FREQUENCY REGULATION BY FREE GOVERNOR MODE OF OPERATION IN POWER STATIONS

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Abstract - **It is necessary for the Power load operators and regulators to manage distribution services efficiently to maintain reliability of the power system. Frequency regulation is one of the distribution services to be supplied by the electricity market participants. The only way to regulate frequency is to maintain the balance between demand and supply in real time. In India, it is achieved through a regulatory approach. In this Paper, an investigation is made on Free Governor Mode of Operation to demonstrate Frequency Regulation by adopting Free Governor Mode of Operation. Simulation is a powerful technique used to predict the performance or analyze the behaviour of any closed loop control system. It is also used to tune the controller gains or to design a control system. Development of mathematical model is the first step in the simulation study. Matlab and Simulink of Mathworks Inc. are widely used in the academic and industrial world. A simple model of a speed governing system of the steam turbine is taken for illustrating the dynamic simulation.**

Keywords - **FGMO, frequency regulation, speed governor**

I. INTRODUCTION

The developing countries have sustained power shortage problems compared to developed countries for many reasons, mostly financial in nature. The developed countries have to address the power deficient areas occasionally. The research literature on operation of generation deficient power system is scanty. The problems faced by developing countries are fundamentally of different nature. The developing countries have to search for alternatives to suit their requirement. The deficient systems have typical features like frequency deviations, abrupt arising of deficiencies of power, low voltages and lack of coordination among the constituents under a region due to indiscipline. In India speed governors have been prevented from responding by the utilities, with dead band configuring from 47.5 Hz to 51.5 Hz. Emergency unloading of a unit is available only when frequency reaches 51.5 Hz. As a consequence excursions in frequency are common up to 1 Hz in a time block of 15 minutes. For the sake of better control efforts are being made to enable the frequency governors to respond to entire range of frequency. This is called free governor mode of operation (FGMO)

II. FREE GOVERNOR MODE OF OPERATION

The Governor is an important controller in the power plant as it regulates the turbine speed, power and participates in the grid frequency regulation. It is the main operator interface
a) To start the turbine from still condition,
b) To vary the load on the turbo-generator when it is on bars (Synchronized) and
c) To protect the turbine from damages in the cases of any unsafe operating conditions.
The steady state and dynamic response behavior of the turbine is influenced mainly by the characteristics of the Governing system.

2.1 Need for the Governing System

The load on the turbo-generator does not remain constant but vary as per the consumer (Grid) demand requirements. The presence of a perpetual mismatch between the generation and the demand in a larger network results into variations in frequency and necessitates a continuous adjustment of generation at the turbo-generators. If not, the speed / frequency will be oscillating which is an indication of poor power quality. A state of unchanging system frequency and zero acceleration indicates that the generation meets the system demand.
The governing system provides for this regulation / adjustment, when the turbo-generator is on bars, by controlling the steam inflow to the turbine. The regulation is envisaged by various control logics and by operating the control valves in the turbine. Stop valves provided in the governing system protect the turbine in case of unsafe conditions by blocking the steam flow into the turbine.

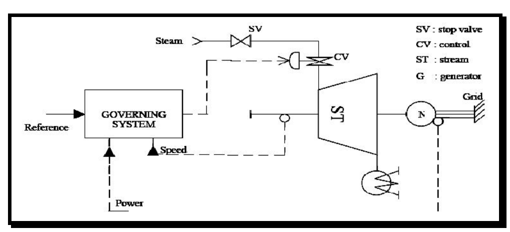

Figure-2.1 Power System Components

2.2 How Governing System Works

The Speed / Power of the steam turbine are controlled by varying the steam flow to the turbine, which in turn is

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varied by manipulating the control valve lift. The control valve is operated by a servomotor driven by a hydraulic signal. The governing system is a closed loop control system which processes speed error, power error and pressure error to operate the steam control valves.

In a Mechanical Hydraulic governing system, mechanical speed sensors viz., fly balls and hydraulic speed transmitters to sense the speed and hydraulic servomotors and hydraulic amplifiers to drive the final control elements (i.e.) control valves are employed.

In an Electro Hydraulic governing system, Halls probe or pulse generators to sense the speed, various logics and control circuits to process the error and electro hydraulic converters / amplifiers and a hydraulic actuator to drive the control valves are used.

