \le DSM_{Shl}^{\max}(t); \forall t \in d, T \quad (11)$$

$$DSM_{Shl}^{\max}(t) = W_{Shl} * D(t); \forall \in d, T \quad (12)$$

Equation 12 is the peak or maximum DSM capacity at every instant t. This limit is modeled as a fraction W_{Shl} of the actual or current demand $D(t)$ during that period.

$$\sum_{t=1}^{T(d)} DSM_{Shl}(t) = 0 \forall d \in 1, D(t) \quad (13)$$

Equation 13 corresponds to the constraints that ensures that the shifted DSM capacity (load) is being put back to energy demanded during the same day but at off peak or intermediate periods.

$$DSM_{Curtl}(t) \le W_{Curtl} * D^{\max}(t); \forall t \in 1, T(d) \quad (14)$$

In this paper, it has been assumed that these resources were modeled as a fraction W_{Curtl} of the peak demand $D^{\max}(t)$ instead of the fraction of the current or actual demand $D(t)$ as was done with the shifted demand. These models were carried with the assumption that the 33 kV feeder power supply is reliable.

$$\sum_{t=1}^{T(d)} A_S = 1; \forall A_S \in T(d), D(t) \quad (15)$$

Where $A_S =$ Availability of 33 kV feeder.

It is necessary to state here that $DSM_{Shl}(t)$ is positive when demand has been removed and negative when it returns to the system.

3.4 Binary Particle Swarm Optimization (BPSO) Algorithm

Binary particle swarm optimization algorithm mimics the swarm behavior of fishes schooling or birds flocking and the particles represent a solution in a D-dimensional search space. Each of the particle makeup of the parts equal to the load or transformers in the network. Each part comprises of two values. The first value represents the fraction of load in percentage to be shifted for a period scheduled, while the second value represent the time intervals the shifted load will remained unserved in the network. The discrete binary particle swarm optimization (BPSO) algorithm is adopted for the optimal load switching operation to implement load shifting around in time in the distribution network to match the available electricity supply with the ever-growing energy demand. The flow chart of BPSO algorithm is presented in Figure 2. The load shifting operation is implemented in real-time scenario with the assumption that the availability of 33 kV feeder is reliable in the network. Section 3.5 presented the Simulink model of the demand side management strategy for the distribution network.

3.5 Simulink Modeling of the Demand Side Management Strategy

Demand side management (DSM) strategy implemented in the distribution network was modelled in Matlab/Simulink environment. The load shifting technique that combines the benefits of the peak load clipping and load valley filling was adopted in the Simulink modeling utilizing the remote controlled switches (RCS) in real-time scenario.

Figure 3 presented the DSM model of the network without automated switching scheme and Figure 4 showed the voltage, active and reactive power measurement system internal configuration. The Simulink model for the distribution network with DSM switching scheme incorporated is presented in Figure 5.

