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Influence of Demand Side Management and Multi Year Tariff Order Pricing Model on Energy Management and Its Sustainability in Nigeria Power Systems

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Abstract

The persistent growth of unserved load and rising customer dissatisfaction in the Nigerian Electricity Supply Industry (NESI) underscore the urgent need for improved energy management strategies. This may not be unconnected to the major causes of frequent power interruptions in the network and stabilizing the network to avoid these frequent power interruptions, efficient energy management response on the consumers' side and cost reflective system on the part of energy governance are required to manage the available power supply with the current energy demand by the consumers to attain energy sufficiency and sustainability in the Nigeria grid. Efficient energy policies are formulated to ensure better service delivery and cost reflectivity in the system; of which Demand Side Management (DSM) and Multi-Year Tariff Order (MYTO) pricing model were veritable tools to actualize energy efficiency and sustainability. Therefore, the study evaluates the influence of DSM and the MYTO pricing model on energy efficiency and cost reflectivity within Nigeria's power systems especially the DisCos. The marginal cost and marginal revenue concepts and the advanced load shifting technique were used to manage the energy demand with the available power supply using the demand response and cost reflectivity systems to make the available energy sustainable for efficient operation of the grid. The advanced load shifting technique optimized by Binary Particle Swarm Optimization (BPSO) and a detailed cost component analysis in the MYTO framework reveals that DSM implementation reduce peak load up to 15% and decrease energy deficits by approximately 12%. Furthermore, adjustments in the MYTO pricing model led to a 10% improvement in cost reflectivity, thereby enhancing revenue collection and operational sustainability.

1. Introduction

A stable and reliable power supply is key to socioeconomic development and industrialization of any nation. A country's standard of living and degree of economic development is primarily determined by its energy use, electricity generation and distribution, influence on productivity and overall economic growth [1]. Every developed nation has conquered an 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 [2]. But in recent times in the Nigerian Electricity Supply Industry (NESI), the frequent power interruptions at the distribution level became worrisome to consumers. It is not news that the Nigeria power sector has faced and is still facing a series of challenges such as high-power losses, poor voltages at consumers' terminals, frequent power interruptions due poor generation, inadequate funding, line limitations, equipment limitations, etc. The epileptic nature of the Nigeria power sector has been a serious concern to all sundry especially the power stakeholders. This necessitates the various reforms put in place to revive the Nigerian Electricity Supply Industry (NESI) through Power Sector Reform Act 2005 (EPSRA-2005) promulgated which necessitates the establishment of Nigerian Electricity Regulatory Commission (NERC) and subsequent introduction of Multi Year Tariff Order (MYTO) in 2008. Despite all these reforms, the Nigeria power sector still struggles with a huge energy deficit without cost reflectivity in the system and high-power losses along the lines especially the distribution lines. The power losses in the distribution networks of the Nigeria power system are huge amidst the huge energy deficit currently in the system. According to [3] who opined that the Nigerian electricity grid has a large proportion of transmission and distribution (T&D) losses-whopping 40%. Study by [4] indicated that up to 13% of the total power generated is being wasted in the form of line losses at the distribution level. [5] asserted that the distribution network is where the greatest number of power losses occurs. These huge power losses in the distribution networks coupled with whimsical load connections on the network lines made it complex and cumbersome and this has inhibited the efficiency of the system. Also, poor energy governance and service delivery have a serious impact on the network especially the distribution system. Engineers and other stakeholders in the system have been battling with this cumbersomeness of the network to find ways to minimize its high-power losses along the lengthening lines and increase the efficiency. Also, the national grid has a lot of constraints ranging from poor generation to faults. According to [6] and [7] 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. Loadshedding

These have affected the availability and reliability of the system in terms of continuous electricity supply and quality to consumers when needed, etc. especially in the distribution networks. According to [8] distribution networks are a key part of power systems that facilitate the energy supply to consumers from the distribution network. In an attempt to ameliorate the prevailing situation in the distribution network, various researchers have dabbled into research in this area with the aim of initiating ways to increase efficiency and minimize the high-power losses in the system along the lines. Various methods or techniques have been developed and adopted in attempt to minimize the high-power losses and manage the available energy, improve performance and service delivery, increase energy efficiency and effective management of demand side management (DSM) to equalize the energy demand with available electricity supply at time t. Consequently, this paper aimed to evaluate the influence of DSM and MYTO pricing model on effective energy management and its sustainability in Nigeria power systems using the distribution network as a case study.

1.1 Brief Description of Demand Side Management

Energy management is as old as the power systems itself, but its effectiveness has become a herculean task for energy managers. Energy management is a special field in electrical engineering with its technicality involved. One of the effective and efficient techniques is demand side management (DSM). Historically, the DSM programme began modestly in the 1970s in response to growing concern about dependence on foreign sources of oil and environmental consequences of electricity generation, especially nuclear power [9]. 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]. 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 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 customers. DSM is a veritable technique for equalizing the ever-growing energy demand with electricity generated. According to [11] Demand side management 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 [12].

