Renewable Energy and Distributed Generations

Lecture 2

Power Systems Planning Basics

Lecturer: Teshome Goa (Assist. Prof.)

Lecture learning outcomes:

At the end of this lecture, you will be able to:

i. Define the Basics of Generation Planning

ii. Understand Transmission and Distribution planning basics

iii. Explain the objective of Generation, Transmission and Distribution Systems planning

Generation, Transmission and Distribution systems (GTDs) Planning.
2.Introduction

- The primary goal of **GTDs** planning is to minimize the overall costs of investment, operation and maintenance while meeting the reliability, generation mix, and demand requirements[1].

For instances;

- Reducing the installation cost of additional power plants/units
- Minimizing the new transmission and distribution systems cost
- Reducing the Expansion costs of **GTDs**

2.1 Generation System Planning(GSP)

- ❖ Generation planning is comes after the load forecasting. Thus,
- ❖ The uncertainty of load forecasting due to the randomness of loads at a time and over/under load forecasting should be considered while planning the generation systems[2].
- ❖ Accordingly, generation planning is defined as the process of *minimizing the overall* **production and operation** costs of the plants based on:

- Which generation units to be built
- When to be built them
- How much power to produce
- How much overall cost (Variable and fixed) is needed

GSP Objectives:

- The Main objective is to determine the sustainable and economic scheduling of Power plants(existing and new plants) based on the forecasted energy demands[3].

This necessitates , Planning of Generations:

- Type, its location, technology, Unit Size, Potentials, Construction period and timing of future generation plants.
- Power economics and costs (investment and operating cost)
- Impacts on environment and society
- Outage/retirement of the Existing Units and Plants

2.1.2 Unit Size of Power Plant and its Potentials

- Once the types of power plant is known, it's followed by sizing the units
- Which needs to know the unit sizes and factors that affects their availability.

The three factors that contributes for unit availability are[4];

- ✓ Forced outage rates
- ✓ Repair times
- ✓ Scheduled maintenance

- **Forced outage rate** is one of the factor that directly affects overall energy availability
- Example: a Unit rated as 1870 MW with a forced outage rate of 10%(availability of 90%) does not have the same performance as 10 units, each rated as 187 MW with forced outage rate of 10% (availability of 90%) each.

Solution:

The reliability of radial/series (R_s) and parallel connected(R_p) 'N' unit/power plant is given by[5];

Reliability of radially connected system ***Reliability of parallel connected system***

$$R_s = \prod_{i=1}^{n} P_i \qquad R_p = 1 - \prod_{i=1}^{n} q_i \qquad \text{eq.(1)}$$

Or

$$Q_s = \sum_{i=1}^{n} q_i - \prod_{i=1}^{n} q_i \qquad Q_P = \prod_{i=1}^{n} q_i \qquad \text{eq.(2)}$$

- Where, P_i is availability of each unit/plant and q_i is unavailability/outage rate of each unit/plants.
- To recall, always power units/plants are connected in parallel, but not in radial[6].
- Accordingly, the solution of above example(10 units connected parallel) is given by:

Given: Pi=0.9 & qi=0.1

- Then, the availability and unavailability of Ten units connected parallel is given as;

$$R_p = 1 - \prod_{i=1}^{10} q_i$$
$$= 1 - (0.1)^{10}$$
$$= 0.9999999999$$

and

$$Q_P = \prod_{i=1}^{n} q_i$$
$$= (0.1)^{10}$$
$$= 0.0000000001$$

It is observed that availability of N units connected parallel is >> better than a single unit, which is 0.9.

