ENGINEERING & ECONOMIC PLANNING FOR ELECTRIC POWER GENERATION, TRANSMISSION AND DISTRIBUTION

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PLANNING

- Broadly speaking, Planning is a deliberate mental process that is undertaken to ensure that a proposed action will be successful.
- It involves deciding on the goal to be achieved, and identifying the steps needed to achieve the goal.
- For a power project, planning requires listing in detail, what is required to complete the project successfully along the three critical dimensions of quality, time and cost.

ENGINEERING/ECONOMIC PLANNING

Engineering planning, together with management, are used to bring a project from the conception phase through to successful implementation.

Economic planning refers to any directing or planning of economic activity outside the mechanisms of the market, in an attempt to achieve specific economic or social outcomes.

ENGINEERING PLANNING FOR POWER GENERATION, TRANSMISSION AND DISTRIBUTION

- Engineering planning for Electric Power Generation, Transmission and Distribution will normally follow the following major steps:
  - Project Conception
  - Feasibility Study
  - Preliminary Planning
  - Detailed Planning
  - Implementation

ECONOMIC ANALYSIS

Electric power Generation, Transmission and Distribution are very capital intensive, and therefore an elaborate economic analysis must be carried out to determine the most economically viable option for the achievement of desired objectives.

PLANT COST

- Plant cost may be considered in various ways. The most common include:
  - Engineering, Procurement and Construction (EPC) cost, which is the most commonly used today.
    - Can often be obtained as a fixed price contract for proven technology.
  - Equipment cost, which includes the cost to fabricate, deliver and construct the plant equipment
  - Total Installed Cost, which is the total cost of the equipment and engineering, including interest during construction. This is the cost that a utility would record on its books without the cost of land and .
  - Total Plant Cost (TPC), which includes all costs

ECONOMIC METHODOLOGIES

Various methodologies may be used to carry out the economic analysis of a proposed power system. Examples include:

Simple Payback

This is the number of years it takes to pay back the original investment

Return on Equity

For regulated utilities, ROE is set by the regulatory body. The equity is determined by the total plant cost being allowed in the rate base.

Discounted cash Flow Analysis

This method is preferred by engineering economists because it considers Time Value of Money. A spread sheet is set up to estimate the cash flow over the life of the project.

POWER PLANT DESIGN AND ECONOMICS

FACTORS AFFECTING POWER PLANT DESIGN

- Location of plant
- Availability of water
- Availability of Labour
- Land Cost
- Operating cost
- Maintenance cost
- Cost of energy generation
- Capital cost

INITIAL COST OF A POWER STATION

The initial cost of a power station includes the following:

- Land Cost
- Building Cost
- Equipment Cost
- Installation Cost
- Overhead Charges, which include the transportation cost, stores, warehouse charges, interest during construction etc.

OPERATIONAL COST

The elements that make up the operating expenditure of a power plant include:

- Cost of Fuels
- Labour Cost
- Cost of Maintenance and repairs
- Cost of stores (other than fuel)
- Supervision
- Taxes

COST OF FUELS

Fuel is the heaviest cost item of operating cost in a thermal power station

Fuel quality and maximum economy of its use are very important considerations in a thermal plant design

Example, wet gas leads to deposit of condensates, which results in higher maintenance cost of the plant.

In hydro plants, the absence of fuel factor in cost is responsible for lowering operating cost

LABOUR COST

Labour cost is a very important cost element which guides the choice of power generation

- Coal fired thermal plants are labour intensive and must therefore consider labour availability
- A hydro power plant or a diesel power plant of equal capacity requires less no of persons
- Labour is further reduced for automated power plants.
- However, no matter the level of automation, labour cost cannot be entirely eliminated.

COST OF MAINTENANCE AND REPAIRS

Maintenance includes periodic cleaning, greasing, adjustments and overhauling of equipment.

Maintenance cost is higher for thermal plants than hydro plants due to the complex nature of principal equipment and auxiliaries in the former, and the effect of heat on the materials.