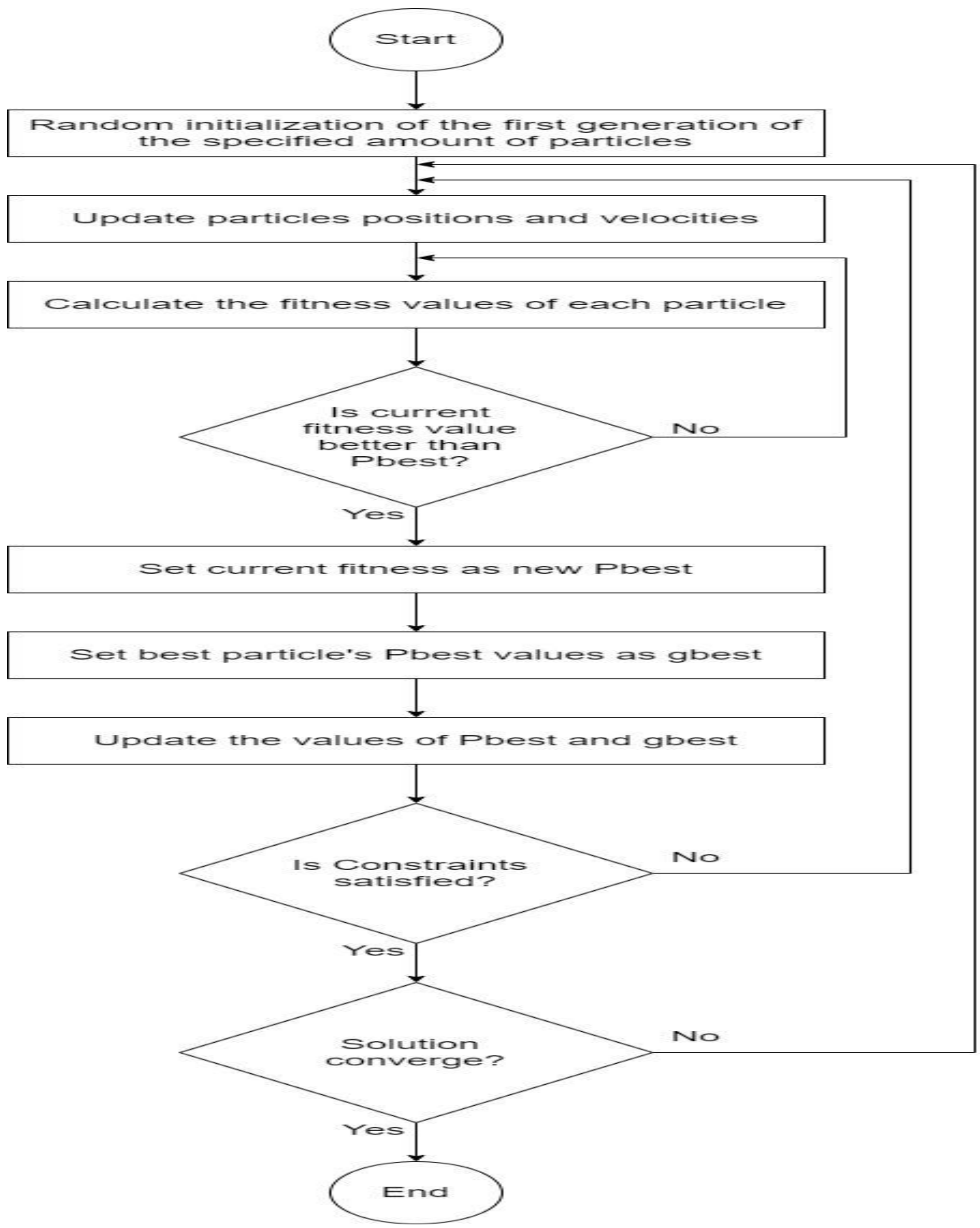

Figure 2: Flow Chart of Discrete Binary Version of PSO Algorithm for DSM Strategy