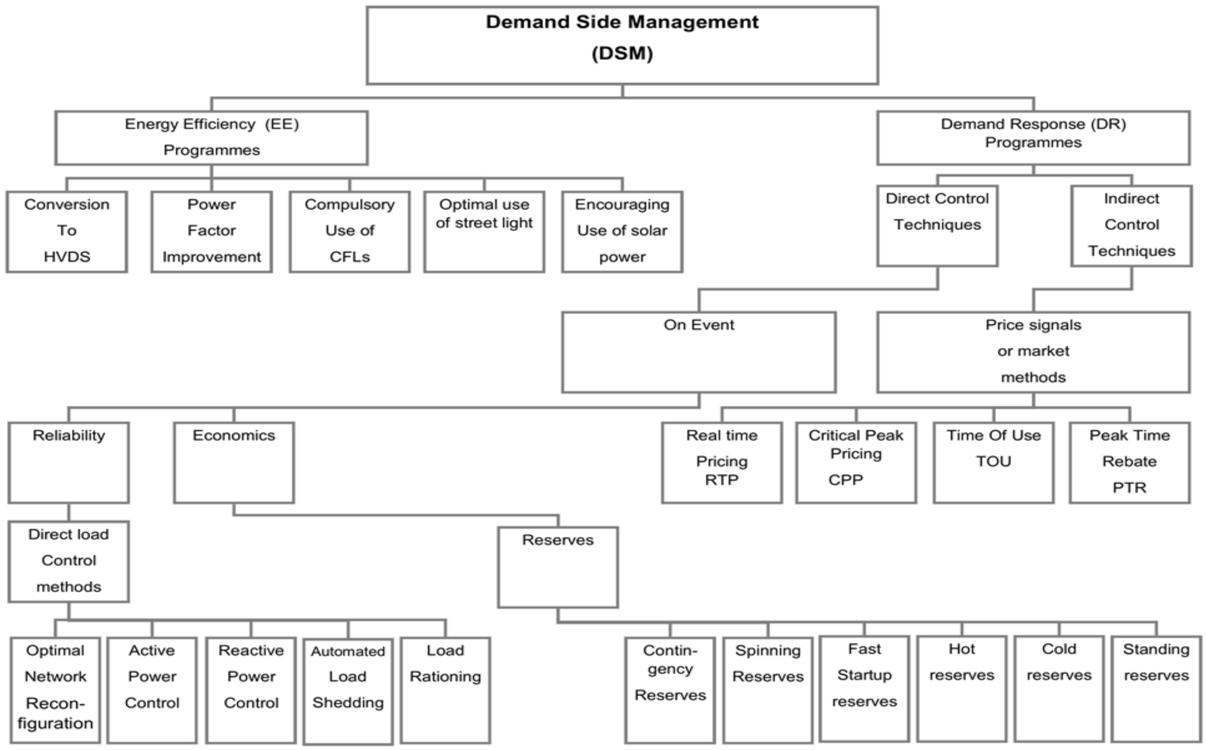

Figure 1: Overview of Energy Management Strategies

1.2 Multi Year Tariff Order (MYTO) Pricing Framework

The Nigeria power sector has faced serial challenges over the years and in order to ameliorate these challenges, the Nigerian Electricity Regulatory Commission (NERC) in July 2008 formulated and made the Multi Year Tariff Order (MYTO) to regulate the cost of energy consumption taking various factors into consideration such as inflation rate, exchange rate, price of gas, etc. The MYTO is a pricing framework for determining the power industry pricing structure for distribution, transmission and generation of electricity in the Nigerian Electricity Supply Industry. The Electric Power Sector Reform Act 2005 (EPSA-2005) empowers the NERC to be able to formulate the price methodologies such as the MYTO and its purpose is to set cost-reflective tariffs which will enhance the Nigerian Electricity Supply Industry and make it to be properly funded and functional. The Nigerian Electricity Regulatory Commission (NERC) divided the MYTO into three parts in the Nigerian Electricity Supply Industry (NESI), one for generation, transmission and distribution respectively. Although the NERC recognizes the major parts of the electricity industry to be generation, transmission, distribution and retailing. These four parts will be regulated by the industry but the transmission and the distribution levels will be treated as monopoly and its prices will be regulated using the chosen approach. The retailing level is yet to be fully operational, hence the retailing sales and marketing section of the network were regulated as part of the distribution systems. Therefore, retail choice is non-existence in the Nigerian Electricity Supply Industry (NESI). The enactment of EPSA-2005 established and empowered the NERC to develop a new and workable tariff structure toward reforming the energy market in the NESI. One of the primary functions of the NERC is to ensure that prices of energy charged in the NESI are fair to consumers and also sufficient enough to allow the Licenses to finance their activities and make reasonable earnings for effective running. Consequently, NERC establishes one or more tariff methodologies for regulating electricity prices to prevent abuse of the market power. Effort by the NERC to restructure the energy market and regulate the prices to avoid abuse of the market has not yielded a monumental effect on the performance of the system and, in 2008, NERC introduced the MYTO as a pricing framework for determining and regulating the electricity industry's pricing structure. The essence of the framework is to bring about a performance improvement plan (PIP) in the Nigerian Electricity Supply Industry that will initiate appropriate cost reflectivity in the industry.

The MYTO methodologies pricing model introduced by the Commission were targeted for fairness, lowest possible regulated end-use tariff without compromising return on investment, simple, transparent and non-excessive regulatory cost (Anosike et al., 2017). The Commission considers the transmission, distribution and retailing sales/marketing as a monopoly using the building blocks approach as prices formulating methodology for the networks. Although the retailing sales/marketing section has not fully been detached from the distribution network for customer choices. The Commission classified the retailing sales/marketing as part of the distribution systems and used the building blocks approach as a regulatory method to set the Distribution Use of System (DUOS) charges. The building blocks approach is simply a way of bringing together all costs identifiable in the industry in a consistent accounting framework [13]. The use of the building blocks approach by the NERC was to project the performance of the system, believed to have a combined positive attribute of rate of return regulation and price cap [14]. According to [15] the three standard building blocks used in the MYTO development were to achieved the following: allowing return on capital-being, the return necessary to achieve a fair rate of return on necessary asset in the business, allowing return of capital-associated with recouping the capital over the useful lives of the assets (depreciation), and finally, efficient operating cost and overheads. The NERC subjected the MYTO model to minor and major reviews in the Nigerian Electricity Supply Industry because of consistent variability of key factors in the system. The minor review was done bi-annually and the major review was done every five years respectively. The minor review is done for any change in the following obvious reasons such as exchange rate, Nigerian inflation rate, US inflation rate, available generation capacity and wholesale gas to power prices. The price variation of ± 5% of any of the aforementioned parameters will lead to the model review. While the major review is done to encompass a comprehensive review and total overhauling of the overall assumptions in the pricing model. Since the introduction of the MYTO pricing model, it has seen two major reviews in 2012 tagged MYTO 2.0 and in 2015 tagged MYTO -2015. The minor reviews seen after the creation of MYTO in 2008 were tagged MYTO -1, others were MYTO 2.1, MYTO 2.1 (amended), MYTO 2.2, MYTO 2024. The objectives of the MYTO 2024 includes ensuring fair and quality reflective tariffs for customers while also enabling the DisCos to fully recover their cost of operations providing a reasonable rate of return on capital invested, and in turn, incentivizing in the improvement of the electricity distribution. The original intention of the MYTO is to address the consistent income shortfall generated from the DisCos in the NESI that affects continuous investment by investors and create a framework to properly manage and cater for the future shortfalls. Despite the good intentions of the MYTO, the variability of the key factors have weakened the impact of the Order and create room for shortfalls in revenues collection in the industry; NERC drive for a better service in the sector, made it to introduced other sub-frameworks to enhance service delivery in the system.

