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A New Control Design for Power Quality Imporvement in Hydro Power Plant

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ABSTRACT

Power generation is done mainly by the non-renewable energy sources. Due to this, environmental problem becomes the hindrance to every country. More over with the usage of the non-renewable sources, there is a problem as these sources get extinct with the continuous usage. So, power grids are to be collaborated with both renewable and non-renewable sources to avoid these problems. This penetration of the power grid with renewable sources is not so easy. The problems like reduced inertia of the power system, the stability of the frequency stability, and the weak grid characteristics of the output system may limit the delivery capacity of renewable energy base. The motor-generator pair (MGP) system can deal with these problems efficiently, by using proposed frequency control methodology i.e., phase difference method. The feasibility of the frequency feedback control method is to be analyzed by the MATLAB simulation.

KEYWORDS: *Power plants, hydro-electric power systems, convectional PI controller, fuzzy logic PI controller*

I. INTRODUCTION

The production, generation and distribution of power have been increasing day by day due to the increase in demand for the electricity. Mostly, the generation of the electrical power is done with fossil fuels i.e., mainly with coal. The major problem that occurs due to the usage of coal is environmental issue. This develops a new era in the generation of electricity i.e., the combination of renewable sources with the non-renewable sources [1]. The production of power through hydro power plants exists already, but the combination of the grid with photo voltaic cells, wind mills etc.., has been developing. Many research methods have been put forth for such an implementation.

The usage of wind, solar and other renewable sources with the grid is not such an easy task. The sources used above as random fluctuations which make the power system to become unstable. The load of the power system is also not constant all the time. High penetration of power systems solve the problem of source load fluctuations, otherwise system cannot run stably. So, technologies for the generation of power with renewable sources are improving to carry all the power generation only with renewable energy sources [2-3] without any load fluctuations.

At the source, wind power and photovoltaic power generation change over time, but the superposition of different regions of wind power and photovoltaic power generation throughout the day is basically stable. When all the days are combined, PV and Wind farm compensate each other [4]. At the load side, the load of one region is not stable, but the total power around the world is basically stable [5-6]. The load is not constant all throughout the day. During morning and evening times the demand is more when compared to noon hours. In the similar way, the demand is not same in residential areas when compared to industrial areas. The power that is to be generated should satisfy all the load demands in every area. So, the power generation estimated is constant.

It can be seen that the random fluctuation of generation of renewable energy can be suppressed by connecting the global power grid together. To achieve this goal, the global energy Internet, or the global power grid, is a necessary architecture. The global energy Interconnection (GEI) can connect large-scale energy bases across the continents, especially the "Arctic-Equator" wind light power generation, which can provide enough power [7]. GEI has received a lot of support, especially the support of politicians [8].

Although GEI can suppress the fluctuation of renewable power, but, there are still other technical problems need to be resolved in high-penetration power grid:

1) In the power-electronized power system, a large number of synchronous motors are replaced by power electronic equipment, the inertia of the system is greatly reduced and the frequency stability of the power system is challenged.

2) All kinds of faults in the power grid can affect the renewable energy farm, and the current solution is not perfect.

3) The weak support terminal grid will limit the power export that the renewable energy farm at remote-barren land with thousands of kilometers long transmission lines.

Many solutions have been proposed to resolve the challenges mentioned above, especially the stable operation of wind farms. The existing means of improvement are mostly starting from the control of the wind turbine, such as improving the converter integration characteristics, the various angles of the blade and so on. However, the complexity of the wind turbines control system will increase significantly if the faults were responded by wind turbines control system itself, and its implementation capacity is also limited; if virtual synchronous machine (VSG) was used to increase inertia, the energy storage is necessary to support the power that VSG need, which will increase the wind farm investment costs. In the event of grid faults, VSG has a limited effect on protecting wind turbines [9-16]. Now, the winds turbines are asked to optimize the power generation, support frequency stability, low voltage ride-through and suppress sub-synchronous oscillation and so on. These requests are not only too strict, and may not be able to achieve in the same time.

The Paper stated here can regulate the frequency stability problems by using phase difference method. Rotor angle stability can also be used for the frequency stability problem by using Motor Generator Pair system. It is possible to control the power transmission by collecting the grid frequency as the output voltage frequency reference of the frequency converter and then directly changing the phase difference as stated in the mathematical modeling. The controller used to regulate the process is done by convectional PI controller. But, the convectional PI controller has disadvantages due to its oscillatory behavior in transient period. To reduce the settling time, fuzzy logic controller is inaugurated into system and results are compared for both convectional PI controller and fuzzy logic controller.