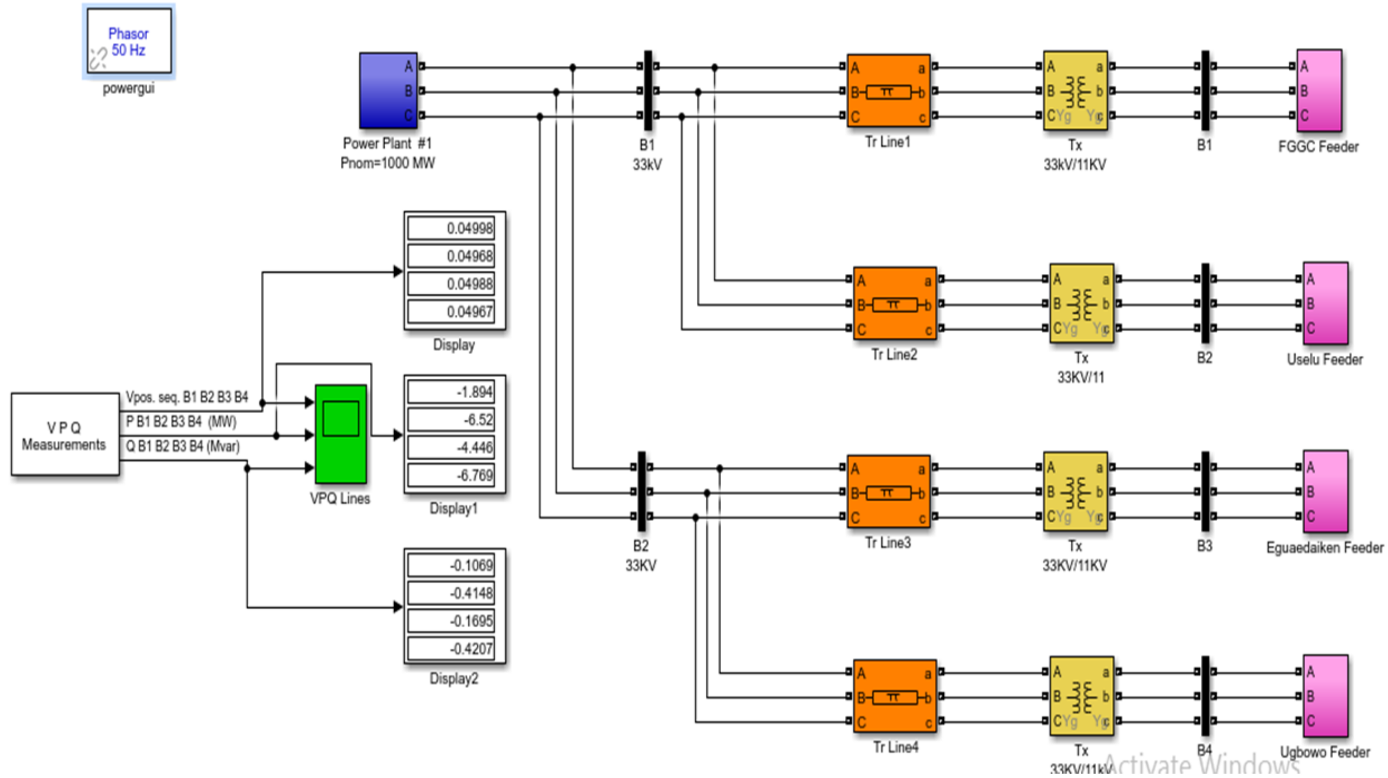

Figure 3: Demand Side Management Simulink Model for the Ugbowo 2x15 MVA, 33/11 kV Distribution Network without Automated Switching Scheme