1.2.1 Cost Reflective Tariff Framework

Cost Reflective Tariff (CRT) framework is an energy pricing structure that reflects holistically the costs of producing 1 kW of electricity and evacuating or conveying it to the end-users. Cost reflectivity actually eliminates the need for government subsidies to make up the gap between the current tariff and the true or actual cost of producing and conveying electricity to consumers. CRT creates a perfect market for energy where supply and demand forces determine the price. CRT is a tariff that envisages the true cost of electricity service delivery to the consumers while giving room for a reasonable Return on Investment (ROI) for the investors. According to [13] cost reflective pricing is when the price of a goods or service reflects its cost of production. A true CRT eliminates government interventions or subsidies. According to [16] a cost reflective tariff eliminates the need for government subsidies to make up the difference between the prevailing tariff and the actual cost of supplying electricity by reflecting the true cost of producing it. CRT intention is to, in accordance with the Trade and Industry Chamber of South Africa, that the revenue from electricity tariffs covers the full and efficient operating and maintenance costs (including staff costs and overheads), primary energy costs (fuel costs, such as gas and coal), and the full capital costs associated with using the assets (including interest and depreciation costs), which enables the asset to be replaced (or refurbished) as necessary and for the assets to be expanded as demand for electricity grows [17]. The aim of CRT is to eliminate subsidies and provide ROI to attract investors into the Nigerian Electricity Supply Industry for improved performance and service delivery. The CRT is facing serious challenges due to variability of the key factors in the industry; the NERC's drives to improve customers' satisfaction and a better service delivery, mounted pressure on the DisCos by introducing service-based or service-reflective tariffs framework on the 1st of November, 2020.

1.2.2 Service-Based or Service-Reflective Tariff Framework

The drive of the NERC to improve performance and service delivery to customers in the industry, introduced a Service-Based Tariff (SBT) on the 1st of November, 2020. The SBT scheme aimed at improving the service delivery to end-users (customers); the SBT is a tariff framework that connects the cost of electricity supply directly to quality and quantity of service received by the customers. The aim of the Service-Based Tariff framework is to improve performance and ensure customers pay actual bills or tariff of what they consume from the industry. The SBT is also known as Service-Reflective Tariff (SRT) framework which is an effort of the NERC to transit the industry from demand-based to cost-reflective based and service-reflective based. The SBT or SRT is a system of tariff that is based on the number of hours of electricity supply a consumer receives from the Distribution Companies (DisCos). I.e. consumers now pay based on how long they receive electricity supply daily and they are classified into Bands or Groups commensurate with the quality and quantity of service offered by the DisCos. Under the SBT or SRT framework, the customers were classified into various Bands such as Band A to receive electricity supply between 20 hours to 24 hours, Band B between 16 to 20 hours, Band C between 12 to 16 hours, Band D between 8 to 12 hours and Band E between 4 to 8 hours. Therefore, applying the SRT framework, customers in Band A pay more for electricity supply than customers in Band B because it receives more hours of electricity supply than the later Band and subsequently. The designed tariffs aim to ensure that consumers who receive fewer than 8 hours of electricity per day do not see tariffs increase until quality improves. The Commission create a caveat for the Order on migration of customers and compensation for service failure under the Service-Based Tariff Framework; i.e. if the DisCos fails to meet the committed service level to a Band A feeder for example, for seven (7) consecutive days, the feeder shall be automatically downgraded to the recorded level of supply in pursuant to provision of section 6 of the Order No. NERC/334/2022. So, there is a caveat to downgrade and upgrade a feeder based on the quality and quantity of service received by the customers in that feeder. All these are to manage and improve the performance of the Nigerian Electricity Supply Industry.

2.0 Materials and Methods

The input data, materials and methods used in this research are presented in this section.

2.1 Input Data

The input data were primary and secondary data generated from the Nigerian Electricity Supply Industry. The primary data were taken from the Ugbowo 2x15 MVA, 33/11 kV Injection Substation four feeders and 33 kV supply, while the secondary data were extracted from the NERC's second quarterly reports for the year 2024 to buttress our analysis.

2.2 Models Description

Two models were developed and used to address the subject matter. The models seek to establish the aim of the study. The first model seeks to test the demand side response of the customers and how it can equalize the available electricity supply with the energy demand. While the second model seeks to reflect the MYTO pricing framework on proper energy management and cost reflectivity by adopting the marginal cost and marginal revenue concepts in improving the Nigerian Electricity Supply Industry using marginal cost and marginal revenue concepts and the advance load shifting technique.

2.2.1 DSM Mathematical Model

Demand side management (DSM) is commonly used to reduce peak load and manage system congestion. It can be used to balance the energy demand - supply in a system thereby increasing the availability and voltage stability of the network. The mathematical formulation of the proposed DSM scheme is to balance supply – energy demand which can be achieved through load shifting modeling techniques in the system.

$$D(t) = \sum_{h=1}^{H} [\, E_c(t) - (W_1 * \frac{P^c}{x}(t) + W_2 * \frac{P^u}{g}\,(t))] \tag{1}$$

Where x is the consumer objective consumption function at time t that was chosen to be inversely proportional to the time of day (TOD) cost reflective tariff for residential, commercial, industrial and special customers in the network, while g is the utility objective consumption function at time t that was chosen to be inversely proportional to spot (pool) electricity market price which aimed to benefit the utility. W_1 and W_2 are the weights that achieve the utility objective curve or the customer objective curve. The weights were made equal in order to benefit both customers and utility such that $W_1 = W_2 = 50\%$.