- The Unit/Power Plant Reliability is always probabilistic ,*depends on the repair and maintenance time.*
- The probabilistic availability for all units/plants available is straight forward, which is 100%.
- But, 100% availability is always ideal. T*he units may not work/generate at full capacity due to several fa*ctors like load change, seasonality of resources, man-made and natural scenarios that leads to unavailability.
- Which means, there is a probability of **available unit to be failed** and unavailable unit will be **available if properly repaired.**
- Accordingly, the availability and unavailability of units/plants depends on the Mean Time to Failure(MTTF) and Mean Time to Repair (MTTR) as given by[7];

- The Mean Time to Failure for a given unit/plants is given by;

$$MTTF = \frac{1}{K}\sum_{k=1}^{K} t_{i(k)}, i = 1....n \qquad \text{eq. (3)}$$

where, K is the number of periods when the power plant is available, $t_{i(k)}$ is the duration of each of these periods and i is the number of unit/power plant.

$$MTTR = \frac{1}{L}\sum_{l=1}^{L} t_{i(L)}, i = 1....n \qquad \text{eq.(4)}$$

where, L is the number of periods when the power plant is unavailable, $t_{i(l)}$ is the duration of each of these periods and i is the number of unit/power plant.

- Then, the failure rate(λ) and repair rate(μ) that the probability of available unit will fail and unavailable unit will be repaired(available), respectively are estimated by:

$$\lambda = \frac{1}{MTTF} \qquad \text{eq.(5)}$$

$$\mu = \frac{1}{MTTR} \qquad \text{eq.(6)}$$

GSP Cont….

- The Probability of availability (P) that a power plant will be available, which is estimated based on the share of a longer time period in which the unit is available is given as ;

$$P = \frac{MTTF}{MTTF + MTTR}$$

$$P = \frac{\mu}{\mu + \lambda} \qquad \text{eq.(7)}$$

- Then, the probability of unavailability(q) that a power plant will be unavailable is estimated by;

$$q = 1 - p \qquad \text{eq.(8)}$$

$$q = \frac{MTTR}{MTTF + MTTR}$$

$$q = \frac{\lambda}{\mu + \lambda}$$

GSP Cont.…

- **Accordingly**, it’s very important to maintain the power availability:
- Thus, the generation, operation and utilization limits has to maintained or should not be violated.

The following points should be known;

- **Capacity factor**: Average available capacity/installed capacity
- **Utilization factor**: average real generation divide by the installed capacity
- **Full load hours**: the number of hours a unit would able to generate its full capacity without exceeding the pre-adjusted annual generation

GSP Cont….

- The plant capacity factor(PCF) defines the **rate** at which the plant operates throughout a year.
- The plant capacity factor is the ratio of the actual energy produced to the maximum possible energy that could have been produced during the same period[8].
- Based on the PCF, the existing types of power plants is categorized into three groups;

✓ Base
✓ Intermediate and
✓ Peak loads

For base load operation the chief requirements are :

- low specific operating cost, reduced cost/kWh supplied
- Improved reliability/availability and reduced unavailability
- High investment/ capital cost, since it can be spread over a large amount of energy, is normally acceptable
- The ability to provide a rapidly changing output is not important

For a peak load operations the desired requirements are:

- Ability to start and provide full output within short period of time is needed
- Low capital cost, with operating cost being only secondary considerations
- A siting near generation centres or accessible transmission facilities so as to minimize transmission costs and losses.

- For maximum reliability and economy, it is advisable to have generation capacity should be greater than demand.
- The power system planner should take these factors into account when considering system requirements.
- Finally, the plant planner should consider **mixing** different generation units/plants for enhanced reliability during the base, intermediate and peak load operation conditions

2.1.3 Short Term-GSP (ST-GSP)[9]

- It doesn't need construction of large power plants, and needs the following basic points;

- Contingency analysis, modeling and operation of the network
- Time step: 1 hour to 24 hours or some times greater

The general objective of ST-GSP is;

Maximizing *profit = Income – costs*, subject to *physical limitations*, *contracts*, *Different restrictions*

i. Short Term Hydro-power Plant(HPP) planning

- HPP, generates power using the difference in potential energy between the upper and a lower water level to a turbine, which powers an electric generator.
- Most hydro-power plants have a reservoir and very flexible. (Large changes can be performed within minutes!)
- However, there is a hydrological coupling between power plants in the same river system

Optimization variables of HPP

- The discharge, Q, is water that is released through the turbines (and thus used for electricity generation).
- The spillage, S, is water that is released through spillways to avoid overflowing the dam.
- The reservoir content, M, is the amount of water that is stored in the reservoir.
- All these quantities are measured in hour equivalents, which is defined as 1 m^3/s released during an hour.

