Augmentation Of Power System Distribution Network And Capacity Inadequacy: Literature Review

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***Abstract*—Electricity supplies in Nigeria have become more erratic, the power infrastructure is dilapidated and many Nigerians have been denied access to Electricity. Many research work have analysed a ways of augmenting the inadequacy of the distributed network and distributed generation in the form of embedded generation into an existing distribution network have also been discussed and the solution lies in the provision of distributed generation into the 11kV feeders connected to the distribution franchise network of the DisCo to improve the quality and quantity of power available to electricity users. This publication seeks to review each literature to understand how all the research work converges in support of the idea of distributed generation**

Keywords— Augmentation, Power Distribution Network, Modeling, Inadequacy.

1. INTRODUCTION

Over the years, Nigerians have witnessed persistent power shortage from the national grid. The implication is that the load demand is never met by the national grid [1,2,3,4,5,6,7,8, 9,10,11,12,13,14, 15,16,17] and so, alternative energy generation approaches have been widely adopted at individual household and organisational levels [18,19,20,21,22, 23,24, 25,26,27,28,29,30,31]. This has occasioned the need for distributed generation of electric energy for the consumer needs.

Accordingly, Distributed Generation (DG) can be described as small units that generate electric power to the location of consumers based on the renewable energy technique and including wind energy, solar energy, geothermal energy, hydro and other forms of energy generation approaches [32]. Also most regulatory practices has also allowed the interconnection of small power generation sources like the gas turbine technology machines of between 50 kW to 10 MW into the distribution network and are called embedded generation (EG) [33] thus the integration of DG and EG which are sometimes used interwoven, has led to increased voltage and frequency stability [2] and the overall power quality in the distribution network.

DG or EG as may be used interchangeably in this research, reduces transmission and distribution losses, augments the distribution network to reduce the inadequacy of the power system grid network and improves power system resilience [33].

The following types of EG are deployed in the delivery of power into the electricity distribution network:

(i) Synchronous generators, which are capable of injecting both real and reactive power.
(ii) Induction generators, such as Wind generation farm which are capable of injecting real power but consuming reactive power.
(iii) Solar or photovoltaic cells (PV), Micro turbines, and fuel cells integrated to the main grids with converters / inverters are capable of injecting real power only.
(iv) Synchronous compensators are capable of injecting reactive powers only.

According to the research done by [34], to accommodate distributed or embedded generation, there must be change in the thinking regarding the planning and design of the distribution network, which includes the protection system and optimally allocate the EG or DG.

During planning and design, which involves modeling and simulation of the power system distribution network, new techniques are developed to determine suitable locations and rating of the DG on the distribution network with respect to the technical constraints which may enable a high penetration of generation on the network and avoid network sterilization, which results when capacity is allocated to the bus / buses whose voltage and or short circuit levels (SCLs) are most sensitive to power injection.

This research studies the significance of injecting power from distributed generation or embedded generation into the distribution network to augment the capacity of the seemingly inadequate power supply from the Nigerian national grid network, thus improving power supply availability, power system quality and provide sustainable electricity to rural areas, urban centres as well as industrial load centres for the development of the Nigerian economy.

2. Modeling and Simulation (Method and Procedure)

Figure 1 shows a simulation procedure designed by the authors in [35], to guide research activities and experiments in a real-world problem solving case study. The process was evaluated through application to a case study where the research intent was to explore the time-related performance of a new product development process. The focus is to identify time as a resource used in the process by work teams and then propose improved strategies for the management of the time such that product development cycle times is reduces. The thirteen-step procedure, shown in Figure 1, and each step is described in the remainder of this section.

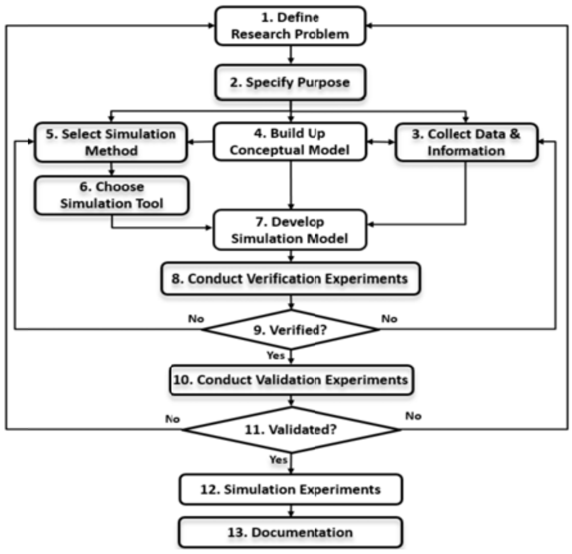

Figure 1: Modelling and simulation procedure

Source: [4].

2.1 Simulation Experiments: According to [35], simulation experiments are conducted to simulate real-world operational scenarios. Simulation results are analyzed and discussed.

2.2 Documentation: Instructions and documents supporting the simulation model and simulation experiments are developed, e.g. how to operate the simulation model, how to set input data values, and how to analyze model results. This step is necessary for other users to understand, modify, or further improve the simulation model if necessary. It also boosts users' confidence when the users apply the model in solving real-world problems. In the case study used to evaluate this process, a user manual for operating the simulation model was developed [36].

2.3 Model Verification and Validation

According to the reference work of [35], the purpose of model verification and validation is to make the simulation model meaningful in a real-world context. Therefore, along with model design and development, model verification and also model validation are included in the modeling and simulation procedure. Figure 2 gives an example of full vision of model verification and validation architecture. Model verification and validation activities include validation of the simulation model with respect to the real-world situation and the conceptual model.