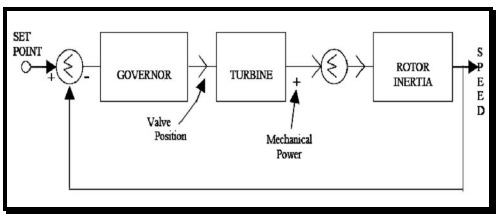


Figure-2.2 Basic Elements of a Governing System

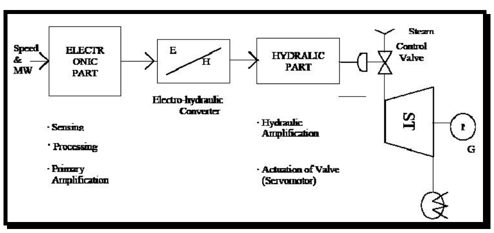


Figure-2.3 Electro – Hydraulic Governor Scheme

2.3 Droop or Regulation:

Droop can be defined as the percentage change in speed for a change in load. Whenever there is a mismatch in power, speed changes. As mentioned earlier, the governing system senses this speed change and adjusts valve opening which in turn changes power output. This action stops once the power mismatch is made zero. But the speed error remains. What should be the change in power output for a change in speed is decided by the 'regulation'. If 4% change in speed causes 100% change in power output, then the regulation is said to be 4 % (in per unit 0.04).

The regulation can be expressed in the form of power – frequency characteristic as shown in Figure-2.4. At 100 % load the generation is also 100 %, frequency (or speed) is also 100%. When load reduces frequency increases, as generation remains the same. When load reduces by 50 %, frequency increases by 2 %, in the characteristic shown. When load reduces by 100 %, frequency increases by 4 %. In other words 4 % rise in frequency should reduce power generation by 100 %. This 4 % is called 'droop' of 4 %. The characteristic is of 'drooping' type. Droop or regulation is an important parameter in the frequency regulation. In thermal power plants droop value is generally 4 % to 5 %.

The sensitivity of the governor for a given change in load varies inversely with the percentage droop. The droop of the hydro turbines will be around 2 to 3% where as that of the steam turbines will be 4 to 5%

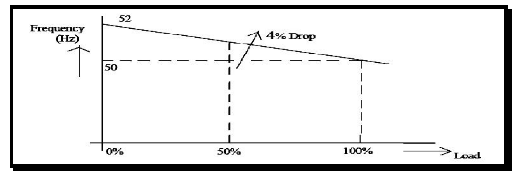


Figure-2.4 Droop Characteristics of a Governor

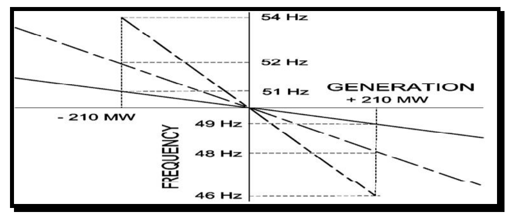


Figure-2.5 Droop Characteristics

2.4 Operation of the Governor

The governor operation of a turbo-generator can be explained using the following diagram.

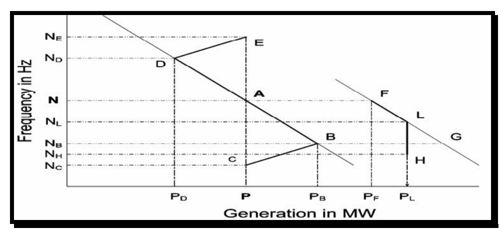


Figure-2.6 Governing Operation - Primary and Secondary Response

Consider that a unit is delivering a power 'P' at a frequency of 'N' Hz denoted by the operating point 'A'. Let us assume that due to some reasons, the frequency dips to 'N_B'. Now because of the droop characteristics of the governor, the operating point of the generator will move to 'B' and the generation will increase from 'P' to 'P_B'. This response of the governor is called the primary response as discussed earlier. The operator subsequently will try to restore the generation to the original value 'P', the new operating point of the set will be 'C' and the frequency will drop further to 'N_C'. This response of the operator is called the secondary response. A secondary response of 1% of the capacity per minute of the set is prescribed by the Load Despatch Center. If no corrective action has been initiated by the Grid Managers by way of tripping out excess demand, then the frequency will settle at 'N_C'.

If the generator is at a higher load denoted by the point ‘F’ and its load limiter is set at ‘P_L’, the rise in generation along the droop line will be limited to only ‘P_L’ and the operating point will only be ‘L’, whatever be the dip in frequency. As the generation does not compensate the additional load, the frequency will further drop to N_H. The load limiter action is a classic example of restricting the FGMO.

On the other hand, if any of the feeders tripped, then the frequency will rise to ‘N_D’ and the primary response governing action will reduce the load to ‘P_D’. The new operating point of the set now will be D. If the frequency is within the operating range, the operator will bring the unit to the point E and the frequency will further rise to ‘N_E’. The effect of further increasing the generation under high frequency conditions will only raise the frequency and several procedures like Availability Based Tariff, Guidelines for Unscheduled Interchanges etc., have been laid down by the regulatory commissions in this regard.