The cost of materials for maintenance is charged under this head

COST OF STORES

- Items of consumable stores, apart from fuel, includes articles such as lubricating oil and greases, cotton waste, small tools, chemicals, etc.
- The incidence of this cost is higher in thermal power stations than hydo – electric power stations

SUPERVISION

A good supervision plan results in lesser breakdowns and extended plant life
Again this cost is higher for thermal plants than hydro plants

ECONOMICS OF PLANT SELECTION

Reliability is the objective of any plant selection
The thermal efficiency and operating cost of a steam power plant depend on the steam conditions such as throttle pressure and temperature
The efficiency of a boiler is maximum at rated capacity. Boilers fitted with heat recovery devices like air preheater, economiser, etc. give efficiency of the order of 90%

Cost of additional equipment has to be balanced against gain in operating cost

PLANT SELECTION – HYDRO PLANT

Power can be produced at low cost from a hydro power plant provided water is available in large quantities.

The capital cost per unit installed is higher if the quantity of water available is small

Cost of transmission lines and loss of energy in transmission also influence the choice of a hydro –power plant
For a hydro power plant the fixed charges are high, of the order of 70 – 80% of the cost of generation.

PLANT SELECTION – DIESEL PLANTS

- Diesel power plants can be easily located at the load center.
- The fuel cost is relatively high in a diesel power plant
- The engine efficiency improves with compression ratio but higher pressure necessitates heavier construction of equipment with increased cost.
  - Diesel plants are very suitable for small outputs.

PLANT SELECTION – GAS TURBINE PLANTS

Gas turbines power plants are very useful in regions with availability of large quantities of gaseous fuel.
The cost of a gas turbine plant is relatively low, but increases as the same plant is modified by the inclusion of equipment like regenerators and re-heaters, intercoolers, with attendant increase in efficiency.

PLANT SELECTION – NUCLEAR PLANTS

- The capital cost of a nuclear plant is more than a steam power plant of comparable size.
- Nuclear power plants require less space as compared to any other plant of equivalent size, but with a much higher cost of maintenance
- Nuclear plants are potentially more hazardous. Even the disposal of wastes from a nuclear plant is a major issue

ECONOMICS OF POWER GENERATION

Economy is the main principle of design of a power plant
Aim is to supply power to consumers at the lowest possible cost per kWh

ECONOMICS OF POWER GENERATION CONTD.

Cost of power generation can be reduced by:
Selecting equipment of longer life and proper capacity
Running the power station at high load factor
Increasing the efficiency of the power plant
Proper maintenance plan to avoid breakdowns.
Proper supervision
Using a plant of simple design

ENGINEERING/ECONOMIC PLANNING FOR ELECTRIC POWER TRANSMISSION

- Generated electricity must be transported to the load centers and thence distributed to end users.
- Transmission systems fundamentally deliver electric power from power stations to industrial sites and substations and thereon to distribution systems which in turn supply the residential and commercial end consumers. They also interconnect electric utilities and allow power exchange for economic advantage.

TRANSMISSION SYSTEM DESIGN

- Transmission systems design is the selection of the necessary lines and equipment to deliver the required energy and quality of service to destination load centers.
- Transmission networks are designed to transport the energy as efficiently as feasible, while at the same time taking into account economic factors, network safety and overall system stability including redundancy.
- The network components include power lines, cables, circuit breakers, switches and transformers.

TRANSMISSION SYSTEM DESIGN FUNDAMENTALS

- Power flow studies to determine capacity of proposed transmission line;
- System stability and dynamic performance analysis;
- Selection of voltage levels:

  - When required transmission capacity is known, then the appropriate voltage of transmission can be selected. In Nigeria, transmission is at 330kV and 132kV for now.

TRANSMISSION SYSTEM DESIGN FUNDAMENTALS CONT'D

Next is the selection of the conductor. This depends on certain factors:

- Large sized conductors for less losses limited by weight and manageability;
- Solid core vs stranded conductor;
- Steel core for strength;
- Sag calculations are important as conductor temperature rises with current and time. Conductor is selected so that it is allowed to sag as temperature rises without snapping.

  Again excessive sagging must be guarded against or the line might become unsafe. It is a trade-off.

TRANSMISSION SYSTEM DESIGN FUNDAMENTALS CONT'D

- Safety and predictability of network operation is achieved by System Control.

  - Voltage, frequency, load factor, reliability capabilities are controlled with generators, switches, circuit breakers and loads to ensure cost effective system performance.

  - The coordination of these activities is known as System Operation which is beyond the scope of this paper.