2.4 Model Verification and Validation Concepts

The authors [36] discussed that model verification concerns the identification and removal of errors in the simulation model by comparing simulation results from the model to analytical solutions from the real-world situation. By this approach, the process employed in the model verification focuses mainly on the mathematical expressions as well as the simulation specifications that are associated with the model. In this way, model validation ensures that the simulation model is useful for real-world problem-solving. Model validation processes are concerned with quantifying the accuracy of the model by comparing simulation results to experimental or operational outcomes in the real world.

2.5 Verification and Validation Architecture

The architecture for the model verification and validation is shown in Figure 2. As shown in Figure 2, three verification and validation activities are needed [36].

Firstly, according to the author in [36] conceptual model verification ensures that the conceptual model is an accurate representation of the research problem in real-world situation. Secondly, simulation model verification ensures that the computer-based simulation model is a sufficiently accurate implementation of the concept model. In addition, at the centre of the diagram in Figure 2, all data used in all aspects of both model design & development and model verification & validation needs to be validated.

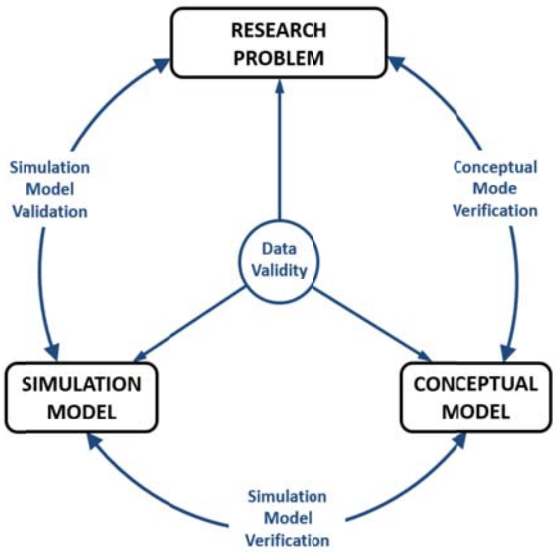

Figure 2: Model verification and validation architecture Source: [36]

2.6 Model Verification and Validation Methods

From the published literature by [37], in section 2.3 of his paper, emphasis was on data collection and there are many model verification and validation methods developed for specific simulation situations. A series of model verification and validation methods are listed as follows.

i. Animation Validation

ii. Model to Model Validation

iii. Event Validation

iv. Extreme Condition Validation

v. Face Validation

vi. Historical Data Validation

vii. Operational Graphics Validation

viii. Sensitivity Analysis Validation

ix. Predictive Validation

x. Traces Validation

xi. Turing Test Validation

xii. Game Validation

Different model verification and validation methods have different advantages and limitations, which means, again, that different methods are suitable for different real-world problem situations and research purposes. Regarding model verification and validation method selection, more information can be found in publications cited above by the authors in [35] and [36].

2.7 Summary

Modeling and simulation methods are becoming increasingly important as research methods that can used for investigating operational and organizational systems. Existing literatures report different views and aspects of modeling and simulation techniques with specified interests, but there is limited literature that presents a full vision of modeling and simulation in a procedure suitable for engineering design applications.

3. Mathematical Model

According to [38], decades before now, distribution systems whether they are radial-type systems or ring-type systems were designed to deliver the electric energy to the consumer without any generation on these systems. However, due to the major changes in the legislative framework for the electric sector and the fast move toward liberalization of the electricity markets, generating units were introduced to distribution systems. These units are of limited size (100 MVA or less) and can be connected directly to the distribution network. These generating units are referred to as *distributed generation (DG)*. Studies have predicted that by year 2010, distributed generation would account for up to 25% of all new generation. The main reasons behind the expected widespread of DG are:

A. Deregulation in the power market [39] which encourages public investment to sustain the development in the power demand.

B. Due to saturation of existing networks and the continuous growth of the demand, this development has led to the breaking up of investments (small generating units)

C. Emergence of new generation techniques with small ratings, ecological benefits, increased profitability, and which can be combined with grid generation.

Adequacy assessment implies the determination of the actual distribution system power capacity and the ability of this capacity to meet the total system demand. The term "distribution system power capacity" is introduced in the research to account for the generating power from the available DG plus the received power from the transmission system.

Mathematically, distribution system power capacity is defined by:

$$P_S = P_T + P_{DG} \quad (1)$$

where $\boldsymbol{P_T}$ is the power received from transmission system in megawatts and $\boldsymbol{P_{DG}}$ is the power generated by the DG in megawatts can be treated as a large generated power located at the substation site, $\boldsymbol{P_{DG}}$ is the expected contribution

of all the online DG where

$$P_{DG} = \sum_{i=1}^{N} P_i \quad \text{Equation 2.2}$$

Where P_i is the power output of DG unit i in megawatts and $\boldsymbol{N}$ is the number of DG units.

3.1 Equal Area Criterion to Determine Time Response of Power System

Eseosa and Promise [40] discussed that the maximum angle excursion of rotor angle of the generators used in electric power system can be obtained graphically by using power angle diagram

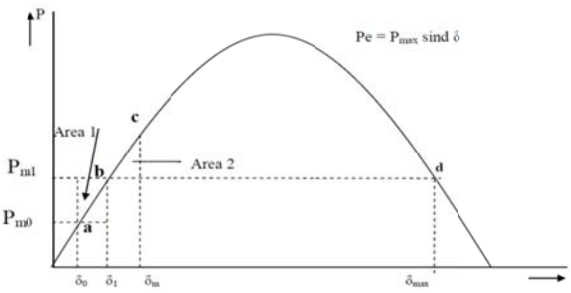

Figure 3: Power-angle variation. Source: [40]