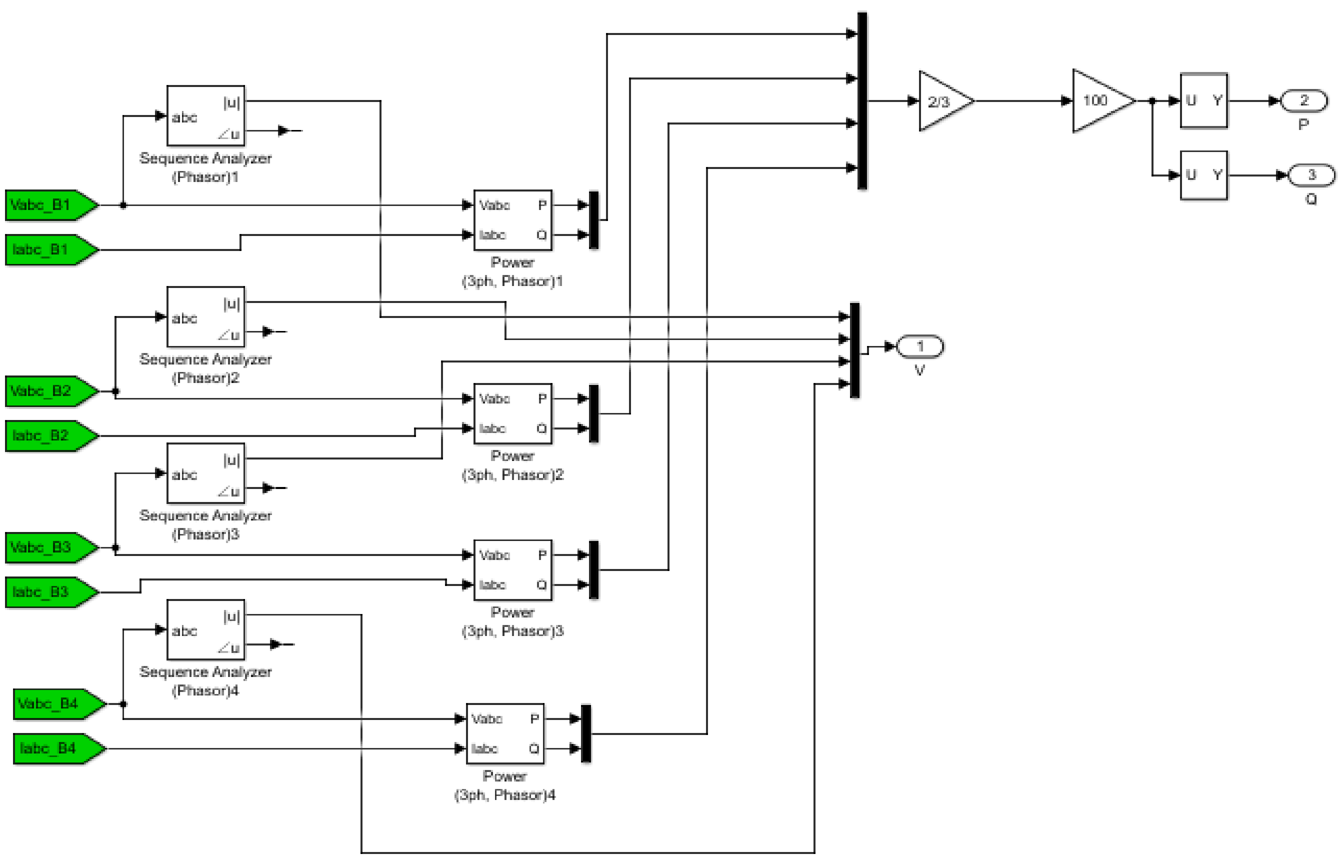

Figure 4: Voltage (V), Active (P) and Reactive (Q) Power Measurement System Internal Configuration of the Simulink Model

