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# Optimized Electric Power Generation Expansion Planning Using Decomposition Technique

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**Abstract**

The decrease in power supply in the country has caused economic problems to small scale industries; one major problem attributed to this is inadequate planning mechanism that will forecast the required amount of power that will be needed to feed the entire population .Power system engineers had used all the conventional methods improve power supply. This issue of not having adequate forecasting mechanism in power generation network that will adequately serve the entire public is overcome by optimized electric power generation expansion planning using decomposition technique, It is achieve in this manner, characterizing the existing output power capacities of the electric power generating plants under study, Forecasting of the load demand of the power generating plants under study, exterminating of percentage power generating capacity contribution and power generating capacity projected contribution to the National Grid, developing a Model for Decomposition Technique, Integrating SIMULINK Model in the Decomposition Technique. The results obtained are in 2009 the residential power demand by numerous consumers is 8075.00MW and the power demand in ten years is 10214.03MW and the commercial power demand is 2009 is 3865.50MW while the forecast power demand by this sector in ten years' time when decomposition technique is introduced in the system is 5481.65MW.With these results, it shows that the power demand in ten years' time is 41.9% generation power expansion.

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## 1. Introduction:

The concern of every Nigerian is the unreliable power supply in the country. Industries are not depending on the National grid to run the day to day business in order to produce goods and services (Ngang, 2020). Recall that the "Electricity Sector NEPA was established in 1972 as a publicly owned utility in Nigeria empowered to generate, transmit and distribute electric energy in Nigeria. NEPA had installed power generation capacity of about 5,000 MW, of which about seventy (70%) percent is thermal and thirty percent (30% hydroelectric power. Generating plant availability is low with frequent transmission and distribution outages. Outdated generation, transmission and distribution power system components cause high energy losses. This had resulted in constant power failure and has contributed to more than 85% of consumers to buy their own power generators for use at higher costs (Aneke et al., 2021). The condition of Nigeria power system has reached a stage for demand of state of emergency in respect of electric power supply (Okoromma, 2019). Recently the Federal Government of Nigeria commenced comprehensive sector reforms in 1999 to tackle the endemic problems in the power sector and harness our generous energy resources for the country's benefit through rapid government initiatives. The reform program has yielded a steady improvement in performance and capital asset. Introduction of Independent power plants (IPP) is to boost power supply in the national grid due to shortage of megawatts to meet our daily demand. The utility companies usually don't have committed maintenance programmes to service the operating equipment. Electric power generation started in Nigeria in the year 1890.However the first utility company: the Nigerian Electricity Supply Company (NESCO) was established in 1929 upon the construction of a hydroelectric power station known as Kura Falls in Kura near Jos. In 1951, the Electricity Corporation of Nigeria (ECN) was set up to manage the expansion of electricity to power more areas in the country. In order to further develop the country's hydropower potentials, government established the Niger Dams Authority (NDA) in 1962. The fusion of the Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) gave birth to the National Electricity Power Authority (NEPA) in 1972. Decomposition Technique was first employed in solving electric power generation expansion problem in the year 1930 by Dantzig and Wolfe. The method enables large scale electric power generation expansion problem to be solved by exploring special matrix structure to solve engineering problem.

This paper is aimed at using Decomposition technique to optimize Electric Power Generation Expansion Planning in Nigeria. Poor load forecasting and projection during peak load has caused constant power failure and due to overloading of the national grid. Therefore, the objectives of this work are to (i) characterize the existing output power capacities of the electric power generating plants under study, (ii) Proper forecasting of the load demand of the power generating plants under study, (iii) Determine the actual plant generating capability and percentage power generating capacity; and power generating capacity projected contribution to the National Grid, & (iv) develop a Model for Decomposition Technique.

## 2. Reviews:

### 2.1 Extent of Past Related Work:

A reliable electrical power supply is non-negotiable for national growth and development, as electricity is needed in virtually every sector of production and commercial activities (Ogunbiyi et al., 2019).In large-scale systems, a special class of linear programming problem is posed as multidimensional problems and is represented by the decomposition technique as a streamlined version of the Linear Programming (LP) is the simple method. The decomposition technique has special characteristics features in that its formulation exploits certain matrices with distinct structures. Most of the complexities of modern power plant operation gave rise from the inherent variability of the load demand by the users (Braide et al., 2016). These matrices representing the formulated problems are generally divided into two parts namely: one with the "easy" constraints and the other with the "complicated" constraints. The partitioning is done such that the desired diagonal sub-matrices and identity matrices are obtained in the reformulated problem (Ogunedo and Okoro, 2017). Recall that energy is the ability to do work; any system/body above absolute zero condition possesses energy. However, this energy is not available for work if the systems temperature/pressure is below that of its environment. A departure in temperature between the system and its environment increases this available energy(Ameh and Idoniboye,2012).If a Linear Programming (LP) problem involving several variables and constraints is to be solved by using the simple method, it requires a large amount of computer storage and time. Some techniques which require less computational time and storage space compared to the original simplex method have as well been developed. Among these techniques, the revised simplex method is very popular. The solution of a linear optimization problem is at the intersection of the constraints defining the extreme vertex. The method decomposes the n-dimensional linear problem into n-1 two-dimensional problems (Heuberger et al., 2017). The principal difference between the original simplex method and the revised one is that, in the former, we transform all the elements of the simplex table while in the latter we need to transform only the elements of an inverse matrix which is associated with every Linear Programming (LP) problem. Another LP problem, called the dual can be formulated . The solution of a given Linear Programming Problem (LPP) in many cases can be obtained by solving its dual in a much simpler manner. As electricity is increasingly generated from intermittent renewable sources, it can no longer be treated as a homogeneous product (Shuya et al., 2016). There are significant and meaningful uncertainties involved in Generation Expansion planning (GEP) (Hammad et al., 2020), and various methodologies have been proposed to address this uncertainty. Work has been done by researchers and on the GEP; proposed work was done on this an a decomposition method for stochastic problems was introduced (Hamlich et al., 2019). The proposed work (Aneke and Ngang, 2020) described the discrete scenarios method adequate to addressed the recurring power system problems. In this method, several scenarios with probabilities are defined or selected in place of a deterministic equivalent approach(Kazeem et al., 2021), and the stochastic optimization aims to identify an optimal solution that gives satisfactory results for some scenarios, however, from the work seen so far the decomposition technique is a "robust model(Ngang and Bakare, 2021).

One of the difficulties in some practical Linear Programming (LP) problems is that the number of variables or the number of constraints is so large that it exceeds the storage capacity of the available computer. If the Linear programming Problem (LPP) has a special structure, a technique known as the decomposition technique can be used to solve the problem more efficiently. In many practical problems, one would be interested not only in finding the optimum solution to a Linear Programming Problem (LPP), but also in finding how the optimum solution changes when some parameters of the problem, such as "cost coefficients change". Hence, the sensitivity or post optimality analysis becomes very important.