This method made it easier to determine the maximum swing of δ and therefore the stability of the system. Incidentally, this method does not apply to multi machine systems with detailed representation of synchronous machines, but it could provide a clue to understand the basic factors that influence the transient stability of power system in Nigeria. The following relationship between the rotor angle and the accelerating power would be considered:

$$\frac{d^2\delta}{dt^2} = \frac{\omega_0}{2H}(P_m - P_e) \quad (2)$$

Pe is a non-linear function of δ, so the equation cannot be solved directly. Let us multiplied by

$2d\delta$ / then,

$$2\frac{d\delta}{dt}\frac{d^2\delta}{dt^2} = \frac{\omega 0(Pm-Pe)}{H}\frac{d\delta}{dt} \quad (3)$$

$$\frac{d}{dt}\left[\frac{d\delta}{dt}\right]^2 = \frac{\omega 0(Pm-Pe)}{H}\frac{d\delta}{dt} \quad (4)$$

Integrating gives

$$\left[\frac{d\delta}{dt}\right]^2 = \int \frac{\omega 0(Pm-Pe)}{H}d\delta \quad (5)$$

Note that the speed deviation $d\delta/dt$ is initially zero and will change when the system is subjected to disturbances. To maintain stable operation, the deviation of angle δ must be bounded. This will require the speed deviation $d\delta\ dt$ to become zero some time again after the disturbance.

Therefore, from Equation 5, as a criterion for stability, we may write

$$\int_{\delta 0}^{\delta m} \frac{\omega 0(Pm-Pe)}{H} = 0 \quad (6)$$

Where, $\delta 0$ is the initial rotor angle and δm the maximum rotor angle.

Thus the area under the function $Pm - Pe$ plotted against δ must be zero if the system is to be stable.

In Figure 3, this is satisfied when area A1 is equal to area A2. The kinetic energy gained by the rotor during acceleration when δ changes from $\delta 0$ to $\delta 1$ is given by:

$$E1 = \int_{\delta 0}^{\delta 1} \frac{(Pm-Pe)}{H} d\delta = 1 \quad (7)$$

The energy lost during deceleration when δ changes from $\delta 1$ to δm is

$$E2 = \int_{\delta 1}^{\delta m} \frac{\omega 0(Pm-Pe)}{H} d\delta = Area\ A2 \quad (8)$$

Assuming there are no losses, the energy gained is equal to the energy lost;

Therefore, area A1 is equal to$A2$.

This forms the basis for the equal area criterion. It helps us to determine the maximum swing of δ and the stability of the system without computing the time response through formal solution for the swing equation.

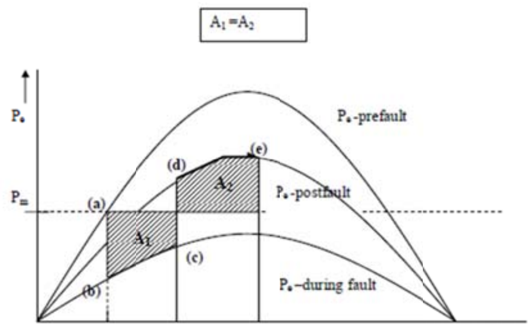

Figure 4: Pe-δ **when A1 = A2**

Source: Eseosa and Promise (2015)

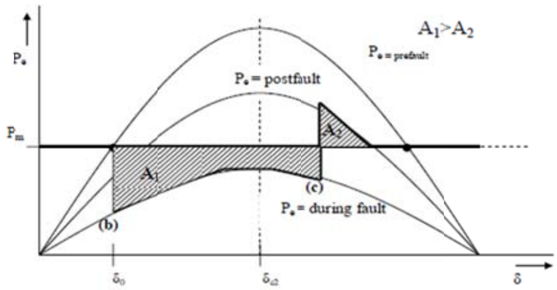

Figure 5: Pe-δ **when A1 > A2** Source: [9]

Figures 4 and 5 show Pe-δ plot for three network conditions on Nigeria power system;

(i) pre-fault, (ii) during three-phase short circuit fault and (iii) post fault.

In both cases, let us assume the input power Pm is constant. Initially, in the stable case of Figure 4, the system is operating with $Pe = Pm$ and $\delta = \delta 0$.

When fault occurs, the operating point changes suddenly from *a* to *b*. Due to inertia, angle δ cannot change instantly. Pm is now greater than Pe, the rotor accelerates until the operating point reaches *c*, when the fault is cleared by isolating the faulty circuit from the system. The operating point at this point moves suddenly to *d.* Hence, Pe becomes greater than Pm, *which* causes deceleration of the rotor. Since the rotor speed is greater than synchronous speed $w0$, δ continues to increase until the kinetic energy gained during the period of acceleration represented by *A1* is expended by transferring the energy to the system. The operating point moves from *d* to *e*, such that the area *A2* is equal to *A1*. At the operating point denoted as e, the speed becomes equal to the synchronous speed, $w0$ and which is at its maximum value denoted as δm. Meanwhile, $Pe > Pm$, so the rotor continues retarding which causes the speed to drop below the synchronous speed. Hence, rotor angle denoted as δ decreases while the operating point retraces its path from point *e* to *d* and then follows the Pe-δ curve of the post fault system farther down. The minimum value of δ is such that it satisfies the equal-area criterion for the post fault system. When there is none of such damping, the rotor will continue to oscillate at a constant amplitude. With a delayed fault clearing in Figure 5, area *A2* above Pm is less than *A1*. By the time the operating point gets to *e*, the kinetic energy acquired during the period of acceleration has not been completely expended yet; therefore, the speed is still greater than synchronous speed and δ continues to increase. Beyond point *e*, Pe is less than Pm, and the rotor begins to accelerate again. The rotor speed and angle continue to increase, leading to loss of synchronism.

4. A Simulation Model for Adequacy Assessment of Distributed Generation

Diversity among energy sources will contribute to the resilience of power grids operating as adaptive distributed generation (DG) systems, capable of reconfiguration in response to failures, natural disasters or human attacks. Technological barriers to the integration and stable management of renewable energy sources are linked to the inherent uncertainties in the operation of renewable generation units, due to intermittency and forecasting imprecision.