The objective of short-Term hydro power plant planning problems are;

- *Max. value of Sold electricity + value of stored water*

Subject to hydrological coupling, limitations in generation & reservoirs, discharge and Spillage.

The objective of ST-HPP is achieved by

- Modeling, scheduling and rescheduling of the generation based on the demand (Existing and New if needed)
- Modeling and optimizing electricity generation pricing. Generation is as a function of:

$$Hpp = \eta(Q, H)\rho QgH$$

Maximizing Value of sold electricity(Vse)

- It's simply defined as the product of electricity generation per hour and its hourly price (h_{pr}).
- Value of sold electricity = h_{pr} * marginal production equivalent(Mpe) * discharge(Q).

Accordingly, it's given as;

$$Vse = hpr * Mpe * Q \qquad \text{eq.(10)}$$

Maximizing Value of stored water(Vsw)

- It's equivalent to the product of forecasted future price of electricity(F_{pre}) and the amount of energy going to be generated(AEG).
- The AEG depends on future production equivalents based on the future stored water and forecasted demands. Whereas,

- The future electricity price *should be assumed and* .
- Accordingly, the value of stored water is as a function of;
- Value of stored water(V_{sw}) = *future price of electricity* (F_{pre}) * Sum of future production equivalents downstream of the reservoir(Sum of Gi) * reservoir content at the end of the planning period(R).

$$Vsw = F_{pre} * \sum_{i=1}^{n} G_i * R \qquad \text{eq.(11)}$$

ii. Short-Term Thermal power Plant planning

- **Thermal power plant g**enerates power using a heat engine.
  - It generates energy from the combustion of a fuel (oil, gas, coal, biomass, etc.) and renewable sources (geothermal, solar thermal).
- Small thermal power plants use an internal combustion engine to power a generator.
- Large thermal power plants use a steam-cycle to power a generator.

- Small-thermal power plants are quite flexible. (Large changes can be performed within minutes.)
- Large thermal plants needs a considerable time to operate (start-up time).
- The generation in large thermal power plants cannot change too rapidly;

Optimization parameters are:

- The generation G
- Start-up cost
- Relation between unit commitments, start-up and stop
- Subjects to generation limits

iii. Other Renewable energy resource Planning's

a. Wind power plants

- Speed and power prediction
- Wind direction
- Generator type selection
- Maximum power harvesting
- Grid integration /synchronizations

b. Solar PV power plants

- Solar insolation
- Temperature
- Selection of module/power electronics devices
- Convertor technology and configuration

C. biomass energy

- Assess resource availability & its quality
- cost of the biomass resources
- moisture content, energy density and chemical compositions

2.1.4 **Long-Term Generation System Planning(LT-GSP)**

- **LT-GSP is also known as** Generation Expansion Planning (GEP) is the first crucial step in long-term planning issues, after the load is properly forecasted[10].
- GEP is, in fact, the problem of determining *when*, *what and where* the generation plants are required.
- There are two ways of GEP: Single-Bus GEP & Multi-Bus GEP in which the Transmission System effects is considered.
- *The single generation planning comprises :*
- Problem definition descriptions, A detailed mathematical modeling's and the solution procedure

- The goal of GEP is to identify the next generation in a manner to answer the "WH" questions, such as where, when, and what kind of allocation for optimized objective function and achieving constraints

The objective function is minimizing;

$$\textit{Objective function} = \textit{Capital costs} + \textit{Operation costs} \qquad \text{eq.(12)}$$