## 3. Methodology:

- The methodology to achieve the aim of this study is the step by step adherence to the stated research objectives which has to do with the characterization of the existing output power capacities of the electric power generating plants under study

- Proper forecasting of the load demand of the power generating plants under study
- Determine the actual plant generating capability and percentage power generating capacity; and power generating capacity projected contribution to the National Grid
- developing a Model for Decomposition Technique,

Characterizing the existing output power capacities of the electric power generating plants under study. The above objective is fundamental because it was meant to prepare the ground upon which other objectives would take root. This is because it is when the underlying characterizing features of these power stations were known that possible optimization and forecasting could be carried out. This objective is more of a fact finding objective involving data collected thus making the research start with a case study design and then progressed to analytical design when the decomposition technique was applied in the optimization required. This would also play out in the forecasting section for expansion planning.

Module 1: Afam Thermal Power Plant, Okoloma, Rivers State.

| | | | | |
|---|---|---|---|---|
| Design Capacity | - | 980MW | | |
| Firm Capacity | - | 980MW | | |
| Type of Plant | - | Combined cycle gas turbine | | |
| Number of Units | - | Five (5) Units | | |
| Unit Capacities | - | 1 | - | 165 MW |
| | | 2 | - | 165 MW |
| | | 3 | - | 165 MW |
| | | 4 | - | 190 MW |
| | | 5 | - | 195 MW |

Turbine Type
1. GT -1 GT13E2
2. GT -1 GT13E2
3. GT -1 GT13E2
4. GT-1 GT13E2
5. ST-1

Type of Fuel – Primary: Fuel Oil Secondary: Natural Gas
Operating Company – Shell Petroleum Development Company.

Module2 : Sapele Thermal Power Plant, Sapele, Delta State.

| | | | |
|---|---|---|---|
| Design Capacity | - | 1020 MW | |
| Firm Capacity | | - | 1020 MW |
| Type of Plant | - | Sub-critical Steam Turbine | |
| Number of Units | - | Ten (10) Units | |
| Unit Capacities | 1 | - | 75 MW |
| | 2 | - | 75 MW |
| | 3 | - | 75 MW |
| | 4 | - | 75 MW |
| | 5 | - | 120 MW |
| | 6 | - | 120 MW |
| | 7 | - | 120 MW |
| | 8 | - | 120 MW |
| | 9 | - | 120 MW |
| | 10 | - | 120 MW |

| | | | | |
|---|---|---|---|---|
| Turbine Type | 1 | GT -1 GT13D | 6 | ST-2 |
| | 2 | GT -1 GT13D | 7 | ST-3 |
| | 3 | GT -1 GT13D8 | | ST-4 |
| | 4 | GT -1 GT13D9 | | ST-5 |
| | 5 | ST -1 | 10 | ST-6 |

Type of Fuel – Primary: Fuel Oil Secondary: Natural Gas
Operating Company – Sapele Thermal Power Plant Plc.

Module 3: Egbin Thermal Power Plant, Ijede, Lagos, Nigeria.

| | | | |
|---|---|---|---|
| Design Capacity | - | 1320 MW | |
| Firm Capacity | - | 1320 MW | |
| Type of Plant | - | Sub-critical Steam Turbine | |
| Number of Units | - | Six (6) Units | |
| Unit Capacities | 1 | - | 220 MW |
| | 2 | - | 220 MW |
| | 3 | - | 220 MW |
| | 4 | - | 220 MW |
| | 5 | - | 220 MW |
| | 6 | - | 220 MW |

| Type of Turbine | Type | Manufacturer |
|---|---|---|
| 1. | Not Stated | Hitachi Japan |
| 2. | Not Stated | Hitachi Japan |
| 3. | Not Stated | Hitachi Japan |
| 4. | Not Stated | Hitachi Japan |
| 5. | Not Stated | Hitachi Japan |
| 6. | Not Stated | Hitachi Japan |

Type of Fuel – Primary: Fuel Oil Secondary: Natural Gas
Operating Company/Owner: Power Holding Company of Nigeria Plc.

Module 4: Kainji Hydroelectric Power Plant, Kainji, Niger State.

| | | | |
|---|---|---|---|
| Design Capacity | - | 760 MW | |
| Firm Capacity | - | 760 MW | |
| Type of Plant | - | Dam on River with Reservoir | |
| Number of Units | - | Eight (8) Units | |
| Unit Capacities | 1 | - | 80 MW |
| | 2 | - | 80 MW |
| | 3 | - | 80 MW |
| | 4 | - | 80 MW |
| | 5 | - | 100 MW |
| | 6 | - | 100 MW |
| | 7 | - | 120 MW |
| | 8 | - | 120 MW |

Type of Turbine

| | |
|---|---|
| 1 | Kaplan |
| 2 | Kaplan |
| 3 | Kaplan |
| 4 | Kaplan |
| 5 | Kaplan |

6 Kaplan
7 Kaplan
8 Kaplan
Type of Fuel - Hydropower Generated from Water falling on Turbine.
Operating Company: Kainji Hydroelectric Power Plant PLC.

Module.5: Jebba Hydroelectric Power Plant, Jebba, Niger State
Design Capacity - 578.4 MW
Firm Capacity - 570 MW
Type of Plant - Dam on River with Reservoir
Number of Units - Six (6) Units
Unit Capacities 1 - 95 MW
2 - 95 MW
3 - 95 MW
4 - 95 MW
5 - 95 MW
6 - 95 MW
Type of Turbine
1 Kaplan
2 Kaplan
3 Kaplan
4 Kaplan
5 Kaplan
6 Kaplan
Type of Fuel - Hydropower Generated from Water falling on Turbine.
Operating Company: Jebba Hydroelectric PLC.

Module 6: ShiroroHydroelectric Power Plant, Shiroro, Niger State
Design Capacity - 600 MW
Firm Capacity - 600 MW
Type of Plant - Dam on River with Reservoir
Number of Units - Four (4) Units
Unit Capacities 1 - 150 MW
2 - 150 MW
3 - 150 MW
4 - 150 MW
Type of Turbine 1 Vertical Fran
2 Vertical Fran
3 Vertical Fran
4 Vertical Fran
Type of Fuel - hydropower Generated from Water falling on Turbine.
Operating Company: Shiroro Hydroelectric PLC.

The specified data/information given in1, 2, 3, .4, 5 and 6 are the characterized parameters of the six power stations under study in this research. Reference to these data would be subsequently made as the research progresses. Additionally, a table of percentage capacity contribution of the 16 different power generating plants connected to the National Grid in Nigeria is shown in Table 1.