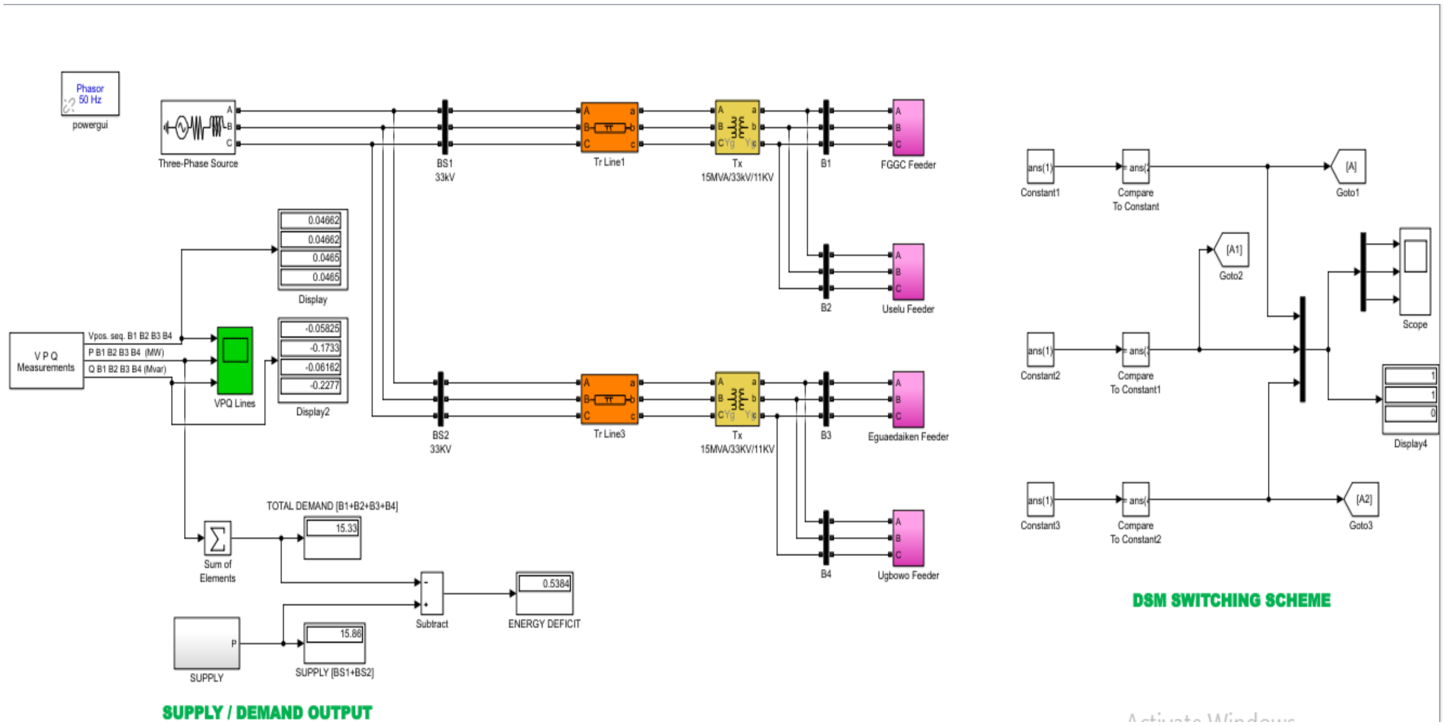

Figure 5: Demand Side Management Simulink Model for the Ugbowo 2x15 MVA, 33/11 kV Distribution Network with Incorporated Automated Switching Scheme in a Run Mode

4.0 RESULTS AND DISCUSSION

The results of the demand side management strategy are presented in this section. The Simulink model results are reported in section 4.1 and the results are discussed in section 4.2 of this paper.

4.1 Results

The monthly load consumption of the four feeders in the network is given in Table 1. The monthly feeders' loads were used for testing our models for correctness. The Simulink model result of the demand side management strategy is presented in this subsection. Figure 6 showed the graphical representation of the input data of Table 1, while Figure 7 provides the Simulink model results before and after DSM application. Table 2 shows the peak supply-demand curve with the balanced electric energy demand with the available electricity supply, while Table 3 compared the existing switching technique and proposed switching technique.

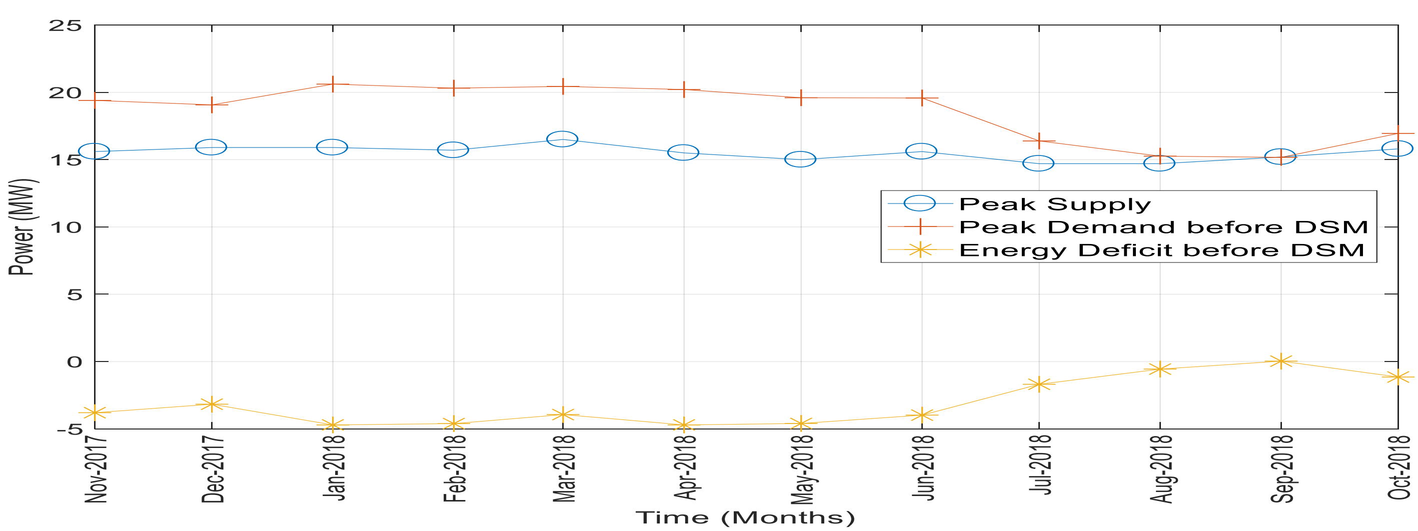

Figure 6: Peak Supply – Peak Demand Curve from November 2017 to October 2018 before the Application of Demand Side Management