Capital cost, mainly due to

- Investment costs (C_{inv})
- Salvation value of investment costs (C_{salv})
- Fuel inventory costs (C_{finv})

While, operation cost, consists of;

- Fuel costs (C_{fuel})
- Operation and maintenance costs (C_{O}& M)
- Cost of energy not served (C_{ENS})

To come up with the objective function, the following constraints should met.

a. Energy conservation $$\sum_{i=1}^{n} G_i = \sum_{j-1}^{n} P_{Dj} + P_L$$ eq. (13)

b. Reserve margin should be considered

c. Loss of load probability (LOLP) should be also considered

- Although power plants are maintained regularly, *they may have unexpected outage due* to any reason.

  The probability of such a failure is defined as Forced Outage Rate (FOR).

- Assume, the objective is to determine the total generation for year t(P_g^t) for the forecasted peak load of P_L^t.
- Then, the power generation (P_g^t) is as a function of existing generation (P_g^e) , power generation new(P_g^n) minus the existing power generation going to be retired/out (P_g^{eo}) as given by;

$$P_g^t = P_g^e + P_g^n - P_g^{eo}$$ eq. (14)

- It's observed that there are two unknowns (total power generation capacity at year t & new required power generation, needs another eqn. based on constraints b.

- That the power utility company should set the minimum reserve margin, R_{est} (in %), as given by;

eq. (15)

$$(1+\frac{R_{st}}{100})P_L^t \le P_g^t$$

.

Example: Determine the total power generation capacity Power utility company needed to satisfy the total forecasted load of 32, 000MW after 20 years considering reserve capacity of 20 %. Consider the current year maximum generation capacity is 6000 MW , which is generated from three power plants(A, B, C) each generates 2000 MW. Assume, three units of generation B, total capacity of 800 MW is going to be retired after 19 years.

Solution:

From eq.(15), the total power generation after 20 years is given by:

$$(1+\frac{20}{100})P_L^t \le P_g^t$$

$$= (1.2) * 32{,}000 \le P_G^{20}$$

$$\Leftrightarrow P_g^{20} \ge 38{,}400\,\text{MW}$$

Then, from eq.(14), the power generation new required after 20 years is given by;

$$P_g^t = P_g^e + P_g^n - P_g^{eo}$$

$$38{,}400 = 6000 + P_g^n - 800$$

$$\Leftrightarrow P_g^n = 33{,}200\,\text{MW}$$

2.2 : Transmission & distribution system Planning

- It is designed to interconnect the generated power and electrical utility systems while transmitting the power from generation station to the load centers.

Transmission and Distribution system planning determines[11]:

- The timing and type of new transmission and distribution facilities
- The timing and type of new Substations facilities
- Expansion of the existing lines and feeders based on the future generation and demands

2.2.1 Transmission System Planning(TSP)

- The main objective of transmission line planning, specifically the new TSP is to determine:
  - The shortest path and better rout path alternatives
  - Line loading of existing system and newly proposed line
  - Voltage level and required high tension line numbers
  - Power controlling mechanisms (for switching, surge voltage and transients)
  - Power-flows and overall stability,
  - Short-circuit level of lines ,
  - Reliability evaluation and Contingency evaluations.

,

- Selecting ***the system voltage takes*** paramount while planning optimal transmission line, because;
- The weight of conductor, Line efficiency, its voltage drop and the overall system stability mainly depend on voltage
- Consider an n-phase system of transmission, let

$$P = VI\cos\phi \ , \qquad I = \frac{P}{V\cos\phi} \qquad \text{eq.(16)}$$

The relation between current and its density is;

$$J = \frac{I}{A} \Rightarrow A = \frac{P}{JV\cos\phi} \qquad \text{eq.(17)}$$

- The resistance of conductor and power loss(PL) are given by;

$$R = \frac{\rho L}{A} = \frac{\rho LJV\cos\phi}{P} \qquad P_L = I^2 R = \frac{J\rho LP}{V\cos\phi} W \qquad \text{eq.(18)}$$

