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Electrical Power Production Engineering Analysis and Heuristic Decisive Electrical Energy Tariff Determination

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Abstract : *There are six type of electrical power plants generating electrical power for residential, industrial and corporal uses. The solar, wind, nuclear, hydro, gas, and coal are the sources of energy utilized to generate electrical power by means of energy conversion. The principles of all the energy conversions are nearly same but mechanism and technologies are different. The electrical power tariff is the direct function of maintenance cost, generating cost, transmission cost and distribution cost, but indirectly involve with the several engineering operational factors. In this paper a brief analysis of electrical power plants operations and its influence in heuristic decisive electrical energy tariff determination is discussed. Among the six types of electrical power generation plants several engineering operational factors, engineering and scientific factor bases involve in the hydroelectric power estimation and influencing the operational power product design have been discussed. It is difficult to manually decide the electrical energy tariff, as the hundreds of factors are implicit or explicitly related on fixing electrical energy tariff. The real per-unit cost of generated electrical power is quite large, an affordable and reasonable heuristic decisive electrical energy tariff determination supportive literature reviewed.*

Keywords: *Power generation, transmission, distribution, Electrical power utility tariff*

I. INTRODUCTION

Power generation, transmission through the grids, power distribution to the residential, industry and corporations is the key research topic in Electrical Power production engineering courses. All most all production sectors, including industries utilize power produced from at least one form of the six types of electrical energy source power producing plants namely, solar, wind, hydro, thermal (gas and coal fueled) and nuclear. The energy conversion from mechanically kinetic process through the magnetic field to electrical energy form is the overall principles in all these plants. Only the operation technologies are different. Therefore the costs for generation, transmission, distribution control, and building maintenance of individual plants are different. But the power transmission grids can use input energy from any one or more from of the said six types of plants, therefore the per-unit electrical energy utilization tariff is a complicated implicit explicit function of different type costs mentioned earlier.

The Electrical power utilization tariff fixation is a multi-objective Optimization problem. The two important objective are minimization of electrical power production cost, and maximization of energy utilization with constraint to the minimum use of source energy. The other engineering constraints are mathematical expressions concerning with the mechanical forces conversion ratio with electromagnetic field potential, and current flow through conductor, potentials difference at transformer, alienator rotor tool capacity, produced current transmission phase changes, polarity angle, thermodynamic relations mathematical expressions, insulator material thermostatic relations mathematical estimation expressions, the Electric voltage controller switch capacity, etc. Before description of Electrical energy utility tariff fixer usable heuristic decision influencing constraints, a brief description on hydroelectric power plant operation constraints' engineering, scientific fact analyses are discussed.

II. HYDROELECTRIC POWER ESTIMATION ENGINEERING MATHEMATICAL ANALYSIS

The engineers estimate the actual output of energy at a dam by determining the volume of water to be released (discharged) from the reservoir at different seasons. The vertical distance or water fall height is one of the factor in the decision of discharge water volume quantity. For a specified water fall height and the fixed volume of water discharge at the generator site, the rotational speed of the generator determine the type of turbine to be used for specific quantity of energy. Because the turbine driven by water pressure varies as the water height varies. Thus the pressure is measured in the quantity of force effecting the area and faster flowing water means more power generation.

The theoretical power measure from a specific site is determined by using the simpler formula

Theoretical power is proportional to product of Q ("flow rate in cubic meter per second") and H (water reservoir height in meter).

(If theoretical power is to be measured in the units of Horse power then this is equal to the product of Q and H along with the product of a constant $\frac{1}{8.8}$. One horsepower = 746 watt).

The expression for the power measure is a function of the variables such as the lost water pressure quantity at the waterbed or penstock, variations due to the efficiency levels of mechanical devices used to harness the power.

Turbines type (blade size, blade spanning, shape and angular displacement, rotor weight, blade strength, blade folder etc.) is one of the mechanical device influences the electric power generation. Roughly two basic types of turbines (impulse and reaction) are used in the power plant. Decision for the specific type of turbine to be used are depend on the completion of powerplant operational studies and cost estimations. A reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged and reduces turbulence.

The work of a reaction turbine is similar to the rotating lawn sprinkler where water is a central point is under pressure and escapes from the ends of the blades, causing rotation. Reaction turbines are the type that most widely used in the hydroelectric power generator.

The impulse turbine is a horizontal or vertical wheel that uses kinetic energy of water striking its buckets or blades to cause rotation. The wheel is covered by a housing and the buckets or blades are shaped so the turn the flow of water about 170 degrees inside the housing. After turning the blades or buckets, the water falls to the bottom of the wheel housing and flows out.