Where:

i. D(t) represents the demand at time t,

ii. $E_c(t)$ represents consumer energy consumption,
iii. $P^c(t)$ is the consumer's objective consumption function,
iv. $P^u(t)$ is the utility's objective consumption function,
v. W_1 and W_2 are weights assigned to the customer and utility objectives.

The goal is to shift peak load consumption to off-peak hours while ensuring that both customers and utilities benefit equally. The values of W_1=50% and W_2=50% were chosen based on the followings:

i. The primary motivation behind DSM is to ensure both customers and utilities benefit.
ii. If W_1 is too high, consumers bear the burden of demand shifting, leading to reduced participation.
iii. If W_2 is too high, utilities bear the cost, making DSM financially unsustainable.
iv. A 50-50 split ensures a *win-win scenario*, where incentives for shifting load are distributed fairly.

According to [9]; [11] suggested that equal weighting leads to optimal DSM adoption when no single party dominates decision-making. Load shifting programs in global markets (e.g., Time-of-Use pricing in the U.S. and Europe) use similar consumer-utility balance models. In regulated electricity markets like Nigeria, cost reflectivity is crucial to stabilizing the grid and ensuring that both consumers and utilities participate in DSM at equal weight helps mitigate power losses and revenue shortfalls.

2.2.1.1 Optimal Load Shifting Technique for DSM Scheme

The optimal objective function of the proposed DSM scheme was formulated to minimize the total energy demand at time t in the distribution network. The optimal fitness of the model was implemented using the binary particle swarm optimization (BPSO) algorithm. The DSM scheme is based on load curtailed and shifting operations at the time of each load in the system to bring the final load curve closer to an objective load curve and is given as:

$$\text{Minimize Fitness} = D(t) - DSM_{Curt}(t) - DSM_{Sh}(t) \quad (2)$$

Subject to system constraints:

The DSM model is subject to system constraints that ensure feasibility and reliability in practical deployment.

Constraint 1: Load Balance Constraint

$$D(t) - DSM_{Curtl}(t) - DSM_{Shl}(t) \leq \sum_{h=1}^{H(d)} A_S\,(t); \forall t \in d, T \quad (3)$$

i. This ensures that demand at any given time does not exceed the available supply.
ii. Load shifting (DSM_{Sh}) and curtailment (DSM_{Curt}) must maintain grid stability.

Constraint 2: Load Shifting Time Constraints

$$0 \leq DSM_{Sh}(t) \leq MaxShift \quad (4)$$

i. Limits the amount of load that can be shifted to prevent overloading off-peak hours.
ii. This ensures fair redistribution without creating *new peaks* during low-demand periods.

Constraint 3: Binary Load Decision (BPSO-based Optimization)

Binary Particle Swarm Optimization (BPSO) $x_i(t) \in \{0,1\}$ (5)

i. Consumers are modeled as binary decision-makers: either they shift their load (1) or they don't (0).
ii. The use of BPSO allows for efficient search and convergence in optimizing load reallocation.

Constraint 4: Economic Viability (Cost Reflectivity)

$$\frac{P^c}{x}(t) \leq \frac{P^U}{g}(t) \quad (6)$$

i. Ensures that the cost consumers pay after shifting remains economically viable.
ii. Prevents unfair tariff increases post-DSM implementation.

The DSM model parameters and constraints were carefully chosen to balance consumer and utility benefits while maintaining grid stability. The equal weighting approach ($W_1 = W_2 = 50\%$) is justified through:

i. A balance between consumer affordability and utility revenue protection.
ii. Empirical evidence from previous studies and market trends.
iii. The need for cost-reflective and sustainable DSM adoption in Nigeria.
iv. Sensitivity analysis that ensures robustness across different scenarios.

This structured justification ensures that the DSM model is both theoretically sound and practically applicable to real-world power systems

2.2.1.2 Brief Description of Binary Particle Swarm Optimization (BPSO) Algorithm

Binary particle swarm optimization (BPSO) 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 two values. The first value represents the fraction of load in percentage to be shifted for peak period to off peak period or a period scheduled, while the second value represents the time intervals the shifted load will remain unserved in the network. The discrete binary particle swarm optimization (BPSO) algorithm is adopted for the optimal load switching operation to implement optimal load shifting around in time in the distribution network to match the available electricity supply with the energy demand. Table 1 compare the superiority of computational efficiency of BPSO in DSM with the Genetic Algorithm (GA) and the Ant Colony Algorithm (ACA).

Table 1: Computational Comparison of Algorithms

	Binary Particle Swarm Optimization (BPSO)	**Genetic Algorithm (GA)**	**Ant Colony Algorithm (ACA)**
1.	With a simpler update mechanism and a lower number of parameters, BPSO generally incurs less computational cost per iteration. In DSM, this efficiency translated into faster convergence and lower overall computational time.	The genetic operators (crossover and mutation) applied over larger populations can be computationally expensive, increasing the time per iteration.	The need to update pheromone matrices and compute heuristic values at each iteration can lead to higher computational demands, especially as problem complexity grows.
2.	**Strength:** Offers robust performance in binary decision spaces and consistently finds near-optimal solutions when properly tuned. **Limitation:** It can sometimes become trapped in local optima if the parameters (e.g., inertia weight) are not set correctly.	**Strength:** Known for strong global search capability due to its crossover and mutation mechanisms, which help maintain genetic diversity. **Limitation:** Susceptible to premature convergence if diversity is lost, which may require additional mechanisms (like elitism or adaptive mutation) to ensure robustness.	**Strength:** Particularly effective for certain combinatorial problems and can explore complex solution spaces through collective learning via pheromone trails. **Limitation:** Its performance can be inconsistent in high-dimensional binary problems like DSM load shifting, where the pheromone representation and updates become computationally intensive.
3.	BPSO is designed for binary decision spaces, making it highly suitable for DSM problems where decisions are essentially “shift” or “don’t shift.”	GA uses evolutionary operators—crossover, mutation, and selection—which can explore a diverse solution space but often require more iterations to converge.	ACA, which is inspired by the pheromone-based path-finding behavior of ants, often takes longer to converge due to the iterative pheromone update process and the complexity of encoding binary decisions.
4.	**Parameters:** Inertia weight, cognitive coefficient, and social coefficient.	**Parameters:** Population size, crossover rate, mutation rate, and selection pressure.	**Parameters:** Pheromone evaporation rate, heuristic information weight, and the number of ants.