**Table 1: Percentage Capacity Contribution of the 16 different power generating plants connected to the National Grid in Nigeria.**

| S/n | Electric Power Generating Stations | Type of Energy | Installed Capacity (MW) | Percentage Capacity Contribution to the National Grid (%) |
|---|---|---|---|---|
| 1 | Egbin Power Station (FGN) | Thermal | 1,320 | 14.87 |
| 2 | Shiroro Power Station (HydroFGN) | Hydro | 600 | 6.76 |
| 3 | Ughelli Power Station (FGN) | Thermal | 812 | 9.15 |
| 4 | Kainji Power Station (Hydro FGN) | Hydro | 760 | 8.56 |
| 5 | Sapele Power Station (NIPP) | Thermal | 1020 | 11.49 |
| 6 | Afam Power Station IV-VI (FGN) | Thermal | 980 | 11.04 |
| 7 | Shell-Afam Power Station (IPP) | Thermal | 650 | 7.23 |
| 8 | Jebba Power Station (NIPP) | Hydro | 540 | 6.09 |
| 9 | Geregu Power Station (NIPP) | Thermal | 440 | 4.96 |
| 10 | Omotosho Power Station (NIPP) | Thermal | 304 | 3.43 |
| 11 | Olorunsogo Power Station (NIPP) | Thermal | 304 | 3.43 |
| 12 | AES Barges Power Station (IPP) | Thermal | 270 | 3.04 |
| 13 | Agip-Okpai Power Station (IPP) | Thermal | 450 | 5.07 |
| 14 | Omoku Power Station (NIPP) | Thermal | 150 | 1.69 |
| 15 | Trans-Amadi Power Station (NIPP) | Thermal | 136 | 1.53 |
| 16 | Geometric Power Station (FGN) | Thermal | 140 | 1.58 |
| | Total | | 8,876 | 100 |

Source: Central Bank of Nigeria Statistical Bulletin and National Bureau of Statistics (NBS) August, 2014.

**Table:2 Actual Electric Power Consumption in Nigeria between Year 2000 and Year 2012.**

**ENERGY CONSUMPTION**

| YEAR | RESIDENTIAL (MW) | COMMERCIAL (MW) | INDUSTRIAL (MW) | TOTAL (MW) |
|---|---|---|---|---|
| 2000 | 4608.40 | 2346.00 | 1011.60 | 7966.00 |
| 2001 | 7714.80 | 2439.00 | 1987.20 | 12141.00 |
| 2002 | 7668.50 | 3297.60 | 1830.00 | 12796.10 |
| 2003 | 7668.50 | 3583.00 | 1659.80 | 12911.30 |
| 2004 | 7725.30 | 3830.30 | 1605.00 | 13160.60 |
| 2005 | 7760.00 | 3851.00 | 1615.50 | 13226.50 |
| 2006 | 7650.00 | 3900.80 | 1575.00 | 13125.80 |
| 2007 | 7860.30 | 3915.00 | 1530.50 | 13305.80 |
| 2008 | 7910.08 | 3852.00 | 1502.50 | 13264.58 |
| 2009 | 8075.00 | 3865.50 | 1585.00 | 13525.50 |
| 2010 | 8205.20 | 3925.80 | 1589.40 | 13720.40 |
| 2011 | 8285.60 | 4004.70 | 1615.50 | 13905.80 |
| 2012 | 8350.00 | 4025.40 | 1648.00 | 14023.40 |

Source: Central Bank of Nigeria STATISTICAL BULLETIN and National Bureau of Statistics (NBS) August 2014.

The data used in objective two as shown in Table 2, is the actual electrical energy consumption in Nigeria from year 2000 to year 2012 broken down into three categories namely: residential, commercial and industrial consumers. By summing up these three categories of energy consumers, a total expected power consumption of 20,136.41MW was realized as a load demand forecast after a look ahead period of 20 years from 2013 to 2032 inclusive. Using regression analysis with the established data from 2000 to 2012 as input, a load forecast result of the power generation optimization for expansion plans and cost saving was determined.

**3.1 Forecasting of the load demand of the power generating plants under study:**

To carry out a forecast of the load demand for the power generating plants under study, the characterized values in objective one were used. Regression Analysis was applied to these characterized values in order to obtain a forecast for the load demand as it relates to the six power generating stations. Eventually, the generated values are summarized and shown in table 3.

**3.1.1 Load Demand Forecast Calculation:**

Case 1: From our straight line (trend line) given by:

Y = a + bx

Where; a = $\frac{\sum y - \sum x}{n \quad n}$

Trend line value, b = $\frac{n\sum xy - \sum x\sum y}{n\sum x2 \ -(\sum x)2}$

Data for residential load demand forecast is shown in Table 4.1

Substituting the data from table 4.1 into the linear equation, the following is obtained

$\sum_{xy}$= 29139.76

$\sum_{x}$ = 0

$\sum_{y}$ = 99481.68

$\sum_{x}^{2}$ = 182

n = 13

From equation 3.1

$$b = \frac{n\sum xy - \sum x\sum y}{n\sum x2 \ - \ (\sum x)2} = \frac{13 \text{ x } 29139.76 - 0 \text{ x } 99481.68}{13 \text{ x } 182 - 02}$$

$$b = \frac{378{,}816.88}{2366}$$

b = 160.1085714

Similarly, from equation 3.1

$$Y = \frac{\sum y - \sum x}{nn}$$

$$Y = \frac{99481.68 - 160.1085 \text{ x } 0}{13x13}$$

Y= 7,652.436923 +160.10 (x)

Therefore; Y = 7652.43 + 160.10x; the trend values are given below:

Substituting the values of a & b into the earlier equation, we get an equation which is used to forecast the load demand for the period of interest.

We have;

Y = 7653.43 + 160.10x

Recall that from equation 3.1; Y = a + bx

Where; a = $\frac{\sum y - \sum x}{nn}$

Trend line value, b = $\frac{n\sum xy - \sum x\sum y}{n\sum x2 - (\sum x)2}$

($\sum$x) 2

Data for commercial load demand forecast is shown in Table 4.5

Substituting the data into the linear equations:

$\sum_{xy}$= 2137269

$\sum_{x}$ = 0

$\sum_{y}$ = 468361

$\sum_{x}^{2}$ = 182

n = 13

$$b = \frac{n\sum xy - \sum x \sum}{n\sum x2 - (\sum x)2} = \frac{13 \times 21371.69 - 0 \times 46836.1}{13 \times 182 - 02}$$

$$b = \frac{277{,}844.97}{2366}$$

b = 117.4323626

Similarly

$$a = \frac{\sum y}{nn} - \frac{\sum x}{nn}$$

$$a = \frac{46836.1}{13} - \frac{117.4323626 \times 0}{13}$$

a = 3,602.776923

Therefore; Y = 3,602.78 + 117.43x; the trend values are given below:

Y = a + b(x)

Now substituting all the value from 1st year to 20th years, look ahead period and we have the trend values as:

Y =3,602.78 + 117.43x

Data for Industrial Load Demand Forecast is shown in Table 4.8

From the earlier equalizer linear equation, Y = a + bx

Where; $a = \frac{\sum y - b\sum x}{nn}$ = trend value

$$b = \frac{n\sum xy - \sum x\sum y}{n\sum (x)2 - (\sum x)2}$$

Substituting the data into the linear equations:

$\sum yx$ = 483.10

$\sum x$ = 0

$\sum y$ = 20755.00

$\sum x^2$ = 182

n = 13

$$b = \frac{n\sum xy\sum x\sum y}{n\sum x2 - (\sum x)2} = \frac{13x483.10 - 0x20755.00}{13x182 - 02}$$

$$b = \frac{6280.3}{2366}$$

b = 2.65439

Similarly,

$$a = \frac{\sum y - \sum x}{nn}$$

$$a = \frac{20755.00 - 2.65439x0}{13x13}$$

a = 1,596.538

Therefore; Y = 1,596.54 + 2.6544x; the trend values are given below:

Now substituting all the values from 1st year to 20th years, look ahead period and we have the trend values as:

Y = 1,596.54 + 2.6544x

The calculation process shown above was applied to the characterized values of the six electric power generating plants under study in order to generate the load demand forecast using regression analysis already discussed in chapter two of this research.

### 3.2 Determination of percentage power generating capacity contribution and power generating capacity

- Determine the projected load forecast for 20 years period which is given as 20136.41MW. See Table 3.1.
- Determine and capture the existing total power generating capacity of the (sixteen) 16 power generating stations currently in operation in Nigeria which is given as 8,876MW. See Table 3.1.
- Determine the percentage capacity contribution by relating individual power generating capacities say (Egbin: 1320MW) to the total capacity say: 8876MW then multiply by 100%.
- Repeat same for all generating stations.

Case Study 1: Afam Thermal Power Plant
Take 100% of 20136.41MW, implying that Afam thermal power generating station contribute 11.04% which will give the capacity allocation of 2223MW which is rounded up to 2250 MW. This means that Afam Thermal Power Plant should contribute a total of 2250 MW by the year, 2032.

Case Study 2: Sapele Thermal Power Plant
Take 100% of 20136.41MW, implying that Sapele thermal power generating station contribute 11.49% which will give the capacity allocation of 2313.63MW which is rounded up to 2350 MW. This means that Sapele Thermal Power Plant should contribute a total of 2350 MW by the year, 2032.

Case Study 3: Egbin Thermal Power Generating Station.
Take 100% of 20136.41MW, implying that Egbin thermal power generating station contribute 14.872% which will give the capacity allocation of 2994.686MW which is rounded up to 3000 MW. This means that Egbin Thermal Power Plant should contribute a total of 3000MW by the year, 2032.

Case Study 4: Jebba Hydro Electric Power Generating Station.
540/8876 x 100% = 6.09%
Forecasted power capacity contribution to the National Grid in the next 20 years will be
6.09% x 20136 = 1226MW which is rounded up to 1250MW.

Case Study 5: Shiroro Hydro Electric Power Generating Station.
600/8876 x 100% = 6.76%
Forecasted power contribution to the National Grid in the next 20 years will be
6.76% x 20136 = 1361MW which is rounded up to 1500MW.

Case Study 6: Kainji Hydro Electric Power Generating Station.
760/8876 x 100% = 8.56%
Forecasted power contribution to the National Grid in the next 20 years will be
8.56% x 20136 = 1724MW which is rounded up to 1750MW.

**Table: 3 Percentage Capacity Contribution of the 16 different power generating plants connected to the 20 years forecast.**

| S/n | Electric Power Generating Stations | Type of Energy | Installed Capacity (MW) | Forecast Capacity in the next 20 years (MW) | Percentage Capacity Contribution to the National Grid (%) |
|---|---|---|---|---|---|
| 1 | Egbin Power Station (FGN) | Thermal | 1,320 | 2995 | 14.87 |
| 2 | Shiroro Power Station (Hydro FGN) | Hydro | 600 | 1361 | 6.76 |
| 3 | Ughelli Power Station (FGN) | Thermal | 812 | 1842 | 9.15 |
| 4 | Kainji Power Station (Hydro FGN) | Hydro | 760 | 1724 | 8.56 |
| 5 | Sapele Power Station (NIPP) | Thermal | 1020 | 2314 | 11.49 |
| 6 | Afam Power Station IV-VI (FGN) | Thermal | 980 | 2223 | 11.04 |
| 7 | Shell-Afam Power Station (IPP) | Thermal | 650 | 1475 | 7.23 |
| 8 | Jebba Power Station (NIPP) | Hydro | 540 | 1226 | 6.09 |
| 9 | Geregu Power Station (NIPP) | Thermal | 440 | 998 | 4.96 |
| 10 | Omotosho Power Station (NIPP) | Thermal | 304 | 690 | 3.43 |
| 11 | Olorunsogo Power Station (NIPP) | Thermal | 304 | 690 | 3.43 |
| 12 | AES Barges Power Station (IPP) | Thermal | 270 | 613 | 3.04 |
| 13 | Agip-Okpai Power Station (IPP) | Thermal | 450 | 1021 | 5.07 |
| 14 | Omoku Power Station (NIPP) | Thermal | 150 | 340 | 1.69 |
| 15 | Trans-Amadi Power Station (NIPP) | Thermal | 136 | 309 | 1.53 |
| 16 | Geometric Power Station (FGN) | Thermal | 140 | 318 | 1.58 |
| | Total | | 8,876 | 20,136.41 | 100 |

In Table3, the projected capacity is rounded off to take care of unenumerated consumers on the power networks who consume substantial amount of power without being captured in the original power plan.

**Table 4: Electric Power Generating Plants in Nigeria under study**

| S/n | Power Generating Plant | Source of Energy | Installed Capacity | 20 Year projected capacity |
|---|---|---|---|---|
| 1. | Afam | Thermal | 980MW | 2250MW |
| 2. | Sapele | Thermal | 1020MW | 2350MW |
| 3. | Egbin | Thermal | 1320MW | 3000MW |
| 4. | Shiroro | Hydro | 600MW | 1500MW |
| 5. | Kainji | Hydro | 760MW | 1750MW |
| 6. | Jebba | Hydro | 540MW | 1250MW |

### 3.3 Implementing Objective Three

Determining the best capacityoptimization arrangement with respect to different number of units of the generating plants under study.