There are three types of hydropower facilities namely impoundment, diversion and pumped storage. Some power plants use dams and some do not. The **impoundment** facility is a large hydropower system, uses a dam to store river water in a reservoir. The **diversion** facility sometimes known as run-of-river, facility channels a portion of river through a canal of penstock. It may not require a dam. P**umped storage** facility pumps water from a lower reservoir to an upper reservoir at higher elevation position. During high electrical demand, the water is released back to lower reservoir.

Hydroelectric Power estimation scientific factors: The water from the dam is led to the water turbine through the penstock, and potential energy of the elevated water is transformed into kinetic energy. The water turbine converts hydraulic energy into mechanical energy, and the generator converts mechanical energy into electrical energy. The generators are usually salient-type rotor with many poles. To maintain the generator voltage frequency constant, the turbine must spin the generator at a constant speed with a mathematical relation as $\frac{120f}{p}$, where f is the voltage frequency and p is the numbers of poles of the generator. Elaborate control schemes are used to regulate the flow of water in order to maintain the turbine speed constant.

The potential energy of the water in reservoir is proportional to mass of the water and the difference in height between the water impoundment and the water outflow. The height difference is known as effective head. That is $P.E = mgh.$ The mass of water is its volume times its density. Therefore $P\,E = volume \times \rho gh$ and the available hydropower becomes $P_w = \frac{P\,E}{t} = \frac{volume}{t}\,\rho gh = q\rho gh$ watt.

Where q is rate of flow of water in $\frac{m^3}{s}$, h is effective head of water in m, ρ is density of water $\approx 1000\frac{kg}{m^3}$, g is acceleration of gravity $= 9.81\,m/s^2$, Given $\rho = 1000$, the available hydro power P in kilo watt is given by $P = 9.81\,qh$ kW.

If η is the overall efficiency of the hydropower plant, the electrical power output in kW is $P_0 = 9.81\,qh\eta$ kW. Here $\eta = \eta_P\eta_t\eta_g$, η_P is penstock efficiency, η_t is turbine efficiency, η_g is generator efficiency.

The statement of Ohm's law for Power is the rate at which energy is used in a circuit during a certain period of time is defined as power. The power that dissipated in a circuit is directly proportional to the square of the amount of current that flows through it.

III. Three Types Of Power Defined In Electric Power Generation And Transmission Literature

The "**True power**", "**Reactive power**" and "**apparent power**" are the three types of power classified from the generating sets. When a generator at a utility plant transmits current through a feeder line to a factory, it provides **true power**, which is consumed by the conversion of electrical energy to heat energy and mechanical energy. 1. True power performs work and its consumption form is the motor required mechanical energy to physically turn the load. 2. The mechanical energy required to overcome the bearing friction and windage (actual air resistance to the rotor turning). 3. Heat dissipation from the resistance on the wire, eddy current and hysteresis on the iron cores.

The remainder of the current from the feeder is used to produce magnetic fields that expand around the coils. When these fields collapse during each AC alteration, they induce a voltage back into the coils, which causes current to be return back from motor through the feeder line to the generator. This type of power is called **reactive power**, does not perform any work.

The combination of true power and reactive power sent to the factory is called **apparent power**. The true power and reactive power those pass through the feeder line are not in phase. Therefore apparent power is the phased sum of the true and apparent power.

Power factor (pf) calculation tips: The ratio of true power to apparent power is referenced to as the power factor. Let P be the real power and S be the magnitude of the complex power then $= cos\theta = \frac{P}{S}$. The power factor is an indication of the efficiency of a circuit, which refers to how energy supplied by the source to perform work. A power factor of "1" is most desirable because the circuit is then purely resistive, and the power is real. If a second load were connected in parallel with the original load, so that the total reactive power to the circuit would become zero, by this way the power factor would be "corrected". In other words, the power factor would become 1.

The two primary effects of power factor correction are 1) the circuit current become smaller 2) the voltage and current in the circuit are in phase.

If the load is capacitive, the power factor is said to be "leading", that means current leads voltage, If the load is inductive, the power factor is said to be "lagging".

Hydroelectric power plant operation cost influencing facts: Maintenance, Monitoring tool for power generator, and transmission grid safety, Hydrology, water quality, Dam safety, Increase production and efficiency by uprating existing power-plants, developing low-height hydropower plants, Pumped storage, tying hydropower to other forms of energy.