	Advantage: Fewer parameters need to be tuned, and the binary version is well suited for discrete decision-making, reducing the risk of extensive parameter sensitivity.	**Challenge:** The performance of GA is heavily influenced by these parameters, requiring careful tuning to avoid premature convergence or excessive computational overhead.	**Challenge:** Tuning these parameters for effective exploration in a binary space is nontrivial and can significantly impact performance and robustness.
5.	**Strength:** Offers robust performance in binary decision spaces and consistently finds near-optimal solutions when properly tuned. **Limitation:** It can sometimes become trapped in local optima if the parameters (e.g., inertia weight) are not set correctly.	**Strength:** Known for strong global search capability due to its crossover and mutation mechanisms, which help maintain genetic diversity. **Limitation:** Susceptible to premature convergence if diversity is lost, which may require additional mechanisms (like elitism or adaptive mutation) to ensure robustness.	**Strength:** Particularly effective for certain combinatorial problems and can explore complex solution spaces through collective learning via pheromone trails. **Limitation:** Its performance can be inconsistent in high-dimensional binary problems like DSM load shifting, where the pheromone representation and updates become computationally intensive.
6.	BPSO emerges as the most efficient choice due to its rapid convergence, lower computational overhead, and ease of parameter tuning in binary search spaces	GA provides strong global search capabilities but requires more extensive tuning and computational resources.	ACA is robust for certain combinatorial optimizations but is generally less suited for high-dimensional binary problems like DSM load shifting due to increased computational complexity.

Number of iterations count to convergence for BPSO:100 iterations; GA: 150 iterations and ACA: 200 iterations. This figures which align with observations reported in studies and according to [11], who suggested that the BPSO not only converges faster but also offers improved computational efficiency and solution robustness for DSM applications. Overall, BPSO's performance makes it a compelling candidate for optimizing DSM strategies, particularly when fast, reliable, and computationally efficient solutions are needed in the energy management context.

2.2.2 MYTO Pricing Framework Model

For the cost reflective tariff to have meaningful impact in the Nigerian Electricity Supply Industry, the total cost of producing and evacuating energy to consumers must be reflective. Hence, all key factors must be taken into consideration when computing the cost reflective tariff. In this model, cost of production or generating energy and its evacuation with hidden costs variation have been taken into consideration as follows:

$$T_r = \sum_{h=1}^{H} (C_{GE} + C_{EV} + C_{EL} + C_s + C_o + C_{EX} + C_M + C_h) \quad (7)$$

Where C_{EV} is the cost of evacuating the energy generated at the transmission and distribution levels.

Therefore, $C_{EV} = C_T + C_d$ (8)

Where:

C_T = cost of transmitting energy generated

C_d = cost of distributing energy generated

T_r = cost reflective tariff

C_{GE} = cost of energy generated

C_{EL} = cost of energy loss along the evacuation lines

C_S = cost of staff salary

C_O = cost of overhead

C_{EX} = cost of expansion of the network

C_M = cost of maintenance of equipment

C_h = hidden and variability cost

The Marginal revenue in the system MR= E_{TG} x T_r (9)

Where E_{TG} is the total energy generated, while the marginal cost in the system

$$MC = C_G + C_{EV} + C_{EL} + C_S + C_O + C_{EX} + C_M + C_h \quad (10)$$

The Nigerian Electricity Supply Industry will see improvement or retardation if the conditions below are applied with the marginal cost and marginal revenue concepts.

$$P_f = MR > MC \quad (11)$$

$$L_s = MR < MC \quad (12)$$

Where P_f is the profit due to electricity provided and L_s is loss due to electricity provided.

3.0 Results and Discussions

This section presents the results of the primary and secondary data collected and deductions that were done technically in the network.

3.1 Results

This section presents the results of the demand side management strategy and MYTO pricing framework.