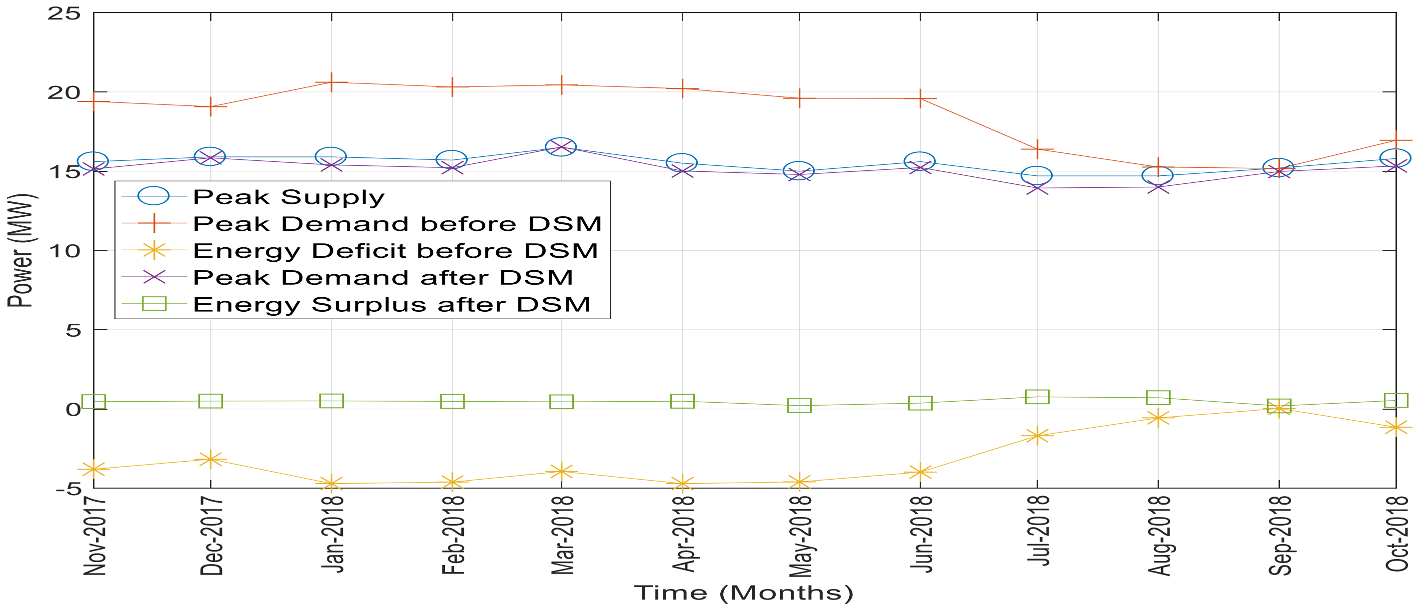

Figure 7: Peak Supply – Peak Demand Curve from November 2017 to October 2018 of both before and after

4.1.1 Application of Demand Side Management.

Table 2: Supply-Demand (MW) from November 2017 to October 2018 of both before and after the Application of DSM Strategy

S/N	Months	Peak Supply (MW)	Peak Demand of the Four (4) Feeders before DSM (MW)	Surplus/Deficit before DSM (MW)	Peak Demand of the Four (4) Feeders after DSM (MW)	Surplus/Deficit after DSM (MW)
1	November 2017	15.6	19.4	- 3.8	15.140	0.461
2	December 2017	15.9	19.07	- 3.17	15.840	0.4998
3	January 2018	15.9	20.61	- 4.71	15.393	0.507
4	February 2018	15.7	20.31	- 4.61	15.219	0.481
5	March 2018	16.5	20.44	- 3.94	16.530	0.451
6	April 2018	15.5	20.21	- 4. 71	15.010	0.490
7	May 2018	15	19.6	- 4.60	14.789	0.211
8	June 2018	15.6	19.58	- 3.98	15.230	0.371
9	July 2018	14.7	16.39	- 1.69	13.936	0.764
10	August 2018	14.7	15.26	- 0.56	14.000	0.710
11	September 2018	15.2	15.17	0.03	14.980	0.192
12	October 2018	15.8	16.95	- 1.15	15.330	0.538