Electricity Tariff influencing facts: The supply of low-cost electricity to defense industries, shipyards, steel mills, chemical companies, oil refineries, automotive and aircraft factories influence the Electric tariff. Farming is tremendously influence the electric power tariff. Farming produces revenue which contributes toward repayment of irrigation facilities, easing the water users' financial burden.

The heuristic method for electric load calculation and Tariff fixation:

The word heuristic method means an approach to problem solving, learning or discovery that employs a practical method not guaranteed to be optimal but sufficient for immediate goals. For a brief knowledge about heuristic optimization read the article heuristic algorithms [1]

The following facts are used for fixing electric power consumption bill charges in Indian corporation cities:

1) Energy Charge: This is the per unit electricity charge that you pay on your bill. It is mostly defined slab wise and the cost increases as units on electricity bill increases.

2) Fixed Charge: This is mostly dependent on the connected load that the utility provides you. Connected load is typically calculated as sum of wattage of all the appliances that you have at your home. The utility allocates this much amount of electricity for your home and that is why the fixed charge is applicable.

3) Electricity Duty & Tax: This is the government tax for using electricity. Duty is applicable per unit of electricity consumption and tax is applied on the whole bill amount.

4) Meter Rent: Rent that you pay for having meter at your home. Rates are different for single phase and three phase connections.

5) Wheeling Charge: The tool also helps you find out how your bill gets impacted if you move from Reliance Energy to Tata Power in Mumbai. Wheeling charges are applicable for the switchover.

6) Minimum Monthly Charges: In some states if the consumption is less than a certain amount, minimum monthly charges are applicable, which means that the bill amount cannot be less than minimum monthly charges.

The bill may not cover following facts:

1) FAC (Fuel adjustment charge) or FCA (fuel cost adjustment), FPPCA (Fuel and power purchase cost adjustment). This is the amount which utilities apply on bills based on varying price of fuel or coal. Every month this value is different and derived based on the current cost of coal. This is a few Paise per unit
2) Arrears or Interest and other charges

IV. ELECTRICAL TARIFF BILL IS A FUNCTION OF ESTABLISHMENT MAINTENANCE COST, GENERATING COST, TRANSMISSION COST, DISTRIBUTION COST

Establishment Maintenance Cost: Cost related to building, power generation, transmit and distribution purpose installation, spare parts assemble, Operating power plants modernization and capacity increase. The **routine maintenance cost are related to the following service costs**, Perform visual inspection and dimensional check, check starter bore for roundness, checking air gap uniformity, check alignment of ready-assembled turbine and generator shaft, check all bearing clearances, check entire generator cooling system, perform hydrostatic pressure and tightness tests on all equipment containing or carrying water, oil and compressed air, Check breaks during breaking and during lifting operations, measure stator-winding Dc resistance, measure insulation resistance of stator winding and determine polarization factor, conduct AC high voltage withstand resistance, measure rotor winding DC resistance, measure rotor impedance, conduct AC voltage withstand test of rotor winding, measure rotor winding insulation resistance, perform operational tests on all generator auxiliary equipment, including calibration of related electric control instruments, check for correctness of wiring and piping, check alarm and protection devices, verify alarm and tripping settings for all supervisory instrumentation. Perform functional test of fire-protection system, **mechanical and hydro-mechanical equipment operation performance tests** including check water leakage from closed gates and emergency valves, conduct pressure test on tunnel and penstocks, conduct discharge tests on regulating and flow controlling gates, mechanically coupled turbine/generator unit's sound with respect to bearing temperatures, rotating parts load balancing, mechanical vibrations and behavior under overs peed conditions, Conduct mechanical run for bearing temperature stabilization, measure shaft run-out (eccentricity), measure vibration to determine general vibration level and assess balance of assembled rotating equipment, Electrical start-up/shutdown sequence, including mechanical braking, conduct functional test of generator protection relays, measure short circuit and no load curves, determine generator reactance and time constants, measure shaft voltages, synchronize with grid system. Conduct load rejection tests on the generating unit at a range of load steps, including overload to check response of turbine governor and excitation system (AVR) under load condition, Conduct reactive capability test, conduct power system stabilizer test, energize transmission circuit,

Generating Cost: Let us discuss the facts associates with generating cost. It is a conventional fact that electrical power generation location should be nearer to the load center (where maximum power is consumed) so that transmission cost could be minimized. The electrical transmission system is the means of transmitting power from generating station to different load centers. But during planning of construction of generating station several facts are to be considered for economical and efficient generation of electrical power.

