A Hypothetical Study on Power System Operation and Control with Its Requisite Constitutes: A Review

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Abstract: **Ever since the 20th century, till the recent times all major power generating stations over the globe has chiefly trusted on A.C. distribution system as the almost efficient and economical option for the transmission of electrical power. After generation, transmission and distribution; the next aspect is making system to operate very effectively. In operation, often there is a problem of instability for which it is very necessary to provide control. For this, we need to study load flow analysis, power system optimization and control problem. In this paper, there is a brushup of above stated submodules which are summarized and discussed that do exist on the power system and will facilitate regarding the basic power flow conditions.**

Keywords: **Constraints, Power Flow Disciplines, Economic Load Dispatch, Optimum Power Flow, Automatic Voltage Regulation.**

1. INTRODUCTION

For operation of every system it is very much necessary to meet the practical requirements in power system and power system operating conditions which are termed as constraints. Being four in number, they are recognized as active power constraints, reactive power constraints, voltage magnitude constraints and load angle constraints.

1.1 Active power constraints:

Electrical power which is consumed in work done is called active power. This power consumed by load is called active power and generated by generator must be within the limits $P_{min} \leq P \leq P_{max}$.

1.1.1: If P>Pmax, in case of loads the excess power causes more currents thereby copper losses increases to a great extent beyond expected .This radiates excess amount of heat thereby the insulation is subjected to thermal breakdown so a dead short circuit is possible between conductor and the body of equipment. In case of generator the excess power requires excess combustion rates by which excess pressure and temperature inside the boiler increases if this pressure and temperature are not assured, the boiler may explode and then the outcomes will be very severe.

We summarize that the thermal consideration most of the time limits the power operated or generated never to be more than Pmax.

Every system to do work requires certain amount of energy for its internal activation .If this is supplied separately then the output equals input in most of the cases, the system will tap a part of input energy for its internal biasing which is defined as loss because this part will not appear as use full output so actually loss is not a loss but is the biasing energy supplied to a system . How much amount of this energy is required is to be marked as Pmin.

1.1.2: If P< Pmin, the system is not properly biased thereby the work done becomes improper which leads to inequilibrium conditions so system becomes unstable.

1.2 Reactive power constraints:

The amount of energy required for magnetization of core material is considered as reactive power. It's very essential in electromechanical energy systems because there is no direct correlation between electrical and mechanical energy. Normally, 85 percent of the load is functioning in electromechanical energy systems so concept of reactive power is very essential. In different context, we can state that reactive power is indexing agent of active power consumption. In case of dc supply systems, reactive power is not present because it is not necessary. DC power itself can produce electric and magnetic fields. In any load or generator, the reactive power generated or operated must be within the limits $Q_{min} \leq Q \leq Q_{max}$.

1.2.1: If $Q > Q_{max}$, excess reactive power increase the flux linkage with core thereby the effects of eddy currents also increases so core may get excessively heated which in turn causes thermal breakdown of the insulation which leads to dead short circuit.

1.2.2: If $Q < Q_{min}$, the magnetic path is insufficient thereby the input energy causes the system to be in oscillatory conditions which clearly shows unstable nature.

1.3 Voltage magnitude constraints:

Potential is the rate at which energy transfer takes place. Voltage magnitude at any bus must be within the limits $|V_{min}| \leq |V| \leq |V_{max}|$.

1.3.1: If $V > V_{max}$, at that bus excess voltage causes insulation breakdown which leads to physical breakdown so its restricted.

1.3.2: If $V < V_{min}$, the power transfer capacity decreases because power fundamentally depends on voltage level ($P = VI$).So, safe range of operating voltages are specified in range of 0.95-1.05 pu.

1.4 Load angle constraints:

Load angle is the angle of deformation between rotor and stator magnetic field under loading conditions .This angular deformation increases with increasing loading .The load angle must be within the operational limits of $\delta_{min} \leq \delta \leq \delta_{max}$.

1.4.1 If $\delta > \delta_{max}$, With increase in load angle, electrical power increase which causes inequilibrium so system gets unsound .Usually ,if the electrical power and the mechanical power are both proportional to each other then we can say the system is under equilibrium condition .Electrical power is depending upon the load angle as per the equation 1. $Pm = Pe = (E \times V \times \text{Sin}\delta)/X$ (1)

1.4.2 If $\delta < \delta_{min}$, power transfer capacity of the system decreases so normal range of load angle to be operated on the power system is in the range of 30° to 45°.