2.5 Frequency Control by FGMO

Frequency control requires provision of primary regulation and supplementary regulation as basic requirement. Primary regulation is provided through speed governors which respond to frequency changes by varying turbine outputs. Keeping governors free to operate in the entire frequency range enables smooth control of frequency fluctuations as well as security against grid disturbances. In India, due to wide range of frequency fluctuations, speed governors were prevented from responding by the utilities with dead band configuring from47.5 Hz to 51.50 Hz with emergency unloading available only when frequency goes above 51.50 Hz. Efforts have been made to enable speed governors responding in the entire frequency range which has come to be known as free governor mode of operation (FGMO).

The introduction of Availability Based Tariff (ABT) though stabilized frequency in a narrower band, the rapid fluctuations continued to occur with frequency excursions of 0.5 Hz over a period of 10 minutes and frequency shooting up to 51 Hz and above when sudden bulk load shedding or maximization of generation takes place before evening peak hours. Dipping of frequency takes place during onset of peak loads or unit tripping. Such frequency fluctuations during normal operation in the grid leads to complex counter actions by the control center operators at regional and state level. Further, the fluctuating frequency even in an interval of 15 minutes does not give out clear signals to operators to plan generation changes, load shedding or to draw/inject Unscheduled Interchange (UI) power responding to signals generated by the commercial mechanism (ABT). Under ABT mechanism, frequency is allowed to float between 49 Hz and 50.5 Hz and drawing / injection of UI power is permitted in this frequency range. However, fluctuating frequency masks the frequency based ABT signals.

In most of the grid disturbances over the last few years, Southern regional grid used to split into four parts in the post fault scenario due to tripping of various lines in the South-West-East-North regional corridor due to power swings. The Eastern part used to have surplus of generation over load resulting in frequency shooting up to 52 Hz and above leading to tripping of several generating units on high frequency. Another pattern observed was isolation of Tamilnadu grid from the Southern part followed by severe frequency decay and under frequency load shedding through df/dt relays which brings up frequency above 52 Hz once again leading to tripping of some generators on high frequency. After inter-connecting with WR and ER grids also, similar pattern continued in the post fault scenario with tripping of generating units on high frequency.

With implementation of free governor mode of operation on generating units, tripping on high frequency could be avoided during grid disturbances as load generation balance can be attained at a faster rate. Even during normal operation, tripping of a 500 MW unit leads to frequency drop of around one hertz due to low system stiffness as the frequency has to be controlled only by load damping effect in the first 20-seconds after the tripping. FGMO would increase system stiffness significantly and avoid large frequency dips in the event of unit tripping.

For example, 10000MW generation on FGMO with 5% droop in Central grid would increase system stiffness by 2000 MW per hertz. Consider a system of 10000 MW at 50 Hz. Assume a droop of 5% for the entire grid system.

Case-1

If due to some reasons, a generator of 200 MW trips and no unit is under FGMO, the dip in frequency will be
50 X 200/10000 = 1 Hz.

Case-2

If FGMO is available only for 5000 MW due to disabling of the governing action in other sets, then the frequency drop will be
50 X (200/5000) X 5/100 = 0.1 Hz.

Case-3

If FGMO is available for all the 10000 MW, the dip in frequency will be
50 X (200/10000) X 5/100 = 0.05 Hz only.

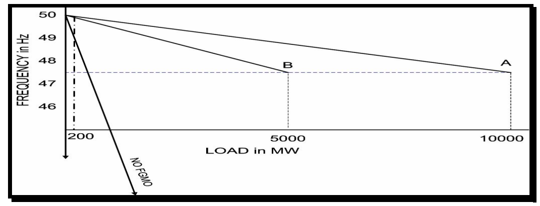


Figure-2.7 Free Governor Mode of Operation

From the above examples, it is clear that, more the constituent units are under FGMO more is the stability of the Grid. In Southern Region, by operating maximum possible number of units with their governors in free mode, by automatic under frequency load shedding and by way of using special protection schemes, etc. the frequency stability is being ensured. If the provisions available in the governor and control circuits viz., load limiter, dead band, switching off the governor etc., when employed will curtail the FGMO and it will lead to higher swings in frequency, instability of the grid and even subsequent pull out of the grid.

Therefore, Free Governor Mode of Operation (FGMO) is the quickest way in Emergency High Frequency Control, particularly during High Frequency regime. It is now clear that, more the constituent units are under FGMO more is the stability of the Grid.

III. DISCUSSION ON SIMULATION OF SPEED GOVERNOR

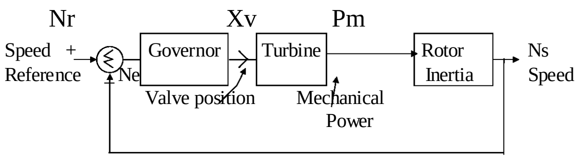


Figure-3.1 Speed Governing System Functional Block Diagram

Each of the blocks in Figure 3.1 can be represented by a first order transfer function as shown below:

[Xv / Ne] = [Kg / (1 + Tg s)] (1)

[Pm / Xv] = [1/ (1 + Tt s)] (2)

[Ns / Pm] = [1/ (Ta) s] (3)

Ne= Nr - Ns (4)

Where Nr, Ns, Ne = machine speed reference, actual speed and speed error respectively

Xv = governor valve opening

Pm = mechanical power output (all in per unit)

Tg, Tt are the time constants of governor and turbine respectively in seconds

Ta = rotor acceleration time in sec.