If the generating station is a thermal power generating station, availability of water, fuel, availability of land and line train or road ways for installing spare parts, fuel and big alternators etc. are considered.

If the generating station is a hydro power station, there must be a dam on river. So proper place near to the river dam must be chosen turbine, fan, alternator will not be affected during channeled stream operation stages.

If the generating station is a nuclear plant, it must be situated in such a distance from common location so that there may be any effect from nuclear reaction of the common people health.

All the facts mentioned above are very difficult to be available at load center. The power station or generating station must be situated where all the facilities are easily available. This place may not be necessarily at the load center.

Technical constraints influencing transmission cost expenses: The power generated at generating station is in low voltage level as low voltage power generation is more economical than high voltage power generation. At low voltage level, both weight and insulation is less in the alternator, this directly reduces cost and size of the alternator. But this low voltage level power cannot be transmitted directly to the consumer end because there are transmission loss due to conductive material resistivity. Electrical power is directly proportional to the product of electrical current and voltage of the system. So for transmitting certain electrical power from one place to another, if the voltage of the power is increased then associated current of the power can be reduced for a constant power. Reduced current means less $I^2 R$ loss in the system, less cross sectional area of the conductor means less capital involvement and decreased current causes improvement in voltage regulation of power transmission system and improved voltage regulation indicates quality of power. Because of these three reasons electric power mainly transmitted at high voltage level.

Technical constraints influencing distribution of transmitted power: For efficient distribution of the transmitted power, stepped down transformers are used to step down the high voltage to desired requisite voltage level. The circuit within transformer are function of variables like wire coil turn numbers at input end, wire coils at the output end, the plate potential, and some other electrical properties.

So it can be concluded that first the electric power is generated at low voltage level then it stepped up to high voltage for efficient transmission of electrical energy. Lastly for distribution of electrical energy or power to different consumers it is stepped down to desired effective comparatively low voltage level.

The power generation, transmission and distribution are conducted with the help of network. The network source or inter mediate stages are either high voltage DC electrical transmission or High AC electrical transmission.

Advantages in using DC transmission system: Only two conductor are required for DC transmission system. If earth is utilized as return path there may be only one conductor of DC transmission system. The potential stress on the insulator of DC transmission system is about 70% of same voltage AC transmission system. Hence less insulation cost is involved in DC transmission system. Inductance, capacitance, phase displacement and surge problems can be eliminated in DC system.

In spite of the above mentioned advantages in DC system, the general electrical energy is transmitted by three phase AC transmission system. Because the alternating voltages can easily be stepped up and down, which is not possible in DC transmission system. Maintenance of AC substation is quite easy and economical compared to DC. The power transformation in AC electrical substation is much easier than the motor generator sets in DC system.

But AC transmission system also has some disadvantages like, the volume of conductor used in AC system is much higher than that of DC. The reactance of the line, affects the voltage regulation of electrical power transmission system. Problems of corona effect, skin effects and proximity effects only found in AC System. Construction of AC electrical power transmission network is more complicated than DC system. Proper synchronizing is required before inter connecting two or more transmission lines together, synchronizing can totally be omitted in DC Transmission system.

Some other facts influence the electric energy generation, transmission and distribution costs: Transmission line lengths (short, medium, long), performance of transmission line, Sag overhead conductor, surge impedance loading (or SIL), types of overhead conductor, conductor resistance, thickness of insulation of power cable, Capacitor bank (or Reactive power compensation, types of capacitor bank), power system stability, power flowing network load analysis etc.

For the glossary of terms used here, read the references www.electric4u.com/electrical-power-transmission-system-and-network/

The decision factors influencing power generation cost:

The electricity tariff in India: At this time year 2016, the following information are related with the electricity tariff used in India.

Tariff refers to the amount of money the consumer has to pay for making the power available to them at their homes. Tariff system takes into account various factors to calculate the total cost of the electricity. Before understanding **tariff of electricity** [2] system in detail a slight overview of the entire power system structure and hierarchy in India would be very fruitful. The electrical power system mainly consists of generation, transmission and distribution. For generation of electrical power we have many PSUs and private owned generating stations (GS). The electrical transmission system is mainly carried out by central government body PGCIL (Power grid corporation of India limited). To facilitate this process, India is divided into 5 regions : Northern, Southern, Eastern, Western and North eastern region. Further within every state we have a SLDC (state load dispatch centre). The distribution system is carried out by many distribution companies (DISCOMS) and SEBs (State electricity board.).