2. POWER FLOW CONDITIONS ON POWER SYSTEMS

Through this analysis we are going to determine basic conditions for flow of active and reactive power from source to the load .A synchronous motor is doubly excited machine. The field winding produces the necessary required flux and the armature current produces the required amount of torque. For better understanding of power flow from source to load side, figure 1 depicts a synchronous generator connected to load through an inductive impedance.

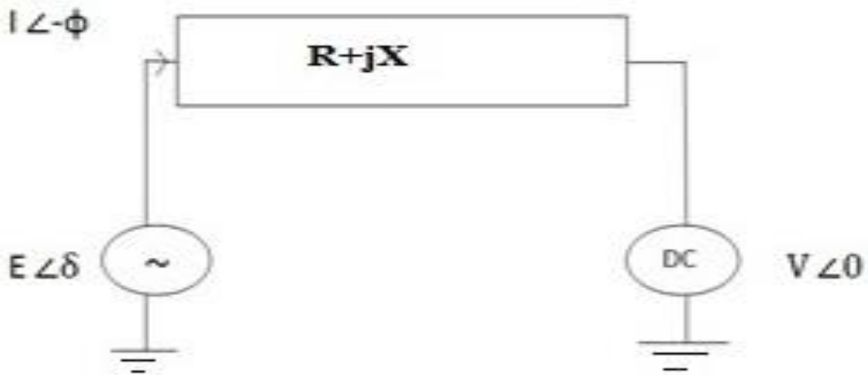

Figure 1: A basic block diagram representing a transmission line with load

The synchronous generator is extracting active power and reactive power .These two must be transferred to load for which the necessary conditions must be derived for which we use loop equations,

$E\angle\delta = V\angle 0 + (I\angle -\varphi)(R+jX)$ (2)

$E(\cos\delta + j\sin\delta) = V\angle 0 + (I\cos\varphi - jI\sin\varphi)(R+jX)$ (3)

$E\cos\delta = V\angle 0 + IR\cos\varphi + IX\sin\varphi$ (4)

$E\sin\delta = IX\cos\varphi + (-IR\sin\varphi)$ (5)

$E\cos\delta \cong E = V + IR\cos\varphi + IX\sin\varphi$ (6)

$E - V = (IR\cos\varphi + IX\sin\varphi)V/V$ (7)

$\Delta V = (RP + XQ)/V$ (8)

$E\sin\delta = (IX\cos\varphi - IR\sin\varphi)V/V$ (9)

$E\sin\delta = (PX - RQ)/V$ (10)

For large section , $R \cong 0$

From(8), $\Delta V = (XQ)/V$ (11)

$[Q \propto \Delta V]$ …***Conclusion 1***

From (10),

$P = (EV/X)\sin\delta$ (12)

$P \propto \sin\delta$, $[P \propto \delta]$ …***Conclusion 2***

For this ,we can say that transmission of reactive power depends upon the potential difference .The sending end should have the more potential than the receiving end as the reactive power transmission is not possible between two equipotential points .Transmission of active power depends upon δ. To transmit specific amount of active power from source to load, source must be kept at phase advancement of $\delta[\Delta\delta = \delta 1 - \delta 2]$.

3. LOAD FLOW ANALYSIS

It is an analysis on the power system to obtain total network solution under incremental loading conditions at present and in future .For the present considerations and upto future circumstances, to lay down equilibrium in performance of power system there is an analysis made to meet minute to minute requirements of the consumer .This analysis is in indigence for sufficient initial conditions where transient behavior of system to be observed.

For understanding of load flow problem hypothetically, we have considered 3 bus connected systems in figure 2.

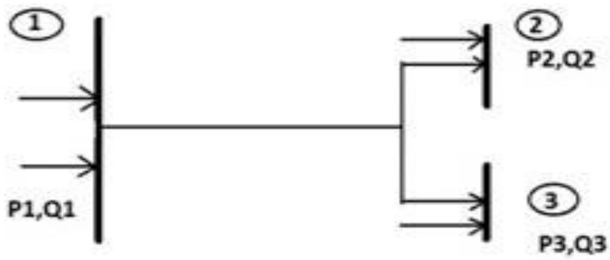

Figure 2: A representation of power system with 3 bus connected systems

Initially each bus is having some loading .At this point ,assume that system is under equilibrium condition .If at any bus for example at bus 3,load gets increased .If this incremental load demand is supplied by bus number 3,the equilibrium is established otherwise the additional load demand must be supplied by neighbouring buses 1 and 2.To resolve the thorough status of power flow its very necessary to calculate |V| and δ at each bus .Reckoning upon the relation of these values , any one of the following may be the condition for power flow.