Voltage drop and percentage voltage drop are given as:

$$V_D = IR = J\rho L \qquad \%V_D = \frac{IR}{V} * 100 = \frac{J\rho L}{V} * 100 \qquad \text{eq.(19)}$$

- The weight of conductor(w), which is a function of the transmission line length(L), density(δ) and area of the conductor(A) as given by;

$$w = AL\delta = \frac{PL\delta}{JV\cos\phi} \qquad \text{eq.(20)}$$

- Then, the overall power transmission efficiency is given by;

$$\eta = \frac{P_o}{P_o + P_L} = \frac{P_o}{P_o + \frac{J\rho LP}{V\cos\phi}} \qquad \text{eq.(21)}$$

$$= 1 - \frac{J\rho L}{V\cos\phi}$$

- It is observed that the power transmission efficiency increases as we increase the voltage.

- In addition, using HV/EHV/UHV AC system increases the power transfer capability as given by;
- If the line resistance is neglected, the power transfer depends on;

i. The magnitudes of sending and receiving end voltages(V_s, V_r)

ii. Their phase difference

iii. the total positive sequence reactance X per phase if the acceptance is neglected.

$$P_T = \frac{V_s V_r \sin\delta}{L.X} \qquad \text{eq.(22)}$$

Assume, the sending and receiving end voltages are equal(V_s=V_r=V);

$$P_T = \frac{V^2 \sin\delta}{L.X}$$

If unity power factor is assumed at load, the current I from power equation is given by;

$$P = VI\cos\phi$$

$$I = \frac{P_T}{V} = \frac{V\sin\delta}{L * X} \qquad \text{eq.(23)}$$

- Then, the total power loss in 3-phase system is given by;

$$P_L = I^2 rL$$
$$= \frac{V^2 \sin^2 \delta * r}{L * X^2} \qquad \text{eq.(24)}$$

- And, the percentage power loss is given by:

$$P_L = I^2 rL$$
$$\%P_l = \frac{100 * P_L}{P_T} = 100 * \sin\delta \frac{r}{X} \qquad \text{eq.(25)}$$

- It's also observed that as we increase the transmission Kv, the power transfer also increases.

- TSP may include *not only the new design* but also the existing lines.
- The starting point is to develop load forecasts in terms of annual peak demand
- Then, the system performance is tested under steady-state and contingency conditions.
- It is followed by checking the effectiveness of the alternative plans, which is determined by;
- load-flow studies under both normal and emergency operations
- Short-circuit analysis
- Stability analysis

2.2.2 Substation Expansion Planning(SEP)

- The SEP is aims at determining the required expansion of *the existing as well* as the locations and the sizes of new substations together with the required facilities.
- It needs determining the loads based on their characteristics, loads to be supplied are widely distributed.
- SEP starts with determining the distribution substation requirements and moving upward, to finally determine the transmission substation requirements.
- It determine the possible allocations and sizes of the substations (either new or expansion of existing)

- The SEP is defined as an optimization problem in which the investment and operational costs have to be minimized, while various constraints are met.
- **The solution should determine;**
- The expansion capacity of any existing substation (provided feasible),
- The allocation and the size of any new substation,
- The investment costs.

Minimize $C_{total} = C_{inv} + C_{opt}$

2.2.3 Distribution system planning(DSP)

- Distribution planners must determine the peak load magnitude and its geographic location.
- Then distribution substations must be placed and sized in such a way as to serve a certain load at minimum cost by minimizing feeder losses and reduced construction costs
- Physically, the primary distribution system can be divided into two distinct subsystems: the substations and the primary feeder circuit.

- In each subsystem, a number of variables must be considered in the planning stage are;
- Substations: location, number, transformer rating and loading, and service areas;
- Primary feeder circuit: number of primary feeders, feeder routing, feeder branch loading, and conductor size.

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Thank you !