TRANSMISSION SYSTEM DESIGN FUNDAMENTALS CONT'D

- Protection is an important aspect of transmission line design and operation.
- Long transmission lines must have adequate protection such that power flow between associated generators and distribution facilities are fully controlled.
- Fault sensing protective relays are deployed at each end of the protected line segment to detect various faults and trigger appropriate response.
- Again, protection coordination is an intricate part of System Operation which requires special treatment. The bottom line is that line faults must be quickly cleared and prevented from flowing back to damage the generators or continuing on to destroy consumer installations.

TRANSMISSION SYSTEM DESIGN FUNDAMENTALS CONT'D

- Another aspect of transmission line design is the selection of the structural support.
  - Steel lattice towers;
  - Steel tubular poles;
  - Wooden poles.
  - Foundations.
  - Earthing arrangement.
  - Guys and anchors.

TRANSMISSION SYSTEM PLANNING

Planning for the realization of the transmission line takes into consideration the economic, social and technical factors that will impact on the project. It is an integral part of the design process.

Planning the line route:

- Shortest route may not be feasible;
- Select farmlands over residential areas;
- Consider economics of compensation payment;
- Health hazards and wellbeing of community;
- Acquiring the Right of Way

TRANSMISSION SYSTEM PLANNING

- Technical and regulatory considerations:
  - Allowable voltage drop at load end;
  - Corona noise, radio and tv interference;
  - Maximum sag, minimum vertical and horizontal clearances;
  - Minimizing line and system losses;
  - Redundancy, radial, and ring networks;

TRANSMISSION SYSTEM PLANNING

Economic considerations:

-Cost / benefit analysis;
-Achieving best overall quality and security of performance at least cost;
-Evaluating community benefits;
-Evaluating expected increase in the tempo of economic activities as a result of the transmission project.

FUTURE OF TRANSMISSION IN NIGERIA

- Transmission will continue to play a great role in the economic development of Nigeria.
- As the electricity industry grows, there will be the need for private transmission grids as obtains in the U.S.A. thus promoting more employment opportunities.
- Local content will grow when the steel industry is fully established.
- Local manufacture of transmission line accessories will flourish as the local manufacturers are patronized.

4.0 POWER DISTRIBUTION PLANNING

4.1 Power Distribution

- The final stage in the delivery of Electricity to the end user.
- The network of a distribution system carries electricity from the transmission system and delivers it to the consumers.
- The distribution system begins as the primary circuit leaves the sub-station and ends as the secondary service enters the consumer meter.
- The Consumer may be Industrial, Commercial or Domestic.
- It is usual for Industrial Consumers and some Commercial Consumers to receive power supply at High Voltage because of the sizes of their loads.
- Domestic Consumers generally receive power at low voltage
- In Nigeria, the Distribution voltages are 33KV, 11KV and 415/230V
- The Low Voltage Phase-to-Phase Voltage is 415 Volts while the Phase-to-Neutral Voltage is 230 Volts.

4.2 The Nigerian Electricity Reform Act and Discos

- In Nigeria, the Electric Power Sector Reform Act, 2005 gave legal backing to the unbundling of the Nigerian Power Sector.
- The Act stipulates the functional unbundling of the Generation, Transmission and Distribution Sectors.
- Under the Act, “Distribution Companies (Discos) shall be established and licensed to perform the functions of distributing electricity in apportioned authorized areas, on 240V up to 33KV networks of the Nigerian Electricity Industry….”
- The Discos are responsible for “overseeing retail operations to end Users of Electrical Energy” as well as Planning and Development of distribution system.
- Therefore the technical feasibility and financial sustainability of Discos depend on the efficiency of utility operation based on its implementation of a credible distribution plan.

