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Original Research Article

Modeling of Demand Side Management Scheme for Matching Electricity Supply with Demand in the Nigerian Power System

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ABSTRACT

The unserved load in the Nigerian power system currently is as a result of the ever-growing gap between electric energy demand and supply which is one of the major causes of frequent power interruptions. Thus, stabilizing the network, equalization of the available electricity supply with the energy demand becomes necessary, of which demand side management (DSM) is a veritable tool being deployed to match the ever-growing energy demand with the available electricity supply. Consequently, this paper presents a concise overview of demand side management scheme and its modeling for matching electricity supply with the ever-growing energy demand in the Nigerian power system. The residential, commercial, industrial and special customers load in the network were used for the modeling and binary particle swarm optimization (BPSO) algorithm was adopted for optimizing the models. The load shifting technique was used to control and carried out load shifting during the peak period. Both customers and utility benefits were considered using the BPSO algorithm and the results showed that the technique can match the available electricity supply with the ever-growing energy demand.

1. INTRODUCTION

Electricity plays a very important role in the socio-economic and technological development of every nation (Sambo, 2008). The amount of electricity supply and its reliability plays a significant role in the socio-economic and technological drive in the country (Oyedepo, 2012). Therefore, evaluating the energy demand and the availability of electricity supply in a country cannot be overemphasized.

The electric energy demand in Nigeria currently far outweighs the electricity supply and the available supply is epileptic in nature (Sambo, 2008). The ever-growing population and developmental needs have resulted in an increased in the gap between electricity demand and supply in Nigeria (Eze *et al.,* 2016).

Historically, the Nigerian electric power supply dates back to 1896 when electricity was first produced in Lagos, fifteen years after its introduction in England (Sambo, 2008). The total capacity of power generation was 60 kW. In other words, the maximum energy demand in 1896 was less than 60 kW (Okoro and Chikuni, 2007). Population growth and developmental needs in Nigeria has been on the increase and the electric energy demand has also been on the increase without a corresponding increase in electricity supply to meet the demand (Oyedepo, 2012). According to Sambo (2008) between 1979 and 1999, the power sector of Nigeria did not witness substantial investment in infrastructural development. Throughout that period, additional plants were not constructed and the existing ones were not properly maintained, making the Nigerian power system to be in a deplorable condition. This caused power generation to drop from the total installed capacity of about 5,600 MW in 2001 to an average of about 1,750 MW. A great margin was created between electricity supply and demand. This has created serious power issues such as frequent power outages which hinder socio-economic and technological development. Power outages can be classified as scheduled or unscheduled. The unscheduled outages are as result of faults occurring in the system, while the scheduled outages are majorly caused by system overloading, poor generation and equipment limitations.

There is no gainsaying that there is a strong correlation between socio-economic development in a given place and the availability of the electricity generated. 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. DSM reduces electricity consumption in homes, offices and factories by continually monitoring and actively managing how appliances consume energy. DSM has been recognized as one of the key enablers for a cost-efficient energy transition. Specifically, energy-intensive industries can contribute to the energy transition by offering high potentials for grid stabilization in terms of DSM and at the same time mitigate their own economic risks related to volatility in energy supply" (Obermeier *et al.,* 2018). Consequently, demand side management (DSM) scheme is a veritable tool to look into for managing and matching the current electricity supply with the ever-growing energy demand. DSM that is regarded as one of the best and cost effective methods of energy management techniques deployed on the consumers' side meter can be utilized for load management. Nowadays, the ever-increasing energy demand has necessitated the utility engineer to think of the best ways of distributing the inadequate electricity generated to customers more efficiently and reliably (Akpojedje *et al.,* 2018). DSM is one of the new trending technologies which began modestly in the United State (US) with view of playing significant role in load management so as to bring the load curve to an objective load curve with the available electricity supply. This paper proposed optimal switching demand side management (DSM) scheme for the Ugbowo 2×15 MVA, 33/11 kV distribution network customers for efficient and effective distribution of electric energy to its consumers with greater reliability and availability.

2. MATERIALS AND METHODS

2.1. Materials

The materials needed for this study includes simulation software (Matlab/Simulink), remote controlled switches (RCS) and optimization tool.

2.2. Input data

The data needed for this study include the number of customers in the network, types of customers, peak load consumption by the customers and peak supply for the period under investigation. The data was collected from the Ugbowo injection substation and the business unit of the network from November 2018 to October 2019.