Kuznetsova in [41] presented a research on multi-state simulation model for the adequacy assessment of a comprehensive distributed generation (DG) system, which incorporates diverse elements, that is solar and wind generators, electrical vehicles, transformers and power loads.

The Monte Carlo simulation (MCS) method was used to take into account the uncertain behaviours of renewable sources, due to the stochastic nature of weather conditions, and the random mechanical failures and repairs of generation units. The simulation result for a case study of a reasonably comprehensive DG system model was satisfactory in comparison to those of a previously developed multistate analytical model. Supplemental electricity generation was required for anticipating uncertainty in electricity generation and limiting the power grid unreliability and instability. Adequacy assessment was used to evaluate the capacity of the DG system of meeting the system demand.

4.1 Methodology Adopted

The study presented in this research work was inspired by previous works on simulation for distributed power systems adequacy assessment by [10]. With the aim of building a relatively comprehensive model of DG systems, the Monte Carlo simulation (MCS) method was used by the authors to account for the uncertain behaviours of renewable sources due to the stochastic nature of weather conditions, as well as for the random mechanical failures and repairs of generation units. Various backbone elements of the system have been incorporated in the model, e.g. solar and wind generators, electrical vehicles, transformers and power loads. This stage also deals with synthesis of the data, concept and the results presented by the authors.

4.2 Models of Individual Component

In order to focus the investigation on the complexity of the overall simulation model of DG systems, at the elementary level the preference has been given by the authors Kuznetsova *et al. (*2014) to simple and flexible models of individual components already developed, tested and validated in different researches

During the study it was discovered that the load curves of individual users depended on the user type, number and type of electrical appliances and way of usage. Also taking into account the difficulty of collecting large amount of reliable input information and building complicated models, the top-down approach, based on chronological and detailed data of overall electricity demand, was more suitable for the research.

Simulation of the yearly electrical load profile, taking into account short-term and long-term seasonal changes, the hourly peak load values were related in percentages to the value of maximum annual peak load. Despite its simplicity, this way of modeling allowed simulating the representative shape of the daily, weekly and seasonal energy demand curves. By changing the value of annual peak, as the input parameter, various sizes of electricity distribution grid were simulated.

4.3 Transformer

Kuznetsova [41] used transformers in electricity grids to adapt electricity voltage to a suitable level from the lower or higher voltage circuits: increase voltage for long distance electricity transmission with minimum losses or decrease voltage for distribution. During the research work, the electricity output from the transformer into the distribution grid was considered related to the generation by conventional units and constant with no uncertainties.

4.4 Solar Generation Unit

In this research by [41] the electricity output from solar generation depends on the conversion efficiency relying on particular weather conditions and technical specifications of the conversion mechanism. In this view, the model for the solar generation units combines two modules: one module simulates the intensity of solar irradiation and the other module was a generation function for the electricity output of the solar units. The main uncertainties lied in the representativeness of the solar irradiation received by the surface of the solar generator and in the mechanism of mechanical failure of the solar generator. Different approaches have been proposed to model the distribution of solar irradiation: the statistic approach used probability density functions (PDFs), times series, and artificial neural networks.

The solar irradiation forecasting precision of these approaches varies depending mainly on the quality of data in reference to the different dynamics of solar irradiation behaviour. In the research work, a PDF approach was embraced by way of the beta distribution validated by different researches as a simple and sufficiently flexible two-parameter distribution, which fitted well the empirical data in many situations.

The average hourly solar irradiation data was used to estimate the beta parameters. The electricity output from one solar generation unit, taking into account solar irradiation, ambient temperature and characteristics of the module, can then be evaluated using the equations and data given.

4.5 Wind Generation Unit

Similar to solar generation, the electricity output of wind turbine is affected by meteorological and environmental conditions (e.g. wind speed, effects of sandblast and icing) and the technical specifications of wind turbine design. Among the numerous existing approaches to generate wind speed profile, including time-series and artificial neural networks, the Rayleigh distribution has been most commonly used, as this statistical distribution has been assessed to provide satisfactory fitness to empirical data.

In the research work by [41] the average hourly data of wind speed was used to fit the Rayleigh distribution. The electricity output from wind turbines was then typically approximated by a linear relationship with the rated power of the wind generation unit corrected by a coefficient of current wind speed. We used wind turbine technical parameters already adopted in previous simulations.

4.6 Electrical Vehicles (EVs)

In addition to production and consumption units, the simulation model here presented by the authors in [0] integrated EVs, which can to plug-in into the electricity distribution grid.

On the other hand, batteries of EVs could function as storage devices and give the stored electricity back to the grid at a later time. In this view, efficient management of electrical vehicles could be used to smooth electricity consumption peaks.

In order to simplify the simulation model but still coherently reflect the most critical situations (e.g. all batteries are charging from the grid), the model represents all EVs as a single electrical device capable of charging, storing and discharging electricity. A three-state model has been used to represent the behaviour of the EV aggregation: charging, discharging and disconnected.

The state probability vector of the EV aggregation is denoted as

$$[Pro\text{-}1(t), Pro0(t), Pro1(t)] \qquad (9)$$

with the complete partition property

$$Pro\text{-}1(t) + Pro0(t) + Pro1(t)=1. \qquad (10)$$

4.7 Simulation of Mechanical Failures and Repairs of Generation Units

The electricity output of renewable generators was also affected by mechanical failures and the production unavailability periods associated to the subsequent repairs, which were decided by the compound quantitative indicator called technical unavailability. In the model by Kuznetsova *et al*. [41] the mechanical failures of generation units of the same type were assumed to be independent from each other: no common causes for failures were considered. Moreover, no particular reduction of power production due to degradation was considered: only two states were possible for the renewable generation units and the transformer, i.e. 100% of technical availability during normal operation and 0% of technical availability during repair following a failure.