4.3 Distribution Planning Overview

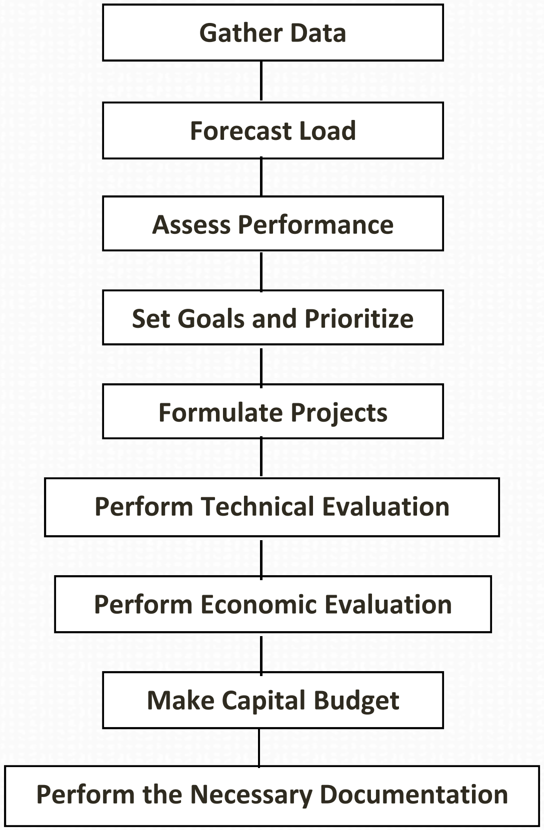
- Electricity must be supplied to end-users at the exact amount and time of need.
- It is unlike other commodities which can be temporarily stored until required for use.
- When electricity supply is unreliable and of poor quality, consumers suffer inconvenience and loss of productivity .
- They are dissatisfied, there is loss of revenue to the utility company and operations at consumers facilities become costly.
- Therefore, planners must ensure that both the quantity and quality need of customers are met through timely expansion and rehabilitation of distribution facilities.
- For effective electricity supply, distribution services must be available continuously with adequate capacity considering the lead time for construction.
- The future demand must be accurately predicted so that distribution facilities are prepared to meet the growing and dynamic needs of consumers.
- Planners must anticipate and quantify the changing demand for electricity as a result of technological innovation, economic situation and even political intervention.

4.4 Distribution Planning Objective

- Clause 2.1.3 of the Nigeria Electricity Regulatory Commission (NERC) Code stipulates that “in order to fulfill the obligation stated in Condition 17 of the Distribution License, the Disco shall develop yearly a 5-year Distribution Plan which shall include:
  - Energy and Demand Forecast
  - Distribution Feeder Routing and Sizing
  - Distribution Reactive Power Compensation Plan;
  - Distribution Losses Reduction Plan;
  - Other Distribution reinforcement plan
  - A summary of the technical and economic analysis performed to justify the 5-year Distribution Plan.
- NERC states the purpose of Distribution Planning to be amongst others:
  - Enable the planning, design and construction of the Distribution System for a safe and economical operation with the specified degree of Reliability as stated in the Standards of Performance Code
  - Enable the Disco to develop, maintain and operate the Distribution System in a coordinated and economic manner in compliance with the Disco’s license.

4.5 Distribution Planning Process

The 9-step general procedure to preparing Distribution Plan



4.6 Data Gathering

Distribution Planning will require the gathering and updating of the following relevant data:

- Historical Customer data – Demand and Sales Data (for at least the past 7 years)
- Historical Distribution System Performance and Statistical Data (at least 7 years), including system loss, Load Factor, Power Factor, total substation transformer capacity (MVA), total length of lines per voltage category, classified into urban and rural, etc.
- Historical and forecast /targeted economic demographic and development plan data, including population within the coverage area of Disco; plans of industrial, large commercial, institutional and special load customers
- Distribution System Maps and Diagrams (latest and updated)
- Distribution Network and Customer Data, including Primary and Secondary Distribution Lines, Capacitors, Customer Service Drops, Customer consumption, etc.
- Fault Data at connection points to the Grid;
- Interruption Data (average of at least 5 years)
- Committed Expansion, Rehabilitation and Electrification Projects.

4.7 Energy Demand Forecasting

- The ability of the Disco to accurately forecast future energy and demand requirement of the distribution system is very important for effective and correct identification of Capital Expenditure projects.
- The Planner is required to carry out, for the different groups of consumers (present and future):
  - Load Survey Analysis and
  - Load Growth Projection
- There are many methods to forecast demand requirements of consumers.
- The traditional method is to use historical figures of existing consumers, or estimates based on the profile of consumers – rural / urban, low density / high density area, Commercial, Industrial, etc.
- Modern methods utilize computer models to forecast, based on useful data that are available.
- It is important to test the validity of the computer model before use, and only the models that passed such tests are used.

4.8 Performance Assessment

The performance assessment identifies and quantifies the problems and deficiencies that must be addressed by the planners in preparing the Distribution Plan.