2.3. Methods

The load shifting technique was proposed for the demand side management scheme using the direct load control method (Gellings, 2017). The aim of the proposed method is to bring the load curve closer to an objective load curve so that the desired demand side management can be achieved. The desired objective load curve was achieved by modeling the system using simple linear algebraic technique. The linear algebraic method was adapted to model network for the objective load curve of the customers that matches the available electricity supply with electric energy demand in the network.

2.3.1. Optimal load shifting technique

The optimal load shifting technique is way of managing peak load in a better and simplest form. According to Kayhani and Ramachandran (2017) load shifting is the simplest method of lowering power demand. The technique is a better way of moving part of peak load around in time during peak period using optimization algorithm for load selection so that the available electricity supply can accommodate the peak load of the network. This is done to forestall the frequent tripping of the feeders or system due to overload during the peak hour of the network. Since the cost of generating additional megawatt to carter for the extra load in the peak period is capital intensive with scarce resources presently. In this paper, the optimal load shifting technique is proposed for load management at the demand side of the residential, commercial, industrial and special customers in the network under study. This technique proposed combines the benefits of peak load clipping and load valley filling techniques to reduce the load of the network during peak period. With this method, the objective consumption is formulated based on the time of day (TOD) tariff and the pool or spot market price of electricity generated which was chosen to be inversely proportional to the objective consumption in the network as depicted in Equations 1 to 4.

2.3.2. Direct load control

The direct load control is a way to reduce the demand for electric energy by consumers using various techniques. It is also a way customers allows the utility to control the manner of electric energy consumption by customers during peak hours of the day by giving some incentive. The principle of the proposed DSM scheme is based on direct load shifting operations and the direct load control technique was adopted for the scheme modeling. This is to bring the final load curve closer to an objective load curve (El Safty *et al.,* 2015). The objective of the direct load control (DLC) technique is to reduce the energy consumption by consumers in the network during certain period (Peak) using various techniques such as load shifting, etc. The load control in the network comprise of direct load control, distributed load control and load control (Gellings, 2017).

2.3.3. Mathematical formulation of demand side management scheme

The aim of the mathematical formulation of the proposed demand side management scheme is to match the available electricity generated with the current energy demand. The DSM scheme was model with the types of customers (residential, commercial, industrial and special) in the network. Hence, the models for matching electricity supply with the ever-growing energy demand is given as:

Residential customers:

$$D_{RC_{(\max)}}(t) = \sum_{t=1}^{T(d)} [E_{RC}(t) - (W_1 * \frac{P_{RC}}{x}(t) + W_2 * \frac{P_{RS}}{g}(t))]^2 \tag{1}$$

Where $D_{RC}(t)$ is the actual or current energy demand at time, t by residential customer in the network, $E_{RC}(t)$ is the energy consumption after load shifting at time, t for the residential customers in the network. $P^C_{RC}(t)$ is the residential customers' objective consumption at time, t that was chosen to be inversely proportional to time of day (TOD) tariff x in the network which aim to benefit the costumers.

$P^U_{RS}(t)$ is the utility objective consumption for residential customers 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 in order to benefit both costumers and utility such that $W_1 = W_2 = 0.5$.

Commercial customers:

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

Industrial customers:

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

Special customers:

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

Where:

$$D_{T(\max)}(t) = W_{RC} * D_{RC}(t) + W_{CC} * D_{CC}(t) + W_{IC} * D_{IC}(t) + W_{SC} * D_{SC}(t) \quad (5)$$

$$DSM_{Curt}^{\max}(t) = [E_{RC}(t) + E_{CC}(t) + E_{IC}(t) + E_{SC}(t)]^2 \quad (6)$$

$$DSM_{Sh}^{\max}(t) = [\frac{W_1}{x}(P_{RC}^C(t) + P_{CC}^C(t) + P_{IC}^C(t) + P_{SC}^C(t)) + \frac{W_2}{g}(P_{RC}^U(t) + P_{CC}^U(t) + P_{IC}^U(t) + P_{SC}^U(t))]^2 \quad (7)$$

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

2.3.4. Objective function of the demand side management scheme

The objective function of the DSM scheme 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 which causes the load demand curve to come closer to an objective load curve. The DSM scheme fitness is given mathematically as:

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

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.

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

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.

2.3.5. Binary particle swarm optimization algorithm for the demand side management scheme

Figure 1 shows the binary particle swarm optimization (BPSO) algorithm flow chart used for the optimal load switching operation carried out for the switching on/off of loads in the distribution network to match the available electricity supply with ever-growing energy demand. This was done with the assumption that availability of 33 kV feeder is reliable with electricity supply to the distribution network.