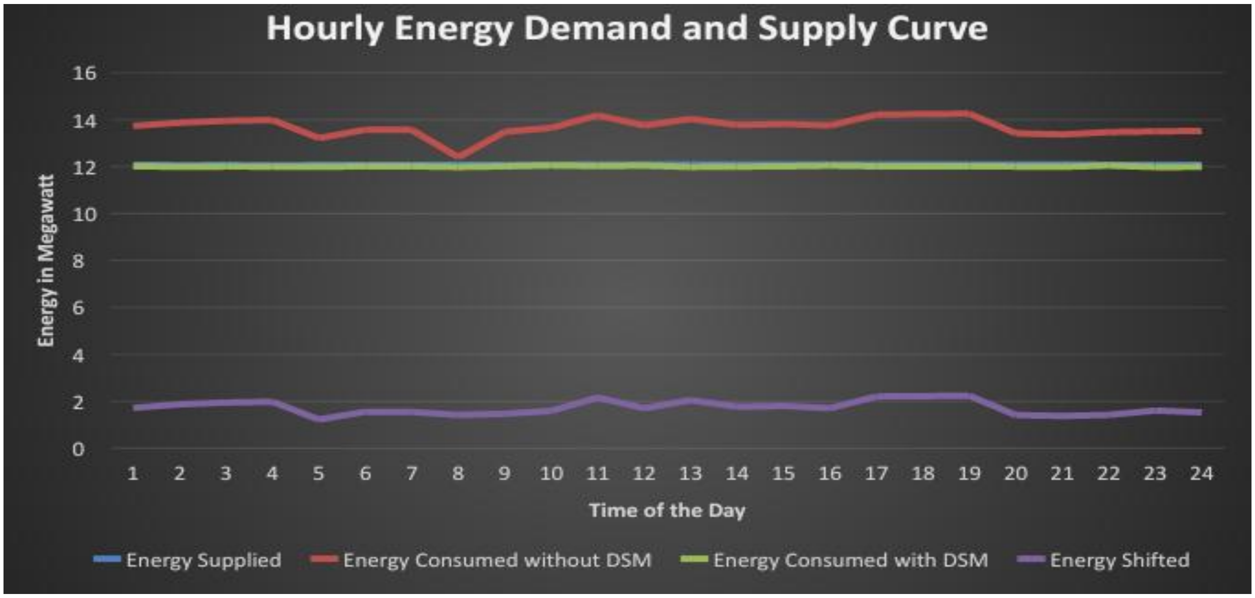

Figure 2: Hourly Energy Profile of the Distribution Network

Table 2: Status of DisCos' Customers Metering as at Second Quarter of 2024

S/N	DisCos	Total Number of Registered Customers	Number of Metered Customers	Metering Rate	Number of Unmetered Customers	Unmetered Rate
1	Abuja	1,244,245	873,083	70.17%	371,162	29.83%
2	Aba	198,531	71,135	35.83%	127,396	64.17%
3	Benin	1,369,840	675,092	49.28%	694,748	50.72%
4	Eko	773,171	438,462	56.71%	334,709	43.29%
5	Enugu	1,396,440	635,042	45.48%	761,398	54.52%
6	Ibadan	2,498,224	1,069,201	42.80%	1,429,023	57.2%
7	Ikeja	1,208,581	926,272	76.64%	282,309	23.36%
8	Jos	747,162	251,689	33.69%	495,473	66.31%
9	Kaduna	877,528	210,229	23.96%	667,299	76.04%
10	Kano	881,922	212,016	24.04%	669,906	75.96%
11	Port Harcourt	1,179,194	502,409	42.61%	676,785	57.39%
12	Yola	817,735	128,710	15.74%	689,025	84.26%
Total		**13,192,573**	**5,993,340**	**45.43%**	**7,199,233**	**54.57%**

Source: [18]

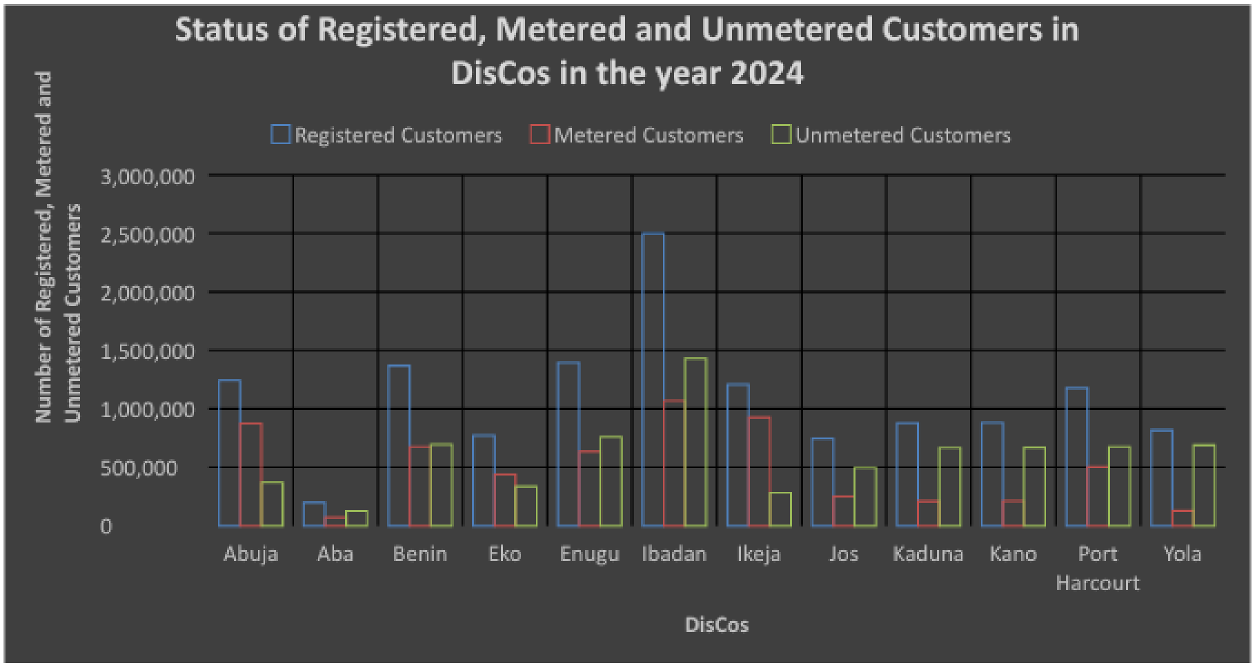

Figure 3: Distribution Network Registered, Metered and Unmetered Customers in the year 2024