The failure and repair times were assumed to follow exponential distributions; during simulation, they were sampled by the inverse transform technique. The Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR) of the generation units are given in the Table 1.

Table 1 Mean Time to Failure and Mean Time to Repair for electricity generation unit

Generation unit	Transformer	Wind turbine	Photovoltaic module
Mean Time to Failure (hrs)	2500	1920	1920
Mean Time to Repair (hrs)	78	25	25

Source: [41]

4.8 Monte Carlo Simulation Model of the Distributed Generation System

The simulation model previously illustrated has been used to perform the adequacy assessment of DG systems over one year (Table 1). The transmission lines and protection devices were assumed to be infallible and "electrically perfect", i.e. their parameters such as cable distribution capacity and associated losses were neglected.

According to Kuznetsova et al. [41] the DG system performance is evaluated in terms of classical adequacy assessment metrics, which characterize the ability of the DG system power capacity to meet system demand. Loss of Load Expectation (LOLE) characterizes the probability of unsatisfied electricity demand and Loss of Expected Energy (LOEE) defines the expected amount of power losses for one simulated time period; for one particular DG system they are calculated as:

$$\text{LOLE} = \sum_{k=1}^{N} t_k \, . \, P_k \, (C_k < L_k) \qquad \text{Equation 11}$$

$$\text{LOEE} = \sum_{k=1}^{N} t_k \, . \, P_k \, . \, CE_k \qquad (12)$$

where *Pk* is the probability of loss of load in time period *k* of duration *tk*, *Ck* is the available capacity in time period *k* (kW), *Lk* is the peak load in time period *k* (kW) and *CEk = Lk – Ck(Ck < Lk)* is the energy that the system is not able to supply in time period *k* (kW).

The available DG system capacity (*Ck*) represents the sum of electricity produced by all generation units in time period *k*.

The situation when the available capacity (*Ck*) is lower than the peak load (*Lk*) in time period *k*, characterizes the electricity shortage in time period *k*.

4.9 Validation of Adequacy Assessment Result and Discussion

The evaluation of the expected system performance for over one year was carried out by the authors Kuznetsova et al. (2014), 105 realizations were executed, subdivided into *n*=20 subsamples of 5000 each.

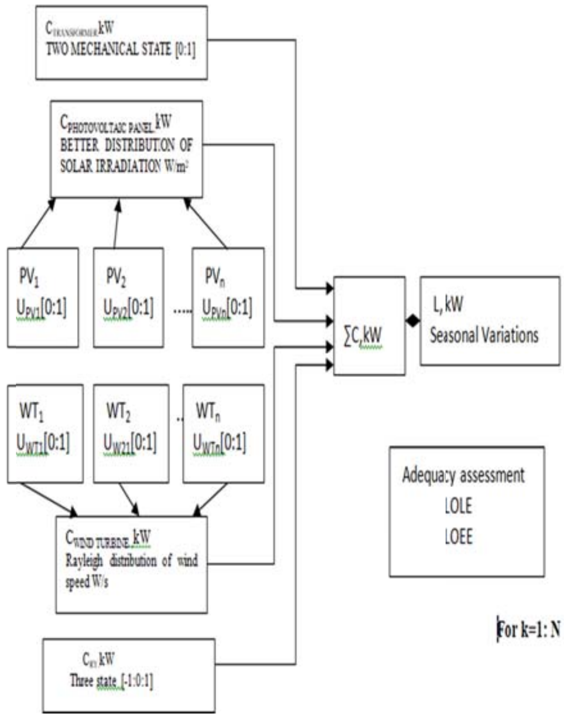

Figure 6: Flow chat for DG simulation model

Source: [10]

The sample variance and mean of LOLE and LOEE were calculated by using the following equations:

$$\text{Var}_{\text{LOLE}} = \frac{1}{n} \, . \, \sum_{k=1}^{n} (\text{LOLE}_K - \overline{LOLE})^2 - \overline{LOLE} = \frac{1}{n} \, . \sum_{k=1}^{n} LOLE_K \qquad (13)$$

$$\text{Var}_{\text{LOEE}} = \frac{1}{n} \, . \, \sum_{k=1}^{n} (\text{LOEE}_K - \overline{LOEE})^2 - \overline{LOEE} = \frac{1}{n} \, . \sum_{k=1}^{n} LOEE_K \qquad (14)$$

where *LOLE* and *LOEE* are the sample mean values, and *LOLEk* and *LOEEk* are measured from the values measured from the kth sample. The convergence values of *LOLEk* and *LOEEk* on *k* samples (*k* = 1,2…,*n*) are calculated using the following equations:

$$\text{LOLE}_{\text{Conv.k}} = \frac{\sum_{k=1}^{n} \text{LOLE}_k}{k} \qquad (15)$$

$$\text{LOEE}_{\text{Conv.k}} = \frac{\sum_{k=1}^{n} \text{LOEE}_k}{k} \qquad (16)$$

The example of convergence curves, presented in Figure

7, manifest good stabilization of *LOLEconv,k* and *LOEEconv,k.* The converged values compare satisfactorily with the results of the multi-state analytical model.

It is noted that *LOLEconv,k = LOLE* and *LOEEconv,k = LOEE* .