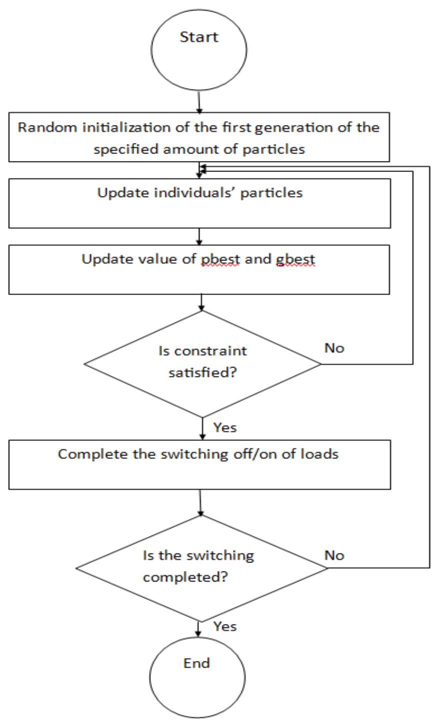

Figure 1: Flow chart of discrete binary particle swarm optimization algorithm for DSM scheme

3. RESULTS AND DISCUSSION

The results of monthly load consumption of each type of customers in the network is given in Table 1. The monthly loads were used for testing the models for correctness. The peak electricity supply, types of costumers, number of costumers and their amount of electric energy consumed, matched energy demand with available electricity supply, etc. Also, the graphical representation of the results of the network energy supply, energy demand, energy deficit/shifting before DSM application and after DSM application for efficient energy distribution and availability are depicted in Table 1, Figure 2 and Figure 3 respectively.

Table 1: Peak supply and load data from 2018 to 2019 before and after DSM

Time (Months)	Available peak electricity supply (MW)	Monthly forecasted load in megawatts (MW)				Total energy consumed (MW)	Energy deficit before DMS	Total energy consumed after DSM (MW)
		Residential load 4967	Commercial load 639	Industrial load 13	Special load 43			
Nov. 2018	14.00	12.2750	1.579	0.3390	0.2070	14.400	0.400	13.85
Dec. 2018	15.00	13.2490	1.793	0.0490	0.0190	15.1100	0.110	14.93
Jan. 2019	14.65	12.8404	1.9539	0.0936	0.1162	15.004	0.354	14.41
Feb. 2019	15.00	13.1472	1.6914	0.0444	0.1238	15.121	0.121	14.84
Mar. 2019	15.10	13.2348	1.7026	0.0346	0.1146	15.118	0.018	14.98
Apr. 2019	14.50	12.7090	1.6350	0.0433	0.2100	14.597	0.097	14.23
May 2019	15.60	13.6731	1.7590	0.0458	0.2184	15.696	0.096	14.38
Jun. 2019	15.40	13.4977	1.7770	0.0553	0.2169	15.547	0.147	15.13
Jul. 2019	15.50	13.5854	1.7478	0.0556	0.2176	15.606	0.106	15.01
Aug. 2019	14.60	12.7966	1.6463	0.0434	0.2108	14.696	0.096	14.45
Sep. 2019	15.00	13.1472	1.7914	0.0444	0.2149	15.198	0.198	14.68
Oct. 2019	15.30	13.4101	1.7925	0.0451	0.2161	15.464	0.164	15.02

It is worth noting that Figure 2 showed the peak electricity supply, peak demand before and after DSM and the energy deficit currently occurring in the distribution network under investigation. Figure 2 showed the peak electricity supply, peak demand before and after DSM and the energy deficit currently occurring in the distribution network under investigation, while Figure 3 depicted the matching of peak electricity supply with peak energy demand. It is observed from the Figure 3 that before the deployment of demand side management scheme, the peak energy demand overshot the peak electricity supply and after the deployment of the DSM scheme the peak energy demand undershot or match the peak electricity supply for the periods under investigation. Therefore, showing the effectiveness of the DSM scheme. Also, from Figure 4, it is observed that the network under review have more of residential customers compare to commercial, industrial and special customers which amounted to 87.7%, 11.3%, 0.8% and 0.2% respectively. This showed that the network under review is populated with residential customers followed by commercial customers with scanty industries in the area covered by the network.