Case Study 1: Afam Thermal Power Generating Station

- The research work relied on the installed capacity of 980MW which is also taken actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 2250MW

Activity 1: First Optimization Plan

Capacity combination (MW) ↓ Number of generating units ↓

[ 200 250 300]

$[1 \quad 7 \quad 1]^T$

Then, by the operation of decomposition:

$$[2250MW] = [200 \quad 250 \quad 300]\begin{bmatrix}1\\7\\1\end{bmatrix}$$

= 200 x 1 + 250 x 7 + 300 x 1
= 200 + 1750 + 300
= 2250MW

Activity 2: Second Optimization Plan
Capacity combination (MW) Number of generating units
[ 200 250 300] [7 1 2]$^T$
Then, by the operation of decomposition

$$[2250MW] = \underbrace{[200 \quad 250 \quad 300]}_{\text{Capacity}}\underbrace{\begin{bmatrix}7\\1\\2\end{bmatrix}}_{\text{Units}}$$

= 200 x 7 + 250 x 1 + 300 x 2
= 1400 + 250 + 600
= 2250MW

Activity 3: Third Optimization Plan
Capacity combination (MW) Number of generating units
[ 200 250 300] [4 1 4]$^T$
Then, by the operation of decomposition:

$$[2250MW] = \underbrace{[200 \quad 250 \quad 300]}_{\text{Capacity}}\underbrace{\begin{bmatrix}4\\1\\4\end{bmatrix}}_{\text{Units}}$$

= 200 x 4 + 250 x 1 + 300 x 4
= 800 + 250 + 1200
= 2250MW

Activity 4: Fourth – Optimization Plan
Capacity combination (MW) Number of generating units
[ 200 250 300] [2 5 2]$^T$
Then, by the operation of decomposition:

$$[2250MW] = \underbrace{[200 \quad 250 \quad 300]}_{\text{Capacity}}\underbrace{\begin{bmatrix}2\\5\\2\end{bmatrix}}_{\text{Units}}$$

= 200 x 2 + 250 x 5 + 300 x 2
= 400 + 1250 + 600

= 2250MW

Activity 5: Fifth – Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] $[3\ 3\ 3]^T$

Then, by the operation of decomposition:

$$[2250MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 3 \\ 3 \\ 3 \end{bmatrix}}_{\text{Units}}$$

= 200 x 3 + 250 x 3 + 300 x 3

= 600 + 750 + 900

= 2250MW

Case Study 2: Sapele Thermal Power Generating Station

- The research work relied on the installed capacity of 1020MW which is also taken as the actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 2350MW

Activity 1: First - Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] $[3\ 1\ 5]^T$

Then, by the operation of decomposition:

$$[2350MW] = [200\ \ 250\ \ 300] \begin{bmatrix} 3 \\ 1 \\ 5 \end{bmatrix}$$

= 200 x 3 + 250 x 1 + 300 x 5

= 600 + 250 + 1500

= 2350MW

Activity 2:Second Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] $[1\ 5\ 3]^T$

Then, by the operation of decomposition:

$$[2350MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 1 \\ 5 \\ 3 \end{bmatrix}}_{\text{Units}}$$

= 200 x 1 + 250 x 5 + 300 x 3

= 200 + 1250 + 900

= 2350MW

Activity 3: Third - Optimization Plan

Capacity combination (MW) Number of generating units

[200 250 300] [6 1 3]$^T$

Then, by the operation of decomposition:

$$[2350MW] = [200\ \ 250\ \ 300] \begin{bmatrix} 6 \\ 1 \\ 3 \end{bmatrix}$$

= 200 x 6 + 250 x 1 + 300 x 3

= 1200 + 250 + 900

= 2350MW

Activity 4: Fourth Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] [2 3 4]$^T$

Then, by the operation of decomposition:

$$[2350MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 2 \\ 3 \\ 4 \end{bmatrix}}_{\text{Units}}$$

= 200 x 2 + 250 x 3 + 300 x 4

= 400 + 750 + 1200

= 2350MW

Activity 5: Fifth Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] [5 3 2]$^T$

Then, by the operation of decomposition:

$$[2350MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 5 \\ 3 \\ 2 \end{bmatrix}}_{\text{Units}}$$

= 200 x 5 + 250 x 3 + 300 x 2

= 1000 + 750 + 600

= 2350MW

Case Study 3: EgbinThermal Power Generating Plant

- The research work relied on the installed capacity of 1320MW which is also taken as the actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 3000MW

Activity 1: First Optimization Plan

Capacity combination (MW) Number of generating units

[200 250 300] [2 8 2]$^T$

Then, by the operation of decomposition:

$$[3000MW] = [200\ \ 250\ \ 300] \begin{bmatrix} 2 \\ 8 \\ \end{bmatrix}$$

2

Capacity Units

= 200 x 2 + 250 x 8 + 300 x 2

= 400 + 2000 + 600

= 3000MW

Activity 2: Second Optimization Plan

Capacity combination (MW) Number of generating units

[200 250 300] [1 4 6]$^T$

Then, by the operation of decomposition:

$$[3000MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 1 \\ 4 \\ 6 \end{bmatrix}}_{\text{Units}}$$

= 200 x 1 + 250 x 4 + 300 x 6

= 200 + 1000 + 1800

= 3000MW

Activity 3: Third Optimization Plan

Capacity combination (MW) Number of generating units

[200 250 300] [5 2 5]$^T$

Then, by the operation of decomposition:

$$[3000MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 5 \\ 2 \\ 5 \end{bmatrix}}_{\text{Units}}$$

= 200 x 5 + 250 x 2 + 300 x 5

= 1000 + 500 + 1500

= 3000MW

Activity 4: Fourth Optimization Plan

Capacity combination (MW) Number of generating units

[200 250 300] [3 6 3]$^T$

Then, by the operation of decomposition:

$$[3000MW] = \underbrace{[200\ \ 250\ \ 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 3 \\ 6 \\ 3 \end{bmatrix}}_{\text{Units}}$$

= 200 x 3 + 250 x 6 + 300 x 3

= 600 + 1500 + 900

= 3000MW

Activity 5: Fifth Optimization Plan

Capacity combination (MW) Number of generating units

[ 200 250 300] [4 4 4]$^T$

Then, by the operation of decomposition:

$$[3000MW] = \underbrace{[200 \quad 250 \quad 300]}_{\text{Capacity}} \underbrace{\begin{bmatrix} 4 \\ 4 \\ 4 \end{bmatrix}}_{\text{Units}}$$

= 200 x 4 + 250 x 4 + 300 x 4

= 800 + 1000 + 1200

= 3000MW

Case Study 4: Jebba Hydro Electric Power Generating Station

- The research work relied on the installed capacity of 540MW which is also taken as the actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 1250MW

Activity 1: First Optimization Plan

Capacity combination (MW) number of generating units

[200 250 300] [2 1 2]$^T$

Then by the operation of decomposition

$$[1250MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 2 \\ 1 \\ 2 \end{bmatrix}$$

= 200 x 2 + 250 x 1 + 300 x 2

= 400 + 250 + 600

= 1250MW.

Activity2: Second Optimization Plan

Capacity combination (MW) number of generating units

[200 250 300] [1 3 1]$^T$

Then by the operation of decomposition

$$[1250MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix}$$

= 200 x 1 + 250 x 3 + 300 x 1

= 200 + 750 + 300

= 1250MW.