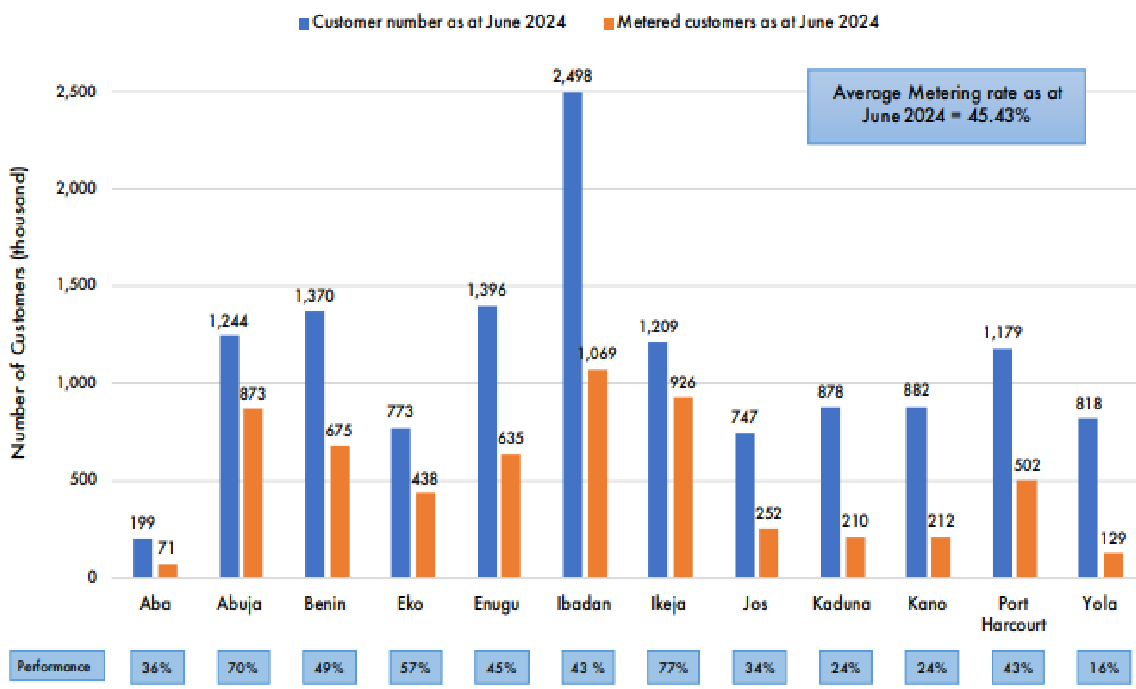

Figure 4: Status of DisCos Customer Metering as of June 2024 [18]