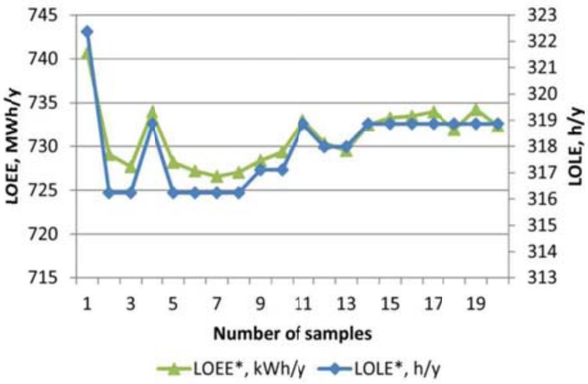

Figure 7: Convergence curve for LOLE and LOEE

Source: [41]

5. Augmentation of the Distribution Network Capacity

Pandya [42] in a research on the augmentation of distribution network capacity through the integration of the photovoltaic panels and energy storage system an indication that the electricity distribution network which remains the end of the electricity services value chain is inadequate in capacity due to demography and requires serious attention.

The research done by Pandya *et al.*[42]was on how the Integration of renewable source into the distribution network under varying load profile and described it as being a daunting task.

5.1 Research Methodology Adopted: Pandya *et al.* [42] presented a paper which showed integration of the PV system with battery energy storage into the distribution system to improve the distribution network utilization. The reactive/real power is required to maintain the distribution systems load profile and hence improve the power utilization. Through D-STATCOM interface, the instantaneous injection of real/reactive power with the use of PV and battery energy storage was made available. Always power from renewable source availability and load demand in the distribution network were mismatching. The intermittent energy storage with batteries did not only resolve this mismatching but also supported the operational efficacy of distribution infrastructure. This operation was proposed through control algorithm based on the battery capacity support in real/reactive power demand by the load.

According to Pandya *et al.* [42] this ensured the negligible reactive power from the source under near unity power factor operation of the distribution feeder which enhances the existing distribution network capacity. This brought improvement in the utilization justified the investment on the batteries. The typical distribution operation under different operating conditions was simulated with the proposed control scheme. The results were verified with its cost analysis on urban feeder.

The other method that reduces overloading of feeder was network reconfiguration using sectionalizing switches and tie switches. This network reconfiguration method was not applicable to large radial distribution network.

Pandya *et al.* [42] also inferred that this reconfiguration was a part of long term planning and requires additional investments. The distributed generation like solar/ wind had the capability to compensate localized real and reactive power. The PV integration issues like its intermittent nature and voltage stability was addressed using the feasible solution of interfacing the PV with ENERGY STORAGES (ES) through custom devices. These custom devices are based on the FACTs technology developed around the power electronics switching devices. The most suitable topology for interfacing the PV and energy storages across the dc bus is DSTATCOM. The type of storage and its sizing depends on the load profile of the feeder and PV inverter capacity. The control and its interfacing techniques are based on the required dynamics in its operation. The feeder capacity enhancement with energy storage was suggested.

This paper by Pandya in [42] presented PV system integration through energy storage to distribution network. The configuration and control is implemented to improve the distribution network utilisation under over loading condition by localised real power support and voltage profile improvement with reactive power compensation. The PV power is used under off load condition is used to charge the energy storage. The source is relived from the reactive power support so as to accommodate the additional real power in existing distribution line. The interface of ES with distribution system is shown in Figure 8.

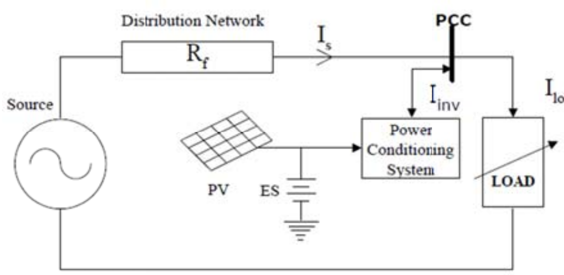

Figure 8: Distribution system with PV and Energy Storage (ES) Source: [42]

The DSTATCOM is operated in hysteresis control mode to improve the dynamics of the system. In proposed scheme, the ampacity is determined by the existing line conductor specifications. The line current control is set to a value corresponding to the limit of line overloading. The effectiveness of the control with different loading conditions was performed to show the improvement in the line utilization. The simulation of the line with the realistic data for the urban feeder was used for the analysis.

5.2 Result and Discussion: The result of the research is that, the battery sizing and relief on overloading with existing loading pattern and PV penetration reflects performance improvement in the existing feeder. The following objectives were achieved through proposed operating methodology

- Always operating the line with power factor of 1.

- Support of reactive power to the load is provided by the DSTATCOM

- The off-peak loading condition and PV power is used for storing the energy in the batteries.

- The thermal limit of the line is exploited in overloading period.

- in view of the proposed scheme reliability and economy are feasible

A. Model of Distribution Network

A model shown in Figure 8 is a single line diagram of radial distribution system supplied by central generation. At point of common coupling (PCC), energy storage was connected. The load current at PCC was considered as

$$I_{load} = I_s \pm I_{inv} \quad (17)$$

$$I_{inv} = I_{pv} \pm I_b \quad (18)$$

Where,

I_s = source current

I_{load} = load current

I_{inv} = Current supplied (+) /drawn (-) by inverter

I_{pv}= Current supplied by PV module

I_b= Current supplied (+) /drawn (-) by battery

The line resistance related to the type of the ACSR conductor (DOG 0.1 i.e. 103.6 Sq mm) was used in this analysis. The X/R ratio was 1 as the resistance was dominant in distribution line.

B. Loading Trend of Distribution Feeder

As discussed by the authors [42], daily load curve of a feeder is shown in Figure 9. The overload and under load condition of feeder with reference to rated loading capacity of feeder is indicated in load curve.