Case Study 5:ShiroroHydro Electric Power Generating Station

- The research work relied on the installed capacity of 600MW which is also taken as the actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 1500MW

Activity 1: First Optimization Plan

Capacity combination (MW) number of generating units

[200 250 300] [2 2 2]$^T$

Then by the operation of decomposition

$$[1500MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 2 \\ 2 \\ 2 \end{bmatrix}$$

= 200 x 2 + 250 x 2 + 300 x 2
= 400 + 500 + 600
= 1500MW.

Activity2: Second Optimization Plan
Capacity combination (MW) number of generating units
[200 250 300] [1 4 1]$^T$

Then by the operation of decomposition

$$[1500MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 1 \\ 4 \\ 1 \end{bmatrix}$$

= 200 x 1 + 250 x 4 + 300 x 1
= 200 + 1000 + 300
= 1500MW.

Case Study 6: Kainji Hydro Electric Power Generating Station

- The research work relied on the installed capacity of 760MW which is also taken as the actual working capacity of the plant.
- Capacity addition due to the twenty years projection = 1750MW

Activity 1: First Optimization Plan
Capacity combination (MW) Number of generating units
[200 250 300] [2 3 2]$^T$

Then by the operation of decomposition

$$[1750MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 2 \\ 3 \\ 2 \end{bmatrix}$$

= 200 x 2 + 250 x 3 + 300 x 2
= 400 + 750 + 600
= 1750MW.

Activity2: Second Optimization Plan
Capacity combination (MW) Number of generating units
[200 250 300] [3 1 3]$^T$

Then by the operation of decomposition

$$[1750MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 3 \\ 1 \\ 3 \end{bmatrix}$$

= 200 x 3 + 250 x 1 + 300 x 3
= 600 + 250 + 900
= 1750MW.

Activity3: Third Optimization Plan

| Capacity combination (MW) | Number of generating units |
|---|---|
| [200 250 300] | $[1\ 5\ 1]^T$ |

Then by the operation of decomposition

$$[1750MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 1 \\ 5 \\ 1 \end{bmatrix}$$

= 200 x 1 + 250 x 5 + 300 x 1
= 200 + 1250 + 300
= 1750MW.

Activity4: Fourth Optimization Plan

| Capacity combination (MW) | Number of generating units |
|---|---|
| [200 250 300] | $[6\ 1\ 1]^T$ |

Then by the operation of decomposition

$$[1750MW] = [200 \quad 250 \quad 300] \begin{bmatrix} 6 \\ 1 \\ 1 \end{bmatrix}$$

= 200 x 6 + 250 x 1 + 300 x 1
= 1200 + 250 + 300
= 1750MW.

### 3.4 Developed Model for Decomposition Technique

The model developed and shown in Figure 1 is that for decomposition technique.