Kg = Governor Gain

s = Laplace operator = [d/dt]

The above transfer functions can be converted into differential equations by substituting for s = (d/dt).

Letting yn(1) = Xv

yn(2) = Pm

yn(3) = Ns

and dyn = d/dt (yn) , the above block diagram is converted into set of first order differential equations as shown below:

```
Ne = Nr- yn(3);
dyn(1)= (Kg/Tg)*Ne - (1/Tg)*yn(1);
dyn(2) =(1/Tt)*yn(1) - (1/Tt)*yn(2);
dyn(3)=(1/Ta)*yn(2);
```

Typical values are:

Nr = 0.01 (corresponds to a step input from 0 to 0.01 p.u change in speed reference);

Tg = 0.1; Tt = 0.5; Kg = 25 Ta=9.9;

To simulate the above equations in Matlab a function called **ode23** is used. This refers to 'ordinary differential equation' (ODE) solution using Runge Kutta second and third order methods.

Initially a function file called **govsys.m** is to be created using Matlab editor. It is given below:

```
function dyn = govsys(t,yn)
nr = 0.01; % step change in speed ref
Tg = 0.1; Tt = 0.5; Kg = 25; Ta=9.9;
ne=nr- yn(3);
dyn(1)= (Kg/Tg)*ne - (1/Tg)*yn(1);
dyn(2) =(1/Tt)*yn(1) - (1/Tt)*yn(2);
dyn(3)=(1/Ta)*yn(2);
dyn=[dyn(1);dyn(2);dyn(3)];
```

All the differential equations are given in the function block. When invoked, this function **govsys** returns dyn ( ) .

The following statements are typed in the Matlab command window:

```
>> tspan = [0 10],yn0=[0 0 0];
>> [t, yn] = ode23 (@govsys, tspan, yn0);
>> plot (t,yn)
```

tspan: indicates time interval from 0 to 10 seconds.

yn0 = gives initial values of state variables.

In the statement [t, yn] = ode23(@govsys,tspan,yn0) , left hand side is the output values 'time' versus states namely yn(1), yn(2)_, yn(3).

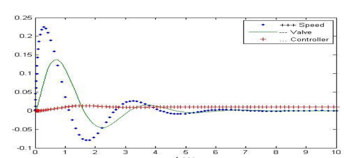
Right hand side the name of the function file is given as @govsys (already saved as govsys.m in the same work space). Tspan and yn0 are also given.

Once the command is given solution of differential equations using Runge Kutta second and third order methods takes place and data are stored. The plot can be made of these variables by invoking **plot(t,yn)** command.

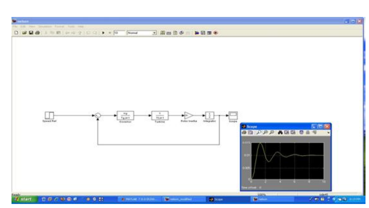
The axis names, titles, legend etc., can be included by typing a command like:

```
>> plot (t,yn(:,1),'.',t,yn(:,2),'-',t,yn(:,3),'+'),...
legend('+++ Speed', '--- Valve','... Controller'),...
xlabel(' t sec')
```

IV. SIMULATION RESULTS



Result-1 (In MATLAB Environment)



Result-2 (In SIMULINK Environment)

V. CONCLUSION

Frequency instability occurs due to the mismatch between load and generation caused by tripping of generators and / or rejection of loads giving rise to a sudden change in frequency. When the turbo-generator is on bars, the governor of the turbine, if its wings are not clipped, responds to a change in frequency by varying the control valve lift and so varying the generation. The change in generation depends on the droop characteristics of the governor. All the turbo-generators in the grid participating in the governing action tend to annul the change in frequency by increasing or decreasing the generation. This mode of governor operation compensates the change in frequency by change in generation and is called Free Governor Mode of Operation (FGMO). If the provisions available in the governor and control circuits viz., load limiter, dead band, switching off the governor etc., are employed to curtail the FGMO, it will lead to higher swings in frequency, instability of the grid and subsequent pull out even. It is clear that, more the constituent units are under FGMO more is the stability of the Grid. In Southern Region, by operating maximum possible number of units with their governors in free mode, by automatic under frequency load shedding and by way of using special protection schemes, etc. the frequency stability is being ensured.

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