Modeling of Long Term Dynamic of Investments in Nigeria Power System.

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Abstract: Availability of adequate and cheap electricity is one of the necessary requirements for industrial and agricultural development and it is also a basic requirement of urban life. Due to very rapid growth of demand for electricity and widespread shortages experienced in Nigeria, investment planning in the power sector is of prime importance. As power sector is also highly capital intensive, there is a definite need for determining least-cost investment plans and the use of operations research techniques for choosing the best expansion path from a large number of alternative system expansion plans for power generation. This paper describes an approach for modeling of long term dynamic of investment in power system and model for determining the least-cost expansion plan for generating capacity of a power system under growing demand over a planning horizon of 15 to 25 years. Given projections of future demand for power, the expected shape of the annual load duration curve and relevant capital and operating cost information, a solution of the mixed integer linear programming model would provide the type, capacity and time schedule of commissioning the additional generating plants needed for meeting the given demand with an accepted standard of service in terms of reserve requirements or load-loss probability.

Key words: Dynamic Investments, Longterm Modeling, Reliability, Economic, and Technical constraints

INTRODUCTION

It is no doubt that the availability of adequate and cheap electricity is one of necessary requirements for industrial and agricultural development. It is also a basic requirement of urban life. A power system is a failure if the objectives with which it was planned are not met to a large degree. This explained while most countries, especially the developing ones experienced widespread ‘blackout’ as is the case of Nigeria.

Investment in power systems is capital intensive and therefore must be handled with care. There is a definite need for determine the least cost investment plans and the use of operations research techniques for choosing the best expanse path from a large number of alternative system expansion plans for power generation, transmission system, and loads (demands). The planning and design of power systems services, therefore, are an important welfare consideration. Over investment is not only wasteful in terms of resource allocation but adds to redundancy. Under investment, as the other hand, causes widespread storages resulting to incessant outages. Therefore, proper modeling of long-term dynamics of investments in power systems would have important implications not only from the stand point of reliability and quality of service, but also from financial view point.

The situation is particularly intriguing as these services are now being deregulated with private sector participation, whose primary objective is not only for ensure welfare gains or an efficient services but to maximize profit. In recent time, technological advances have had as enormous effect on Nigeria by enabling greater access to information and increased awareness across the nation. As a result, government face pressure to raise finance to balance budgets; fund infrastructure development and job creation, increase spending on social services, cut out debt servicing and institute economic reform. To achieve this, Nigeria government has embraced market liberalization and privatization in various sections of the economy, including the petroleum and Electric Power Industries.

Nigeria government based on a shared vision and commitment to overcome poverty; promote democracy, human rights and economics and political integration; sustain economic development; and ensure peace and security, various strategies have been formulated to address the country’s social, economic and developmental challenges, and to promote national integration.

Weak infrastructure links have hampered growth and restricted the country’s competitiveness in the global market. Bridging the gap by building an efficient infrastructure network is essential to boosting national and international trade, which is central to economic growth and development.

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Every facet of a nation’s development is woven around a sound and stable electric energy supply. Yet Nigeria almost 46 years independent nation with installed generating capacity of 4.654MW which is about % of West Africa installed capacity of 9.79GW. The development of strong and stable electric power infrastructure is vital to Nigeria’s modernization and entry into the information technology (IT) age.

Modeling in power systems is not new. Many of the raising modeling in power systems has been as the three basic elements: generations that produce the power, the loads that distribute the power for consumption; and the transmission system that connects generators to the load centres. These modeling have made significant progress forwards more practical applications and broader economic analysis of power system in both have and space dimensions. Unlike the modeling of power system networks, investment modeling is more complex as it involved a lot of uncertainties.

This includes future demand-supply characteristics under alternative regulatory choices. This report will be organized in the following order, state of art of Nigerian power system, concept of system modeling, overview of power system modeling, mathematical formulation of investment modeling, case study on the on-going research, concluding remarks, and list of references.

State of the Art of Nigeria Electric Power System:
The Nigerian power system operates under the normal three subsections of any power system network namely; generation, transmission and distribution.

More than 90% of the generating stations in Nigeria are based on thermal and hydro generation. The power plants location and their designated outputs are as shown in Tables 1-4 attached. The only combine-cycle plant among the list in the above table is the newly commissioned IPP generating plant at okapi in Delta state put in place by Agip with a capacity of 480MW.