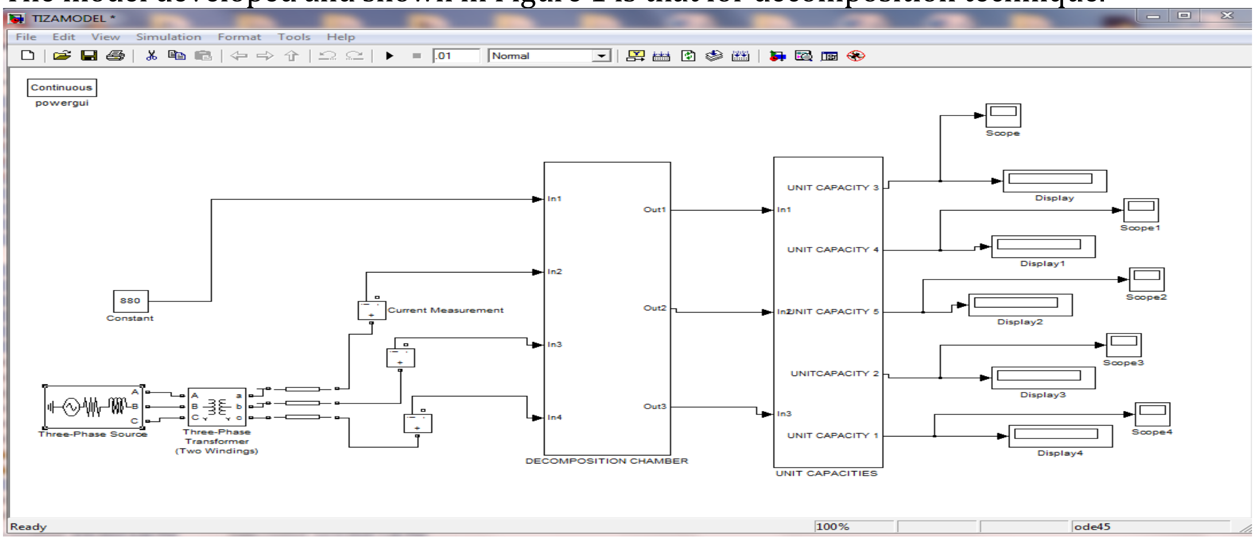


**Figure: 1** Model for Decomposition Technique.

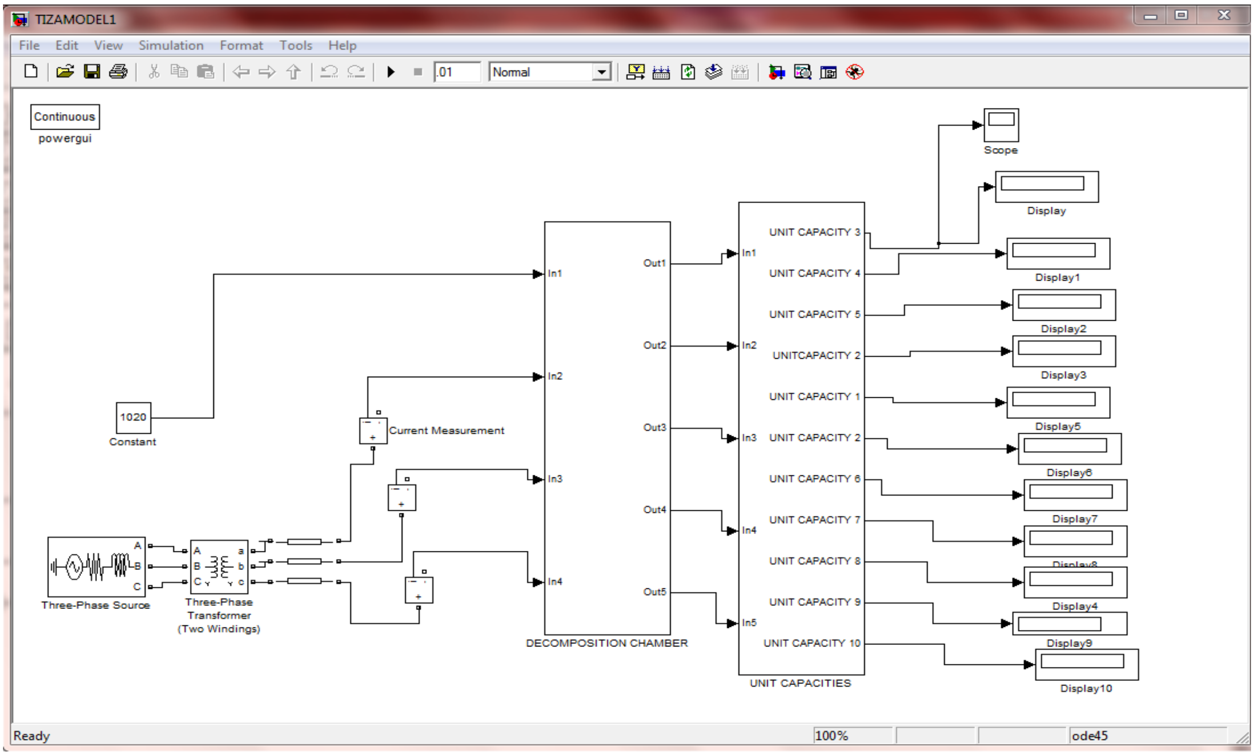

**Figure 2:** Integrated Simulink Model for the Decomposition Technique

## 3.5 Developed Model for Power Expansion Planning

Figures3 shows the integrated Simulink models for power planning expansion plans for a twenty year look ahead period, for Afam .Thermal Power Plant . Simulation results are generated and further analyses presented in figs 4 an 5.

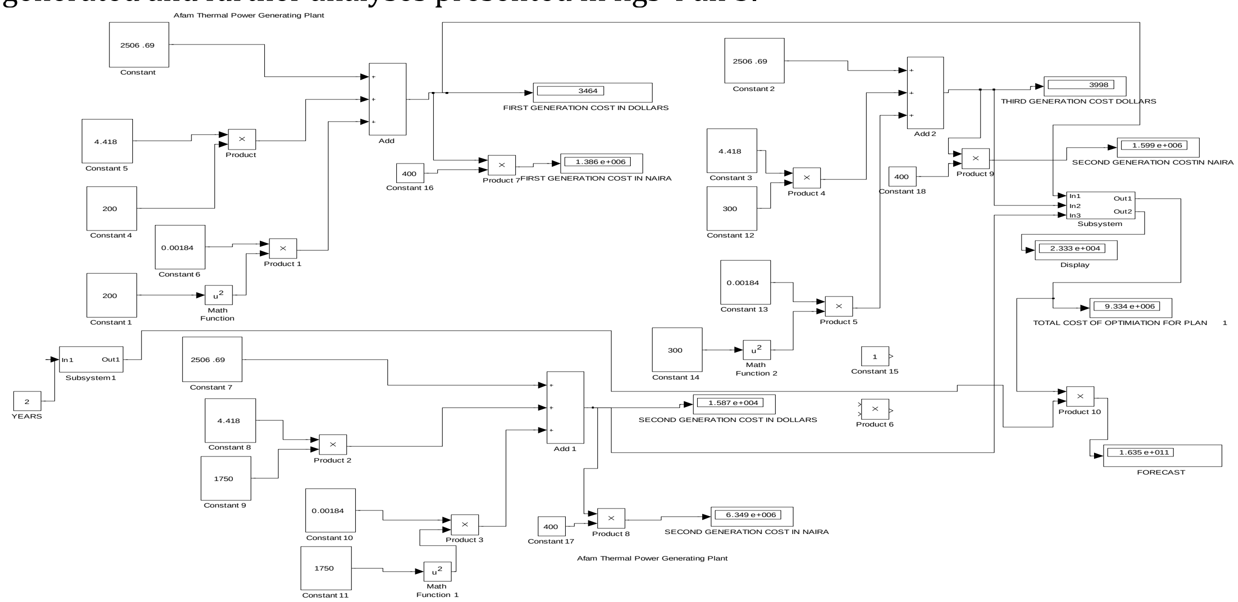

**Figure 3**: Simulink Model for Afam Thermal Power Plant Expansion Planning

## 4. Discussion of Result

Figure 1 shows a Simulink model for the Decomposition Technique; the model contains the different optimization plans as was encountered during the optimization process. Figure 2 shows an integrated version of the model for the decomposition of all the six power generating plants under study. These power generating plants are made up of three thermal stations and three hydro plants. Any of the output powers of the six power generating plants can be decomposed to any desired number of units using the model of Figure 2. Further analyses are done in chapter four after model simulation. Figure 3: Simulink Model for Afam Thermal Power Plant Expansion Planning; Fig 4 shows comparison between Residential power Demand and its Forecast in ten years' time. In fig 4 in 2009 the power demand by numerous consumers was 8075.00MW, and the power demand in ten years to come is 10214.03MW. Fig 5 is the comparison of commercial power Demand and its forecast in ten years to come. In figure 5 the commercial power demand as at 2009 was 3865.50MW, while the forecast power demand by this sector in ten years' time when decomposition technique was introduced in the system stood at 5481.65MW. A closer look at these results, it showed that the power demand in ten years' time would be 41.9% generation power expansion.

**Table: 4** comparison between Residential power Demand and its Forecast in ten years time

| YEAR | RESIDENTIAL DEMAND (MW) | RESIDENTIAL LOAD DEMAND FORECAST Y (MW) |
|---|---|---|
| 2000 | 4608.40 | 8773.13 |
| 2001 | 7714.80 | 8933.23 |
| 2002 | 7668.50 | 9093.33 |
| 2003 | 7668.50 | 9253.43 |
| 2004 | 7725.30 | 9413.53 |
| 2005 | 7760.00 | 9573.63 |
| 2006 | 7650.00 | 9733.73 |
| 2007 | 7860.30 | 9893.83 |
| 2008 | 7910.08 | 10053.93 |
| 2009 | 8075.00 | 10214.03 |