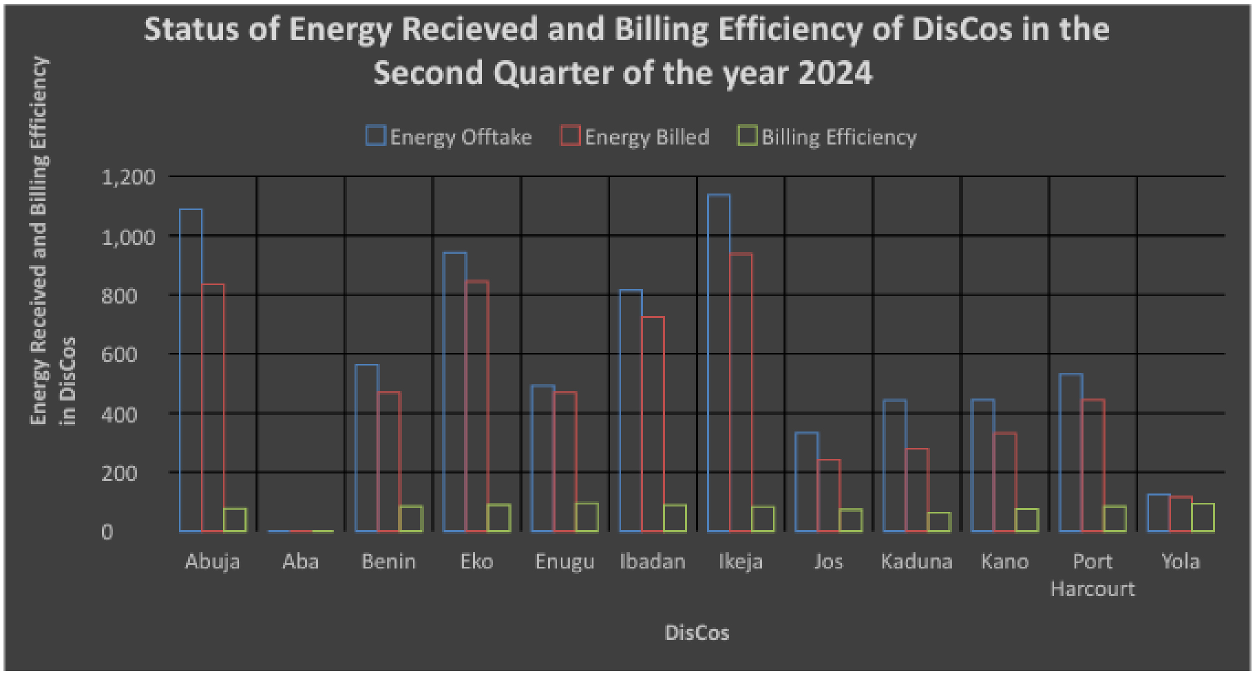

Figure 5: DisCos Energy Offtake and Billing Efficiency in the Year 2024

3.2 Discussion

The graphical analysis of daily input data of the network under study is shown in Figure 2. Hourly Energy Profile of the Distribution Network before and after DSM Implementation is presented. The blue curve represents the original energy demand without DSM, while the red curve shows the adjusted load profile following DSM application. Figure 2 clearly demonstrates a 15% reduction in peak load, illustrating the effectiveness of the DSM strategy in balancing supply and demand. Time is shown in hours, and energy demand is measured in megawatts (MW). From Figure 2, the daily energy demand by customers outweighs the daily energy supply without DSM application in the distribution network. The energy demand that outweighed the supply had created an energy deficit in the system which is one of the major causes of regimented loadshedding in the Nigerian Electricity Supply Industry (NESI) today. This energy gap created frequent regimented scheduled outages in the NESI today. Besides, the incessant unscheduled outages that is caused by fault in the system which affect the reliability and stability of the NESI services. Also, the 11 kV circuit breakers (CBs) in the network substations were being used as a sectionalizing medium in the downstream which is not healthy for the network. But when the DSM strategy was deployed as seen from Figure 2; the fraction of the energy demanded that overshot the supply was shifted within the time to Off-Peak Period to balance the supply with energy demand. This action creates stability and reliability in the system and it is obvious from Figure 2, that the current generating capacity cannot accommodate the current energy demand. Hence, the frequent power interruptions in the system. But with the DSM technique, the supply – energy demand has been balanced giving room for stability, reliability, improved performance and better service delivery to consumers. Also, MYTO has initiated cost reflective tariff (CRT) that has not seen much visible impact on the Nigerian Electricity Supply Industry. MYTO was initiated in the year 2008 with the aim of improving NESI performance and this has not been actualized due to various factors in the system especially the distribution network. One of the major factors that impacted the MYTO negatively is unmetered customers in the DisCos. From Table 2 and Figure 3 shows the visual representation of the customer metering status in the distribution network for 2024. This bar chart displays the distribution of registered, metered, and unmetered customers across different DisCos. It emphasizes the metering gap by showing that over 54% of customers are unmetered, which has significant implications for revenue collection and DSM efficiency. Percentages for each category are clearly indicated on the chart. Figure 3; 54.57% of the DisCos declared registered customers were unmetered, while 45.43% of them were metered. It shows that the network has more unmetered customers than the metered customers, this contributes to the poor revenue collection in the system. This metering gap throws up challenges to the efficient and cost reflectivity of the MYTO pricing framework for energy price determination. It is on record that out of the thirteen million, one hundred and nine-two thousand, five hundred and seventy-three (13,192,573) registered customers in the distribution networks, only five million, nine hundred and nine-three thousand, three hundred and forty (5,993,340) customers were metered; while seven million, one hundred and ninetynine thousand, two hundred and thirty-three (7,199,233) customers were unmetered representing 54.57% of the registered customers in the network. This is one of the major causes of revenue lost in the industry and it has affected the efficient operation and recouping of return on investment in the industry. The number of DisCos that have larger unmetered customers are 66.67%, while the DisCos that have lowest unmetered customers are 33.33% in the industry. MYTO appears to be efficient and cost reflective as a framework for energy price determination in the NESI but the variability of key factors often in the industry such as inflation rate, gas prices, foreign exchange rate, etc. have affected MYTO efficiency. According to [13] opined that when assumptions and parameters of MYTO methodologies - available generation capacity, electricity demand, expansion of transmission and distribution networks, capital expenditure, actual and projected sales, operating costs, fuel costs, interest rates, weighted average cost of capital, revenue collection efficiencies, subsidies, gas prices and foreign exchange rates – are not violated, the set energy prices (tariffs) are cost reflective but the assumptions are always violated. The variability of the key factors in the power sector, make MYTO prices framework are not cost reflective but misleading. Therefore, the good intentions of MYTO have not significantly impacted the industry. To make the MYTO have a significant impact on the NESI, the service-based or service-reflective tariffs were initiated which created various Bands for customers in the DisCos with different tariffs based on the hours of services rendered. This is to ensure the customers feel the impact of MYTO and make the tariff cost reflective by creating service-based tariffs that receive various hours of electricity supply based on the Bands allocation. All these are to improve performance and increase service delivery in the DisCos. The DisCos being the channel for revenue collection in the industry has not fared well over the past because of poor revenue collection due to large metering gap in the sector as shown in Figure 4. It provides a visual breakdown of metered versus unmetered customer ratios, reinforcing the challenges in achieving accurate energy consumption data. The caption highlights that the high percentage of unmetered customers (e.g., 76% in certain regions) adversely affects the DSM implementation and overall energy management. Also, the poor revenue collection and billing efficiency in the sector is shown in Figure 5. This Figure illustrates the correlation between energy offtake and billing efficiency among DisCos. Improved DSM strategies, as indicated by a 10-15% increase in billing efficiency in some regions, are shown to correlate with reduced energy losses. From our results, it reveals that DSM implementation can reduce peak load up to 15% and decrease energy deficits by approximately 12%. Furthermore, adjustments in the MYTO pricing model led to a 10% improvement in cost reflectivity, thereby enhancing revenue collection and operational sustainability. The graph includes annotations that specify efficiency improvements, helping to clearly connect DSM implementation with financial and operational performance. All these accumulate to poor return on investment which discourage investors in the industry. Hence, MYTO significant impact is yet to be obvious in the industry but some milestones have been achieved since its creation in the year 2008. Therefore, the huge unmetered gap created the following in the system:

i. Inaccurate customers/consumption information in the system.
ii. Unaccounted electricity consumption by unknown customers and unquantified losses in the system.
iii. Poor administration of the distribution system and service delivery.
iv. Poor revenue collections and inaccurate revenue projections in the system.

4.0 Conclusion

The DSM technique has shown capacity to eliminate the gap created between supply – energy demand in the system, while the MYTO appears to be efficient and cost reflective as a framework for energy price determination in the system. The advanced load shifting techniques adopted was optimized by the Binary Particle Swarm Optimization (BPSO) and a detailed cost component analysis in the MYTO framework was used to reveals the DSM implementation which reduced peak load by 15% and decrease energy deficits by approximately 12%. Furthermore, adjustments in the MYTO pricing model led to a 10% improvement in cost reflectivity, thereby enhancing revenue collection and operational sustainability. These quantitative improvements not only validate the effectiveness of the proposed methodologies adopted but also provide actionable insights for policymakers aiming to achieve a more reliable and financially sustainable energy supply system. However, MYTO has not pulled its full weight on the Nigerian Electricity Supply Industry (NESI) because of the huge metering gap existing in the network due to poor governance in the energy sector as seen in Figure 4, that 54.57% of the declared registered customers are unmetered as at today. DSM strategy has shown capacity in the conventional and even in the future grid been referred to as set of measure that allows the energy providers to reduce the peak load demand and reshape the load profile of the system with the aim of bringing the final load curve closer to an objective load curve in order to improve the energy supply at the consumers' end. The influence of DSM and MYTO is essential in the Nigerian Electricity Supply Industry. Therefore, all customers should be metered to provide accurate customers and consumption information in the system which will increase revenue collection and unaccounted electricity consumption in the system. Also, the currently administration system in the power industry should be overhaul for more effectiveness and efficiency.

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