The transmission process in the Nigerian power system involves evacuation of power from all the generating stations to the national grid, closing the grid to the North via Enugu in Enugu state and connecting to the West through Onitsha in Anambra State. Some new projects indicated in Table 1 are still on-going. The following will be added to the transmission infrastructure:

- Additional 330kV Capacity - 5590MVA
- Additional 132kV Capacity - 3313MVA
- New 330kV Lines - 2194km
- New 132kV Lines - 809km
- New 330kV substations - 10

Expansion of 32 existing 330kV & 132kV substations.

The distribution projects have been divided into eleven (11) zones. A new distribution system has been adopted at higher voltage to reduce losses and smaller transformers to isolate distribution faults. About 250 projects have been identified all over the country. The spread is as follows:

- New 33kV Lines - 1701km
- New 11kV Lines - 2666km
- Additional injection substation capacity - 3540MVA
- New Distribution transformers - 22598

All villages within 5km radius of the power stations are to be connected directly to stations. All the new power stations are to be fuelled by gas. The Joint Venture partners in consortium with NNPC are to supply gas from associated and non-associated gas sources. To be constructed are gas transmission pipelines to convey the gas from new and existing gas sources to the station sites. The gas supply scope is as follows:

- Calabar - 90km from off-shore Adanga to Calabar.
- Ihovbor - 1km off Escravos-Lagos pipeline system (ELPS)
- Egbema - 12km to Izombe.
- Gbarian/Ubie - 6km to Gbarian/Ubie
- Omoku - 1km to Omoku line
- Sapele - 1km to ELPS Oben-Sapele system

The current PHCN available capacity of about 4000MW is to be increased by 2,744 or 68%. Further improvements are expected from PHCN projects under construction that will add another 1,882MW.

The new projects are to effectively improve transmission evacuation capacity throughout the country. A significant reserve of redundancy will be added with the completion of the northern and western loops. The overall increase in the transmission capacity is estimated at about 48%. The quality of electricity supply is expected to improve significantly. The overloaded distribution network is to be relieved and expanded to accommodate the growing number of consumers. Distribution capacity is to increase by about 30%.

The flaring of gas in the Niger Delta is to reduce significantly as the supply of about 748 million metric standard cubic feet per day gas is supplied to the power stations.

Modeling Concept: The process of describing something in terms of only a few of its attributes, is
called modeling. The techniques usually employed include:

1. Deliberate simplification to allow researcher to reach approximate conclusions quickly and easily.
2. The representation of small signal behaviour around a particular operation point.

The ‘best’ way to model a device always depends on the use to which the researcher wishes to put the device. There is no perfect model, the device itself embodies all its characteristics. A good model represents what seems to be important to the problem at hand and ignores what seems to be unimportant. A researcher has to select or invent the model which helps him/her with the task. He/she may choose unwisely and achieve a poor result. A good researcher chooses well, because he understands the problems. This is why background theory is essential.

Long term investment in power system models are basically concerned with optimization, usually in finding the least-cost development plan for power utility. If we accept the established planning objectives, we must state the constraints which the utility must satisfy when trying to achieve planning objective, some imposed from within the utility itself, others imposed from outside, mainly by the economy or government:

- Reliability constraints
- Economic constraints
- Technical constraints
- Environmental and social constraints
- Legal constraints
- Political constraints

Each system planning exercise has its own mixture of these constraints plus some constraints unique to the occasion.

**Overview of Power System Model:** The energy flow equation is given as:

\[ E_{in} = E_{out} + E_{losses} \]  

or

\[ P_{in} = P_{out} + P_{losses} \]  

and

\[ \text{Efficiency, } \eta = 1 - \frac{P_{losses}}{P_{in}} \]  

Equation (3) has to be optimized by making \( P_{losses} \) very small.

The model of the energy with its spinning reserve dispatch in a competitive pool can be formulated as an optimization problem as follows:

\[ \text{Minimize } \sum_{i} \left[ C_T(P) + C_E(Q) + C_R(Q) + C_H(U) \right] \]  

The minimization is subject to network and system constraints enforced by each of the base case and contingencies. These constraints include nodal power balancing constraints:

\[ F_{n} (\theta, V, P, Q) = 0, \quad j = 1, \ldots, J, \quad K = 0, \ldots, K \]  

The network and system constraints include the following:

- Line power flow constraints:
  \[ |S_{ij}| \leq S_{ij}^{\text{max}}, \quad l = 1, \ldots, L, \quad K = 0, \ldots, K \]  

- Voltage magnitude and phase angle limits/security limits:
  \[ V_{j}^{\text{min}} \leq V_{j} \leq V_{j}^{\text{max}}, \quad j = 1, \ldots, J, \quad K = 0, \ldots, K \]  