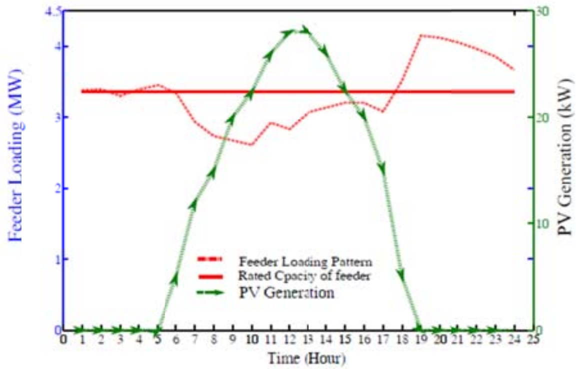

Figure 9: Loading pattern of urban feeder with PV generation Source: [42]

5.3 Dynamic Performance under Different Loading and PV Integration

The system was simulated for different load conditions with PV integration. The dynamic support of energy storage for PV integration has improved the stability of feeder. Real and reactive power demand by the load is indicated in Figure 10.

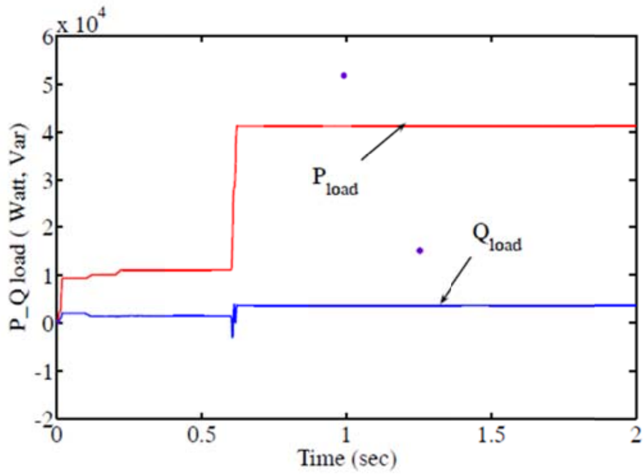

Figure 10: P Q load for load ref 1.0 Source: [42]

The source has supplied real power as per the reference set to 1.0. For the duration 0.2 sec to 0.6 sec load was less than source capacity so the excess power supplied by source was utilized for charging energy storage this is indicated in Figures 11 and 12.

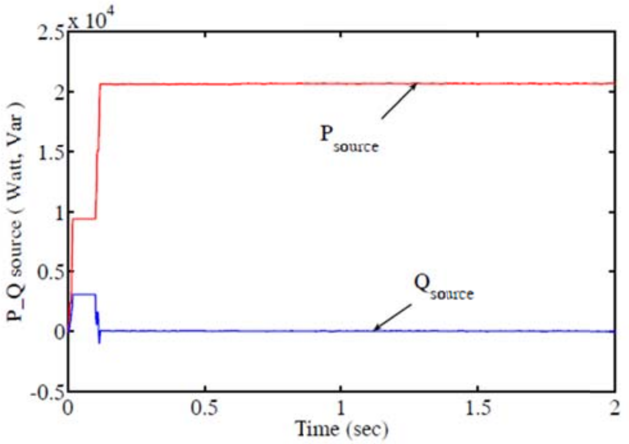

Figure 11: P Q source for load ref 1.

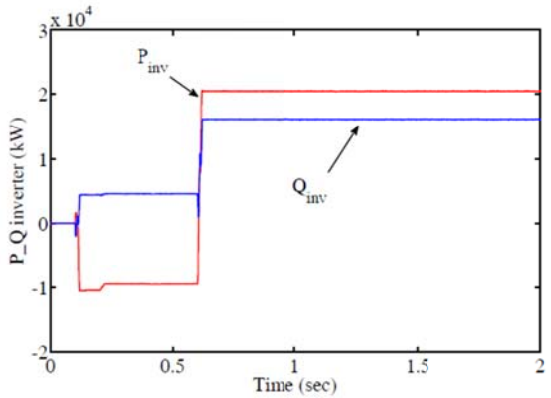

Figure 12: P Q Inverter for load ref 1.0

Source: [42]

The source supplying power at thermal rating of feeder is shown in Figure 13. A feeder can supply a peak current of 120A. This source current remained constant during under load and over load operation of feeder.

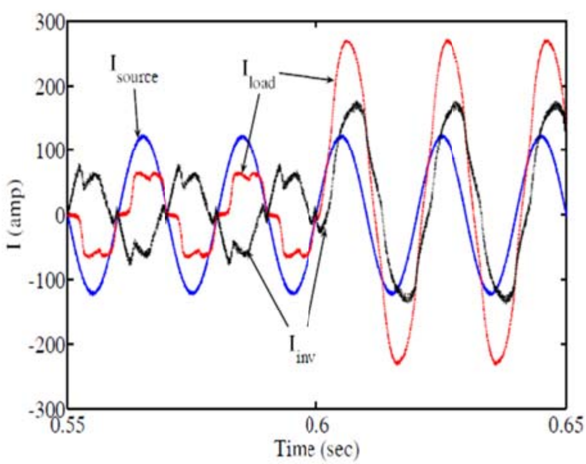

Figure 13: Source current, load current and inverter current (Amps) Source: [42]

During under load condition extra energy from feeder was used to charge energy storage while during over load condition the deficit energy was supplied by energy storage.

5.4 Conclusion

The authors in [42] concluded that the proposed controller ensured the full capacity utilization as the feeder operated with unity power factor under varying loading condition. The source power in feeder was controlled up to the feeder thermal limit under overloading conditions. The proposed control of urban feeder was reflecting the improved utilisation of feeder by energy storage. The compensation of the reactive part of the load was provided by the custom power device DSTATCOM. The PV and matching battery sizing required for the given feeder was obtained from the loading pattern of the given line. The increment in energy supplied per year is 20% due to reactive power compensation and 23% due to integration of PV. The PV power and capacity relief of feeder during off-peak hours were used to maintain the battery charge at economical rate.