Types: There are two tariff systems, one for the consumer which they pay to the DISCOMS and the other one is for the DISCOMS which they pay to the generating stations. Let us first discuss about the **tariff of electricity** for the consumer i.e the cost consumer pay to the DISCOMS. The total cost levied on the consumer is divided into 3 parts usually referred

as 3 part tariff system. Total cost of electrical energy = fixed cost + semi fixed cost + variable cost = (a + b*KW +c*KW-h) Rs. Here, a = fixed cost independent of the maximum demand and actually energy consumed. This cost takes into account the cost of land, labor, interest on capital cost, depreciation etc. b = constant which when multiplied by maximum KW demand gives the semi fixed cost. This takes into account the size of power plant as maximum demand determines the size of power plant. c = a constant which when multiplied by by actual energy consumed KW-h gives the running cost. This takes into account the cost of fuel consumed in producing power. Thus the total amount paid by the consumer depends on its maximum demand, actual energy consumed plus some constant sum of money. Now electrical energy is generally expressed in terms of unit, and 1 unit = 1 KW-hr (1 kw of power consumed for 1 hr).
IMPORTANT : All these costs are calculated on active power consumed. It is mandatory for the consumer to maintain a power factor of 0.8 or above otherwise penalty is levied on them depending on the deviation.

Let us now discuss about the tariff system existent in India for the DISCOMS. It is regulated by CERC (central electricity regulatory commission). This tariff system is called availability based tariff (ABT).

As its name suggest it is a tariff system which depends on the availability of power. It is a frequency based tariff mechanism which tends to make the power system more stable and reliable.

This tariff mechanism also has of 3 parts: Fixed charge + capacity charge + UI (Unscheduled interchange).

The fixed charge is same as that discussed above. The capacity charge is for making the power available to them and depends on the capacity of plant and the third one is UI. To understand the UI charges let us see the mechanism.

Mechanism of ABT (availability based tariff)

- The generating stations commit a day ahead about the schedule power which they can provide to the regional load dispatch centre (RLDC).
- The RLDC conveys this information to various SLDC (state load dispatch centre) which in turn collects the information from various state DISCOMS (distribution companies of India) about the load demand from various types of consumers.
- The SLDC sends load demand to RLDC. And now RLDC allocates the power accordingly to the various states.

If every things goes well, power demand is equal to power supplied and the system is stable and frequency is 50 Hz. But practically this rarely happens. One or more state overdraws or one or more GS under supplies. This led to deviation in frequency and system stability. If demand is more than supply frequency dips from normal and vice versa. UI charges are incentive provided or penalties imposed on the generating stations. If the frequency is less than 50 Hz, implies demand is more than supply, then the GS which supplies more power to the system than committed is given incentives. On the other hand, if frequency is above 50 Hz, implying supply is more than demand, incentives are provided to GS for backing up the generating power. Hence it tries to maintain the system stable.

Time of Day: Usually during day period the demand for power is very high and the supply remains the same. Consumers are discouraged to use excess power by making the cost high. Contrary to that during night time, demand is less compared to supply and hence consumers are encouraged to use power by providing it at cheaper rate. All these are done to make/keep the power system stable.

Heuristic Algorithms: A heuristic algorithm [1] is one that is designed to solve a problem in a faster and more efficient fashion than traditional methods by sacrificing optimality, accuracy, precision, or completeness for speed. Heuristic algorithms often times used to solve NP-complete problems, a class of decision problems. In these problems, there is no known efficient way to find a solution quickly and accurately although solutions can be verified when given. Heuristics can produce a solution individually or be used to provide a good baseline and are supplemented with optimization algorithms. Heuristic algorithms are most often employed when approximate solutions are sufficient and exact solutions are necessarily computationally expensive. Several authors have described heuristic algorithms for solving several constrained optimization problem. The list of their discussions are found in the internet and reference are also available there.

V. CONCLUSIONS

Heuristic decision on Electric Power tariff: The electric power utility tariff or unit cost is based on a set of functions such as topographical, hydrological, design flow of annual electricity generation costs. Implemented engineering design's budgetary investment cost, financial target and consumption cost economy aspects, net present value (NPV) obtained by calculating at a constant interest rate and the differences of all economic costs separately for each year, cost of dynamic unit electricity generated from gas and coal consumption. The dynamic unit electricity generation costs are determined by division of present value of cost with value of electric production.

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