Possible choices are:-

(i)ΔP , ΔQ from bus 1 ; $\delta 1 > \delta 3 > \delta 2$; $|V1| > |V3| > |V2|$

(ii)ΔP , ΔQ from bus 2 ; $\delta 2 > \delta 3 > \delta 1$; $|V2| > |V3| > |V1|$

(iii)ΔP from 1 ; ΔQ from 2 ; $\delta 1 > \delta 3 > \delta 2$; $|V2| > |V3| > |V1|$

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(iv)ΔP from 2 ; ΔQ from 1 ; δ2>δ3>δ1 ; |V1|>|V3|>|V2|

(v)A part ΔP , ΔQ from 1 and remaining from bus number 2 ; δ1>δ2>δ3 ; |V1|>|V2|>|V3|

At any bus if |V|>1pu, at this bus reactive power is available similarly at any bus δ>0, active power is available.

4. POWER FLOW OPTIMIZATION

Optimization is a theory in which maximization of profit or gain or minimization of loss as expenditure is continuously monitored .This maximization or minimization must be considered with certain practical conditions which are considered as constraints .Every problem of optimization is framed with two equations;

4.1 Objective function:

Minimize $Ct={}^{Ng}{}_{i}Fi(Pgi)$

Here ,Ct is the net cost of generation ,Ng is the number of generating units, Fi(Pgi) is the cost function and Pgi is the power output of unit i.

4.2 Constraints:

They are of 2 types-

[8]Inequality constraints : $Pgi^{min} \leq Pgi \leq Pgi^{max}$;

Equality constraints : ${}^{Ng}{}_{i}Pgi=P_L+P_D$

Here, P_D is total demand and P_L is losses.

The optimization theory applicable to power system can be considered as power system optimization which is further considered in two ways;

4.3 Economic load dispatch (ELD):

4.4 Optimal power flow (OPF):

Economic load dispatch unremarkably concents with a single generator .The objective in this case is that the total power generated must be at minimal cost and at the same time it should satisfy demand plus loss. Under incremental loading conditions the load flow will give several solutions .Out of them one solution can be found as best in economical sense thereby economic load dispatch in short form can be defined as solution of several load flows .It has some disadvantages like generating units and loads are not all connected to the same bus and may result in unacceptable flows or voltages in the network. Now suppose some of the load is transferred from the unit with higher incremental cost to the unit with lower incremental cost. Reducing the load on the unit with higher incremental cost will result in greater reduction of cost than the increase in cost for adding the same amount of load to the unit with lower incremental cost. The reassign of load from one to other can be continued with a reduction of total cost until the incremental costs of the two units are equal. This is explained through the figure 3.

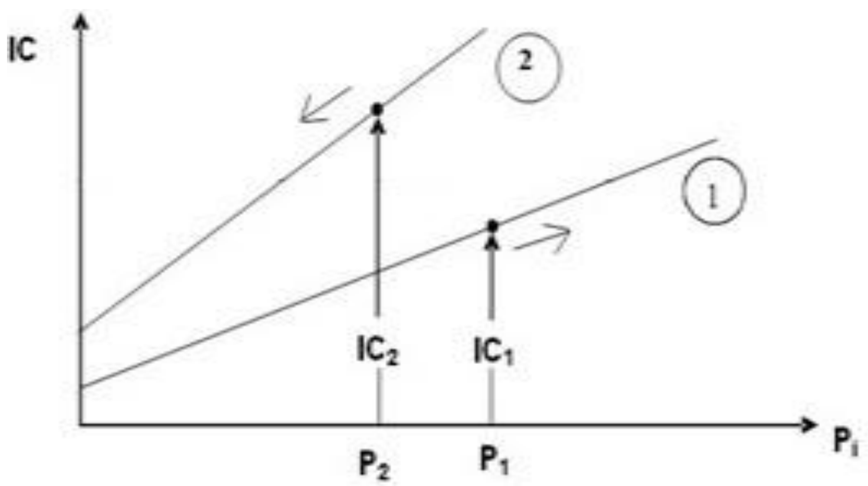

Figure 3: A basic explanation of economic load dispatch using cost curves of two different generator sets.