The performance test, according to the author, indicated the dynamic stability and economic feasibility of PV integration with ES for distribution feeder. The availability of the extra capacity for the same feeder and PV power revenue generated justified the investment cost of PV and energy storages. The line utilisation with uninterrupted power supply to load for distribution network improves the feasibility under power demand crisis.

6. Electricity Distribution Industry – Problems, Case of Akwa Ibom State, Nigeria.

This research was carried out to identify the problems associated with the electricity distribution network. Roland and Okedu in [43] described the dilapidated electricity network as being responsible for the abysmal electricity services rendered by the Distribution Company particularly in Akwa Ibom State of Nigeria.

Several substations were without electricity during the course of the research and many urban and rural communities were disconnected from the national grid which as at the time of the research was strictly government's responsibility to provide electricity through the National Electric Power Authority (NEPA) and the Power Holding Company Limited (PHCN), a monopoly.

6.1 Research Methodology: The research was inform of assessment and data collection focused on the existing electricity distribution facilities, with particular attention to the KVA rating and voltage rating of the transformers, details of up-risers (number and sizes), name and location of the substation, and level of connections to the substation and the general conditions of the distribution substation. For the three towns, the number of the available distribution substations were Uyo:-364, Ikot Ekpene:- 53, and

Eket:- 94.. Also, the conditions survey of the 33kV, 11kV and 0.415kV distribution network was carried out in detail, noting the defects also.

Quite a number of defects were identified and were adjudged based on the condition of the poles, displaced/damaged tie straps, broken cross arms, broken insulators, snapped stays, damaged feeder pillars, leaking transformers, overloaded transformers, distribution substations overgrown with vegetation and broken conductors. The details of the defects in the three major towns were recorded. For each of the three towns, the total number recorded defects are Uyo-98, Ikot Ekpene-20, and Eket 18.

.

6.2 Result and Discussion

The research work by [43] unveiled the root causes of epileptic power supply in Akwa Ibom State.

The power system distribution network was in quagmire and could not convey successfully to the load centre power wheeled from the generating station through the transmission lines to the distribution networks. The resultant effect was the stranded power at the generating stations. The power system is dynamic and power generated must be utilized otherwise it will lead to frequency fluctuation and eventual system collapses that has been prevalent in the Nigerian power system network.

7. Review of Electrical Energy Losses in Nigeria.

The inadequacy of the electric power system distribution to the population of over 200 million people is about 60w per person that is if only the 12GW installed capacity of the generating stations in Nigeria produce power that is successfully wheeled to the end users. The research work by Komolafe and Udofia in [44] frowned at the Nigerian electric power sector which holds a lot of unfulfilled potentials for the economic development of Africa's most populous country; and assert that the electric energy generated was not up to 30% of the national demand and worse still, over 50% of this paltry sum was recorded as losses—this was not any indicative of commercial viability.

In the research, [44] saw the visible efforts being made to address the problems, though laudable, but do not fully demonstrate complete appreciation of the underlying root causes. The paper examined the structure of the Nigerian electricity industry, followed by a technical review of factors responsible for the excessive losses (technical and non-technical) in the system and proffered solutions that would enable improved responses in managing efficiently the available energy and also to grow the industry for the good of Nigerians.

7.1 **Research Methodology**: This research by Komolafe and Udofia in [44] was in the form of a review of the progress made in the Nigerian power sector, the challenges, especially on losses both commercial and technical (ATC&C) as experienced in the industry that has militated against progress that should result in adequate power supply. The authors also proposed mitigation approach to reduce these losses. The salient point in this review related to the current research on power system adequacy and capacity augmentation in the power system distribution was section 4.4 where the authors discussed extensively on the prevalence of electrical fault.

7.2 Result and Discussion: The research pointed out the poor collection, lack of metering and dilapidated network facilities including load rejection from the distribution companies lead to poor power supply and blackout as being experienced. Here are some excerpts. "It is common knowledge that there is a direct correlation between the onset of rainfall and initiation of power outage for the average Nigerian electricity consumer. When at the distribution level there is large-scale rejection it can cause overvoltage the transmission system which can eventual lead to equipment damage and collapse of the system. Rainfall by itself does not necessarily represent a trip command to an adequately designed distribution system but can easily expose inadequately designed/maintained systems. Faults can occur when mechanically weak sections on the line way, when wind cause trees to make contact with the feeder, lighting causes flashing of degraded insulators and short circuit (direct contact or by string of water) between sagged line conductors in high wind.

According to Komolafe and Udofia in [44] the energy cost of an electrical fault in a well-designed 500 kVA distribution substation, as shown in Table 2 is relatively insignificant at under N5000.

Table 2: Simple Estimate of the Cost of a 3-Phase Fault

Parameter	Value	Comment
Transformer Capacity (kVA)	500	Typical
Line Voltage (kV)	0.415	Typical
Impedance, Z (%)	5	Typical
Full Load Current, FLC (A)	695.6	kVA / (1.732 * kV)
3 Phase Max Short Circuit Current (A)	13912.05	FLC / %Z
Fault Clearing Time (s)	0.1	Assumes 5, 50Hz cycles
Fault Impedance (Ohms)	0.01722	Converted %Z to Ohm
Energy Dissipated (kWH)	92.59	Calculated; I2Rt
Cost of Energy Dissipated (N)	4629.63	Assumes N50 per kWH

Addressing the system problems causing frequent trips requires some capital outlay but considering the cascaded effect, it is an undertaking that must be done if the dream of constant power supply is to be achieved.

8. Conclusion

The Nigerian power distribution network could be improved by leveraging on the available and modern technology of applying distributed generation into the distribution network. Adequate planning could be carried out using Etap to perform load flow analysis to determine the needed capacity that could effectively and efficiently augment the distribution network inadequacy and for proper penetration level of the distributed generation energy resources.

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