4.2 Discussion of Results

The peak electricity supply and amount of electric energy consumption by consumers in the network, matched electric energy demand with available electricity supply, etc. are presented in Table 2 of this paper, while Figure 6 showed the graphical representation of the input data of the network under study. From Figure 6, the electric energy demand outweighs the available energy supply in the distribution network except for the month of September 2018 which is as result of faults and vandalization that caused many of the outdoor substations (transformers) to be out of service. This deficit in the energy demand by consumers causes frequent scheduled and unscheduled outages in the network with the scheduled outages predominate using the 11 kV circuit breakers (CBs) presently as a means of load management.

These 11 kV CBs were original provided for isolation of the downstream in the event of fault, using this as a means of load management cause poor availability of the feeders and service hour to consumers. Table 3 compared the existing and proposed switching techniques in the network.

Table 3: Switching Technique of Existing and Proposed Network and Percentage of Reduction of Blackout Area

Existing Switching Technique				**Proposed Switching Technique**	
FGGC Feeder	Uselu Feeder	Eguaedaiken Feeder	Ugbowo Feeder	Four (4) Feeders	
ON	**ON**	**OFF**	**OFF**	**ON**	
36.62% of the area of the network supplied with electric power		63.38% of the area of the network is on blackout		85.92% of the area of the network supplied with electric power	14.08% of the area of the network is on blackout
OFF	**OFF**	**ON**	**ON**	Four Feeders **ON**	
36.62% of the area of the network is on blackout		63.38% of the area of the network supplied with electric power		85.92% of the area of the network supplied with electric power	14.08% of the area of the network is on blackout

Figure 7 presents peak electricity supply-energy demand, energy deficit/surplus energy before and after DSM strategy application for efficient energy distribution in the network and also, showed the demand and supply curve of electric energy in the distribution network under study before and after application of DSM. The peak electricity supply of the network and peak electric energy demand for the year 2017 to 2018 has been depicted. It was observed from Figure 6 that the peak energy demand outweighs the peak electricity supply for the period under study before the application of demand side management (DSM) strategy. The gap created between electric energy demand and electricity supply in the system may get worsen as energy demand by consumer increase without appropriate measures to bridge energy supply deficit in the existing network. If the energy gap created not addressed, the frequent outages of the 11 kV feeders due to overload or regimented scheduled outages as a result of the energy supply gap created will further lower the availability of 11 kV feeders in the network. This is as a result of equipment limitations and inadequate electricity generation capacity currently witnessed in the network. In order to bridge this gap that has been created with these limitations in the distribution network under study, the proposed DSM strategy was deployed to bring the load curve closer with the available electricity supply. 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, improve the availability of the feeders from twelve hours per day to twenty-four hours as shown in Table 3. It was also observed that the demand (load) curve after the application of the suggested DSM strategy in Figure 7 was brought closer to the available energy supply, which culminated that the objective or desired load curve was met in the distribution network. This brings the load curve closer to an objective or desired load curve that matched the available electricity supply. Additionally, the energy deficit before the application of the proposed strategy and the energy surplus after the application of the proposed DSM strategy were depicted in Figure 7 and Table 2.

5.0 CONCLUSION

The study presented the simulations of demand side management strategy for alleviating power shortages in the Nigerian power system. The mathematical models of the DSM strategy were used in modeling the Simulink model in Matlab/Simulink environment. The simulation model was developed and simulations were carried out to show the effectiveness of the model in matching the ever-growing electric energy demand with the available electricity supply in the network. From the results, it was seen that the model has the capacity of bringing the load curve closer to an objective or desired load curve in the network thereby meeting the energy demand with minimum deviations from the available electricity supply. The discrete binary particle swarm optimization (BPSO) algorithm was adopted for optimizing the model and the load shifting technique was deplored with the direct load control (DLC) method to control peak loads. The results showed that the method can match the available electricity supply with the ever-growing energy demand thereby bridging the huge gap in energy supply with the ever-growing demand by consumers in the distribution network under study as shown in Figure 7.

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