Initially,IC2>IC1.Decrease the power output in unit 2 by ΔP and increase the output power in unit 1 by ΔP .Now, IC2 ΔP>IC1 ΔP .Thus ,there will be more decrease in cost and less increase in cost thereby bringing the total cost lesser .This change can be continued until IC1=IC2 at which the total cost will be least .More or less ,a decrease in P2 and increment in P1 will result in IC1>IC2 calling for decrease in P1 and increase in P2 until IC1=IC2.So,the net cost is expected to be lowest degree when the incremental costs are equal.

Optimal power flow is a numerical investigation of the stream of electric power in an interconnected system. A power flow study usually uses easy notation such as a one-line diagram and per-unit system while at the same time focussing on various aspects of AC power parametric quantities such as voltage magnitudes, voltage angles, real power and reactive power. It dissects the power systems in conventional steady-state cognitive execution. It projects to maintain the power system operation agreeing the state cost, planning or reliability criteria without violating the system and equipment operating limits. It is reckoned as one of the most intensely used tools when there arises the necessity of network optimization, voltage control, state estimation and market studies.

It has control variables as,

i. Active power output of the generating units

ii. Voltage at the generating units

iii. Position of the transformer taps

iv. Position of the phase shifter (quad booster) taps

v. Status of the switched capacitors and reactors

vi. Control of power electronics (HVDC, FACTS)

vii. Amount of load disconnected

Power plants comprises of various generating units which are constructed utilizing huge amount of money. Fuel cost, staff salary and maintenance cost are some of the constituents of operating cost. Fuel cost is the crucial portion of operating cost and it can be checked.

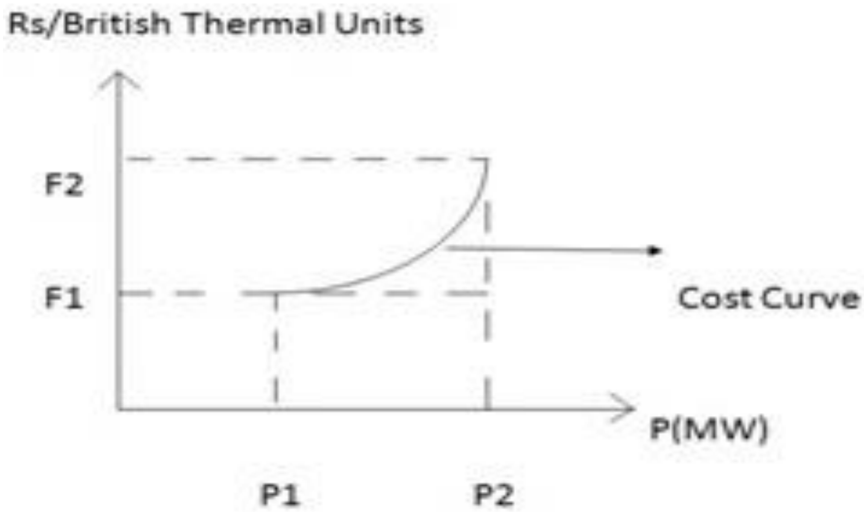

Figure 4: Illustration of incremental costs in case of two separate generating units.

The generator initially generating the power of P1 for which the corresponding cost is F1 and if generation is increased to P2, correspondingly the cost curve increase to F2.Under these circumstances the incremental production cost

$$Ipc=(F2-F1)/(P2-P1)=\Delta F/\Delta P \quad (13)$$

If these deviations are small, it can be approximated as $\Delta F/\Delta P \cong dF/dP$

So as a result of this, dF/dP can be treated as Ipc. The incremental cost usually includes incremental cost of fuel , maintenance and lubrication ,wages and incentives to the operating staff .Out of all these costs ,the fuel cost is more than 95% thereby incremental production cost can be approximated as incremental fuel cost i.e. Ipc≅Ifc. In case of hydroelectrical power plants ,the fuel cost is practically zero thereby it can be stated that the problem of economic load dispatch does not belongs to or has no consent to hydroelectric power plants.

5. CONTROL PROBLEM

The power system is said to be operating under normal operating conditions as long as its operational quantities P ,Q ,|V| ,δ are amongst their limits of working .If by chance among them ,any one of the operating quantity comes out of the operational range ,system's normalcy is disturbed .To bring back the system to normal operating condition ,certain control force must be applied.