- Generation (Real and Reactive Power) supply limits:
  \[ P_{j}^{\text{min}} \leq P_{j} \leq P_{j}^{\text{max}}, \quad i = 1, \ldots, I, \quad K = 0, \ldots, K \]  

- Real and reactive power demand bid blocks:
  \[ 0 \leq P_{d} \leq P_{d}^{\text{max}}, \quad d = 1, \ldots, D \]  
  \[ 0 \leq Q_{d} \leq Q_{d}^{\text{max}}, \quad d = 1, \ldots, D \]  

- Thermal limits:
  \[ I_{g}(\theta r) \leq I_{g}^{\text{max}}, \quad i = 1, \ldots, I \]  

- Unit capacity limits:
  \[ P_{k} + S P_{k} \leq P_{k}^{\text{max}}, \quad i = 1, \ldots, I, \quad K = 1, \ldots, K \]  

and other network limits such as nomograms;

Power flow limit on a transmission interface represented by a function of other variables such as output of a certain group of generators, loads of a certain area, or flows on other transmission interfaces.
Such functions are modeled by piece-wise linear functions.

**Mathematical Formulation of Investment:** As the electric power industry goes through the deregulation process, modeling the long-term dynamics investment because more important not only form the stand point of reliability and quality of service, but also from the financial viewpoint. A good estimate or model of the future demand for electric power is necessary to plan a power system. However, the demand, is addition to being a random quantity at any given time, is also to some extent dependent on the type of power system and its parameters. This is another dilemma façade by planners.

The type of investment model to be formulated will depends as the following:

i. determination of the set of relevant technologies or mixes of technologies
ii. estimation of the present and future demand for electric power given each of the possible technologies (power systems).
iii. Optional functional planning of each power system for the related demand.
iv. Choice of one of the power systems as the 'best' one.

Each one of the above is in itself a complex problem.

![Fig. 1.1](image)

**Generation Investment**

= the cost of generating investments + cost of operational and maintenance of existing and new generation investments i.e.

Minimize: \[ \sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} (O+M)_i U_i + \sum_{i=1}^{n} (O+M)_e U_e \]

subject to:

1. Technical constraints:
   \[ U_i \leq X_i, 1,\ldots,n \]
   \[ U_i \leq X_e, 1,\ldots,E \]
2. \[ \sum U_i + \sum U_e \geq D_t (1 + r_a) \]
3. Financial constraints
   \[ \sum_{i=1}^{n} X_i \leq B_t \]
4. Environmental and Social Constraints
5. Legal Constraints (see the permit processes in Nigeria, Fig. 2 attached).
6. Political constraints
7. Reliability Constraints

   Where \( X_i = \) Capacity addition of plant \( i \)
   \( U_i = \) Output of plant \( i \) in MW
   \( X_e = \) Capacity of existing plant
   \( U_e = \) Output of existing plant
   \( C_i = \) Cost of 1MW of new plant type \( i \)
   \( O+M)_i = \) Operation and Maintenance cost of new plant type \( i \)
   \( O+M)_e = \) Operation and Maintenance cost of existing plant \( e \)
   \( r_a = \) reserve margin at time \( t \)
   \( B_t = \) Budgetary value at time \( t \)
   \( D_t = \) total demand

**Case Study on the On-going Research:** The study which is on-going would be tested with MATLAB/SIMULINK codes which is being developed and when all the necessary data are collected.

**Concluding Remarks:** Nigerian government is making an aggressive push in electric power sector reform in changing at a rapid pace.

Several projects in power generation, transmission grid reinforcement and expansion, and expansion and distribution aim is to interconnect West Africa power grid. These initiation — often supported by multi-lateral lending agencies (like World Bank) as well as public and private partnership.

However, literature has shown that worldwide total instable power generating capacity has increased from 3 terawatts (TW) in 2000 to about 3.75 TW, and it estimate to hit 6TW by 2020; says by chief executive of ABB Norway (Divnd Lund). It is expected that this increase will take place in developing country like West Africa, but of $150bn of private-sector investment between 1990 and 1999, less than 2% went to Africa according to Issa Diaw, if the West African Power Pool (WAAAP). Despite challenging operating conditions arising from weak infrastructure, the average return in investment in Africa is in excess of 30% largely because of a rich resources sector. Investment will be essential in the Nigeria's electronic power sector.

The International Energy Agency projected more than $250bn of investment will required in power generation, transmission and distribution between 2001 and 2030 to ensure universal electricity access in Africa. It is clear to say that transmission and distribution networks in Nigeria even many African contribute are very weak, over-worked and in urgent need of investment.

In Nigeria, electricity demand grossly exceeds supply.
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