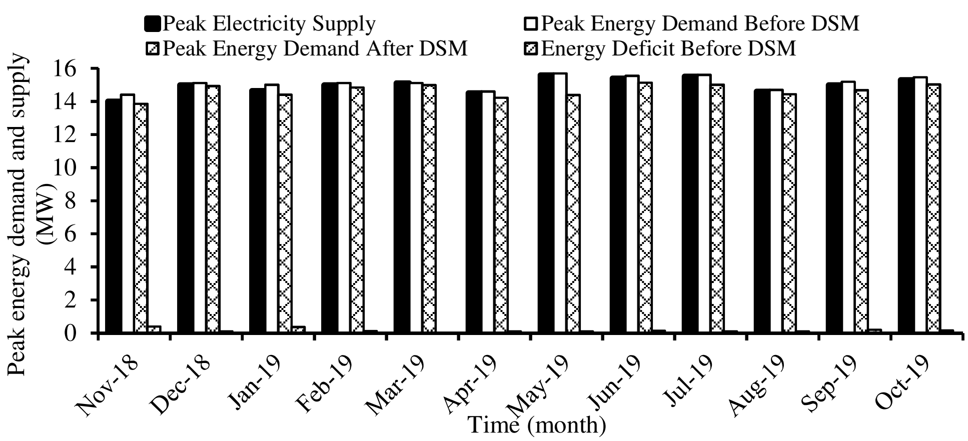

Figure 2: Peak electricity supply and energy demand before & after DSM

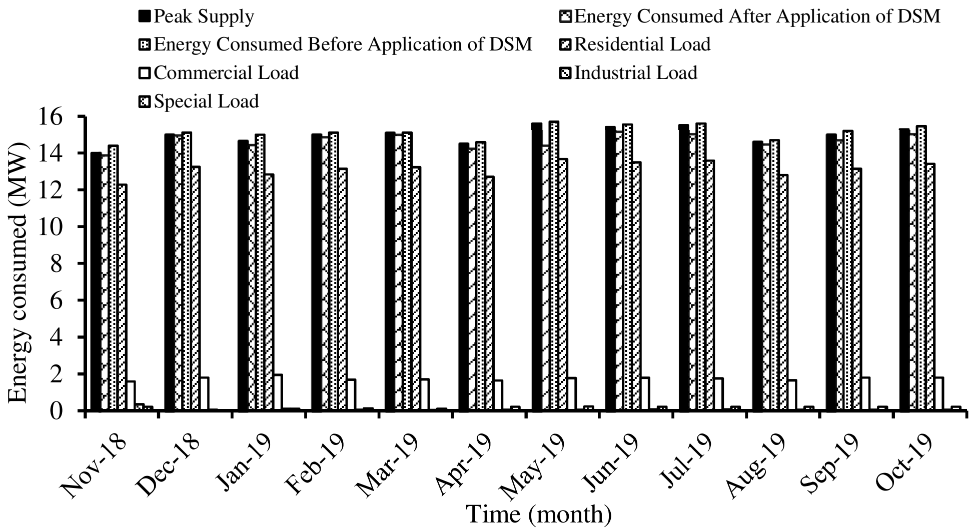

Figure 3: Peak supply and energy demand in the network for a year

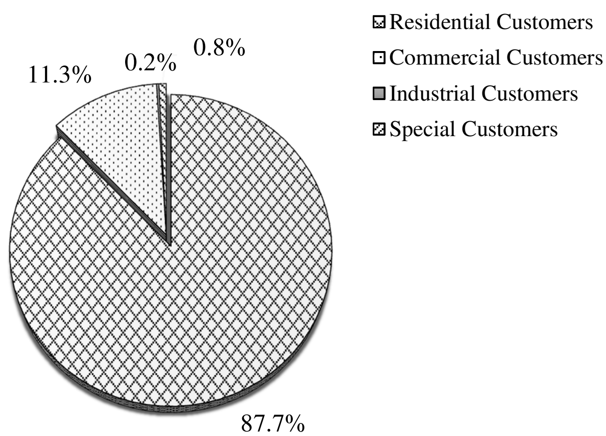

Figure 4: Pie chart representation of the types and number of customers in the network

4. CONCLUSION

The study presented the modeling of demand side management scheme for matching electricity supply with demand in Nigerian power system. The mathematical models of the DSM scheme were deplored in the modeling. The residential, commercial, industrial and special loads in the network were used for the modeling and a heuristic algorithm was adopted for optimizing the DSM scheme models. The simulation model was developed and simulations were carried out to show the efficacy of the model in matching the ever-growing electric energy demand with the available electricity supply in the network. The discrete binary particle swarm optimization (BPSO) algorithm as one of the heuristic algorithms was used for optimizing the models and the load shifting technique was deplored with the direct load control (DLC) method to control the 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 energy demand by consumers in the network.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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