The voltage at the sending end or generation end are controlled with automatic voltage regulator and automatic excitation controllers. This control is considered as internal control where as the voltage at the load or receiving side can be controlled with reactive power regulation which can be also termed as reactive power compensation or external control .While seeking the load demand at the generating station, automatic load frequency control comes into handy which are in the category of mechanical interfacing controllers. Figure 5 shows basic represent able and understandable form of automatic voltage regulator (AVR);

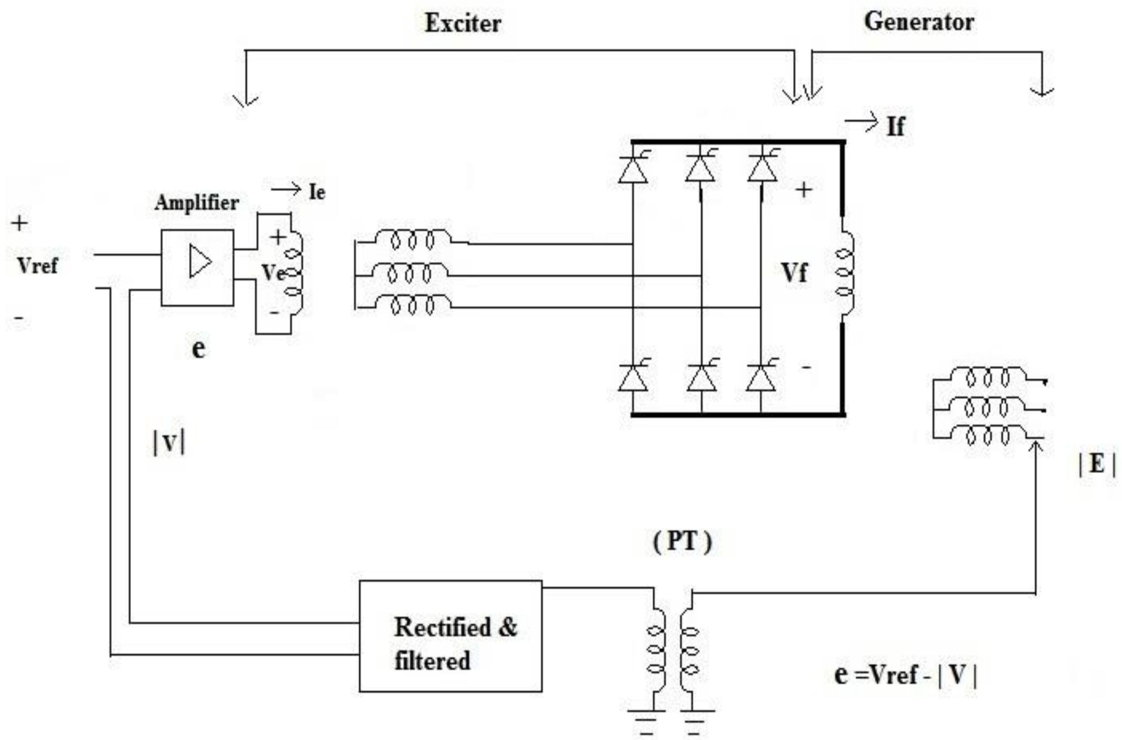

Figure 5: An internal block diagram representing Automatic voltage Regulator

It has a closed loop control to regulate the terminal voltage of the generator. There is a fundamental assumption that the generator is under no load thereby the terminal voltage is equal to induced emf . The control action can be realized in three ways as under;

5.1: If e=0,during this condition the generator is generating rated voltage thereby no control action is required.

5.2: If e>0,the generator is developing under voltage .The control action follows as the positive error is amplified in the amplifier which strengthens the excitation for exciter field thereby exciter output increases .This results in applying more voltage to the field of generator due to which the field gates strengthened and consequently output voltage gets increased.

5.3: If e<0,the generator is developing over voltage and it is regulated as the negative error is amplified which weakens the exciter field thereby the exciter output decreases which further decrease the generator field as result it weakens and output voltage is suppressed.

In this way, the regulation of the voltage is possible within one second.

6. CONCLUSION

India's electricity sector faces some problems which are system of cross-subsidization, residential building sector, key execution challenges ,deficit of fuel, poor pipeline linking and infrastructure ,stealing of power , losses in the connector systems as well as in the service connection, shortage of clean and authentic energy resources, insufficient coal-fired, oil-fired and natural gas-fired thermal power plants etc. Power System Automatic Controls are installed to control energy costs and enable us to increase power reliability at our facility, we have a vast array of power system control undergoing .They provide reflexive survival of useable utility or generator sources to maintain service continuity to connected loads , control peak demand levels or ensure service continuity to critical load or operate breakers in accordance with user specified sequences and time delays , stabilize critical power systems to the greatest extent possible by monitoring frequency and power sources from utility .So, a proper factual information with realistic knowledge is required regarding power system operation and control.

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