- Capacity – analyze the capacity requirement of substations, lines and distribution transformers
- Future Requirements of Large Customers
- Safety Analysis – calculate and analyze the available short circuit currents in the distribution system.
- Power Quality – undervoltage, overvoltage and unbalance
- Reliability Assessment – frequency and duration of interruptions, loss of load and energy not supplied.
- System Loss Segregation – the system loss is segregated, technical and non-technical. E.g. NERC estimate the non-technical losses (losses attributable to unbilled consumers) in PHCN Distribution System as 36% (very high!).
- Rural Electrification – List the electrification projects that are being proposed or requested to be implemented by the Disco for the next five years.

4.9 Goal Setting and Prioritization

- The planners must prioritize the identified problems (i.e. the power supply problems for which projects would be formulated to solve).
- The utility goals for the plan period is set based on
  - the comprehensive lists of problems
  - deficiencies in the power distribution system
  - the mandate to the Disco
  - the available resources and priorities of the Disco.
- During the process of prioritizing, problems in meeting safety and performance standards are deemed "mandatory" while the problem of system improvement above standard are deemed "desirable"

4.10 Project Formulation

- The next activity after setting the goals and prioritizing the problems, is to formulate projects, to solve the identified and quantified problems.
- The project ideas must be validated to check whether they are physically feasible and practical to implement.
- The solution to the identified problems that resulted from the generated project ideas could be a combination of any of the following:
  - Safety Compliance Projects – e.g. replace protective devices for adequate short circuit duty
  - Capacity Augmentation Project – uprating of an existing substation capacity or construction of a new substation;
  - Expansion Projects – to meet the demand of new customers
  - Power Quality Correction Projects – capacitor placement, Conductor uprating, etc
  - Reliability improvement projects – installation of sectionalizing (switching) devices at some sections of the distribution system to reduce the frequency of system interruption, etc.

4.11 Technical Evaluation

- Each formulated project is evaluated for technical feasibility
  - loading,
  - short circuit,
  - load flow / voltage drop,
- reliability and system loss analysis is carried out for the project to predict the performance of the distribution system with the proposed project.
- The project ideas that are not technically feasible will be screened out of the list while feasible ones will be ranked according to the technical effectiveness.

4.12 Economic Evaluation

- The technically feasible projects are evaluated for economic and financial feasibility.
- In carrying out the economic and financial feasibility the project are divided into two categories:
  - projects that “Must Meet Criteria” or “Mandatory” projects (i.e. compliance with safety, capacity and power quality standards) and
  - those considered “desirable” or project that “optimize system attributes” (e.g. reliability and system loss improvement).
- For the first category of projects (“Mandatory”) those that provide the least total cost, among the identified alternatives, are selected.
- The key measures used to assess the financial viability of the second category of projects (the “desirable” projects) include
  - Net Present Value (NPV)
  - Internal Rate of Return (IRR)
  - Benefit / Cost Ratio (B/C)

4.12 Economic Evaluation contd.

- If the NPV is positive the project is economically viable.
- Also the IRR will exceed the discount rate and the B/C greater than one, for the project to be considered viable.
- The Project Cost is based on the Life Cycle Cost which include
  - Investment Cost
  - Renewal Cost
  - Operation and Maintenance Cost and
  - Technical Loss Cost (where applicable).

4.13 Capital Budgeting.

- The sources and schemes of funding for each project are identified.
- Also it is important to analyze the impact of the projects on the financial condition of the Disco by undertaking the following activities:
  - Financial Plan for the 5-Year Capital Expenditure
  - Determine the available funds and sources, needed to carry out the project,
  - Determine the financing conditions including modalities for the debt-service.
  - Carry out Financial Performance Assessment
    - income statement,
    - balance sheet, and
    - cash flow.
  - Sensitivity Analysis – the following scenario may be considered:
    - Sales is +15% of forecast
    - Sales is -15% of forecast
    - Interest Rate is above or below expected
    - Repayment period above or below expected.
- Indicators derived from these statements can help in evaluating the current and future financial performance of the Disco.

4.14 Documenting the Distribution Plan.

The documentation contains amongst others

- Detailed Description of the Project
- Project Justification
  - Problems being addressed by the project
  - The consequences if the project is not pursued
- Technical Analysis
  - Criteria
  - System performance without the project and
  - System performance with the project
- Economic Analysis
- Annexes
  - Data
  - calculations sheets
  - assumptions used in technical analysis
  - Assumptions used in economic analysis.