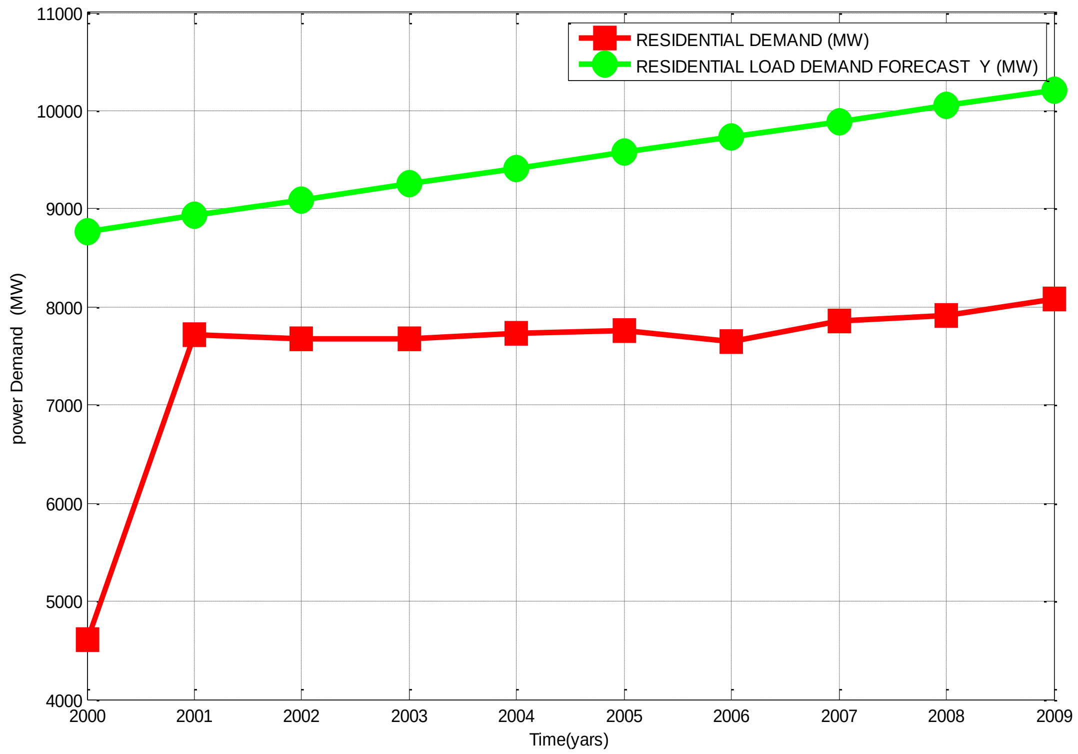


**Figure: 4** comparison between Residential power Demand and its Forecast in ten years time

**Table: 5** Comparison between commercial power Demand and its Forecast in ten years' time

| YEAR | COMMERCIAL LOAD DEMAND (MWH) Y | COMMERCIAL LOAD DEMAND FORECAST Y (MW) |
|---|---|---|
| 2000 | 2346.00 | 4424.78 |
| 2001 | 2439.00 | 4542.21 |
| 2002 | 3297.60 | 4659.64 |
| 2003 | 3583.00 | 4777.07 |
| 2004 | 3830.30 | 4894.50 |
| 2005 | 3851.00 | 5011.93 |
| 2006 | 3900.80 | 5129.36 |
| 2007 | 3915.00 | 5246.79 |
| 2008 | 3852.00 | 5364.22 |
| 2009 | 3865.50 | 5481.65 |

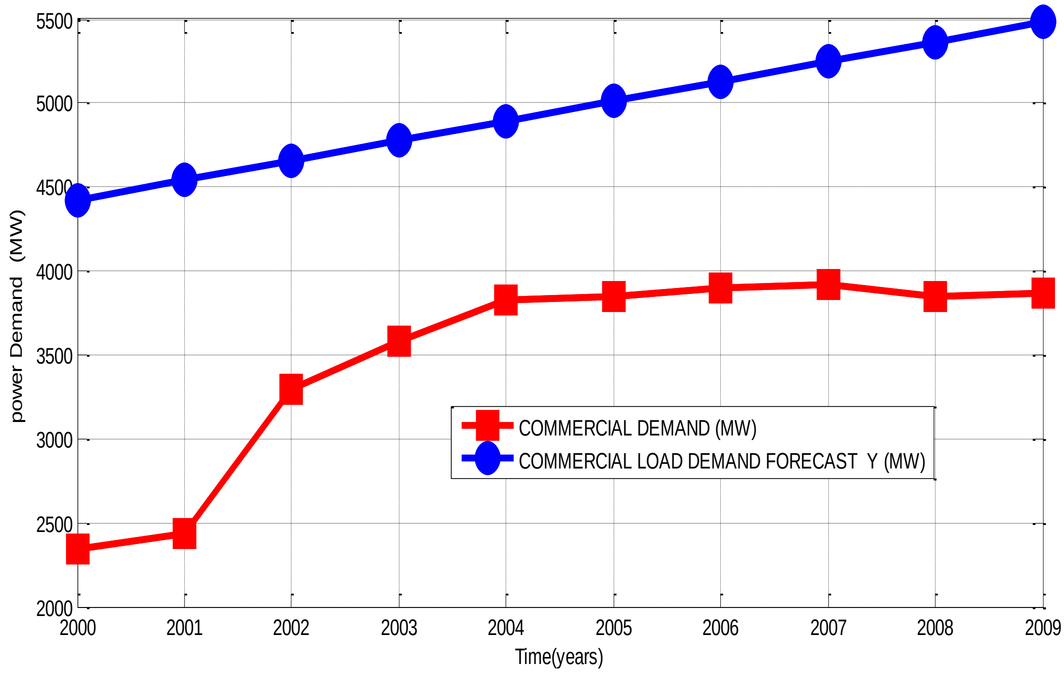


**Figure: 5** comparing commercial power Demand and its Forecast in ten years' time

## 5. Conclusion:

This study presents an optimization of electric power generation for expansion planning and cost saving, using decomposition techniques. The traditional method of comparing the economics of thermal and hydro stations has been to calculate generating costs for each type of plant using suitable capital, operating, and fuel cost data along with an assumed plant load factor. This approach was adequate until recent years because the choice of generating equipment available to an electric utility was fairly limited. The step-by-step procedure of calculating the installed capacities of all generating plants in the entire country, estimating the average load consumption on daily basis up to thirty days, projecting that for say seven years was the conventional practice. This was not very accurate Generation Expansion Planning procedure, hence, the need for optimized electric power generation expansion planning using decomposition technique the works strongly rely on the conduction of load forecast results in order to know the capacity of energy generation to be produced at different generating stations, particularly in Nigeria. The demand-side management of the consumers in a developing country like ours has its disadvantages. Consumers do not usually declare accurately the total consumption to the supply authority. We do experience national system failure more than 6 times in a month due to overloading of the generating stations, transmission line faults, and bridging of feeders due to vandalism by unpatriotic citizens. This issue of not having an adequate forecasting mechanism in power generation network that will adequately serve the entire public would be overcome by optimized electric power generation planning using the decomposition Technique. This is achieved in this manner, characterizing the existing output power capacities of the electric power generating plants under study, forecasting of the load demand of the power generating plants under study, exterminating of percentage power generating capacity contribution and power generating capacity projected contribution to the National Grid, developing a Model for Decomposition Technique, Integrating SIMULINK Model in the Decomposition Technique. The results obtained are in 2009 the residential power demand by numerous consumers is 8075.00MW and the power demand in ten years is 10214.03MW and the commercial power demand is 2009 is 3865.50MW while the forecast power demand by this sector in ten years' time when decomposition technique is introduced in the system is 5481.65MW.With these results, it shows that the power demand in the next ten years is 41.9% generation power expansion.

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