II. MATHEMATICAL MODELLING

ANALYSIS FOR HYDRO ELECTRIC POWER PLANT:

The velocity of the water in the penstock and turbine mechanical power is given by

$U=K_uG\sqrt{H}$ (1)

$P_m=K_pHU$ (2)

Ku and Kp are constants of proportionality.

Tw called as water time constant or water starting time and its value varies between 1-4 s. Tw is 1 s for low head, 2.2 s for medium head and 4 s for high head.

$$\frac{Pm}{G}=\frac{1-Tw}{1+0.5TwS}$$

Here linear turbine model is considered. Surge effects and other disturbances in hydro power plant has been neglected.

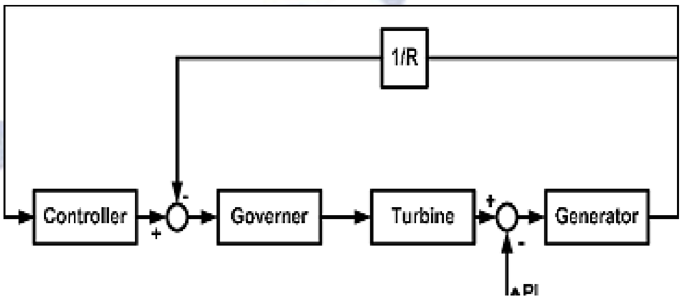

Fig.1 Block diagram of hydroelectric power plant

ANALYSIS OF THE MOTOR GENERATOR PAIR

The MGP system consists of two synchronous machines. For each individual machine, the basic model is identical except for specification of the generator and the motor. Therefore, the generator model is used to analyze the MGP system model.

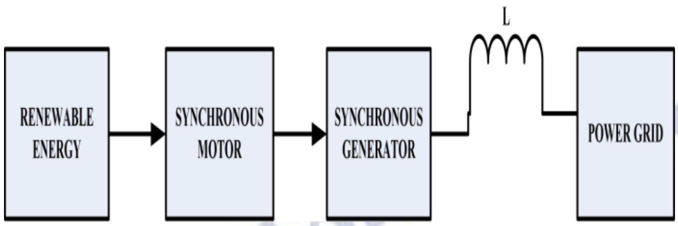

Fig.2 Block Diagram of Motor Generator Pair

U_a, U_b, U_c, U_f: stator voltage(3 phases), field voltage

i_a, i_b, i_c: stator current (3 phases), field winding current

i_{Kd}, i_{Kq}: d-axis and q-axis damper winding current

i_{fD}: field current

$\Psi_a, \Psi_b, \Psi_c, \Psi_f$: stator winding flux(3 phases), field winding flux

θ: rotor position

From the basic voltage equations and flux linkage equations, we get

$$\begin{pmatrix} U_a \\ U_b \\ U_c \\ U_f \\ U_D \\ U_Q \end{pmatrix} = \begin{pmatrix} r_s & 0 & 0 & 0 & 0 & 0 \\ 0 & r_s & 0 & 0 & 0 & 0 \\ 0 & 0 & r_s & 0 & 0 & 0 \\ 0 & 0 & 0 & r_s & 0 & 0 \\ 0 & 0 & 0 & 0 & r_s & 0 \\ 0 & 0 & 0 & 0 & 0 & r_s \end{pmatrix} \begin{pmatrix} -i_a \\ -i_b \\ -i_c \\ i_f \\ i_D \\ i_Q \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Psi_a \\ \Psi_b \\ \Psi_c \\ \Psi_f \\ \Psi_D \\ \Psi_Q \end{pmatrix}$$

When the mutual inductance is considered, then

$$\begin{pmatrix} \Psi_a \\ \Psi_b \\ \Psi_c \\ \Psi_f \\ \Psi_D \\ \Psi_Q \end{pmatrix} = \begin{pmatrix} l_{aa} & m_{ab} & m_{ac} & m_{af} & m_{aD} & m_{aQ} \\ m_{ba} & l_{bb} & m_{bc} & m_{bf} & m_{bD} & m_{bQ} \\ m_{ca} & m_{cb} & l_{cc} & m_{cf} & m_{cD} & m_{cQ} \\ m_{fa} & m_{fb} & m_{fc} & l_{ff} & m_{fD} & m_{fQ} \\ m_{Da} & m_{Db} & m_{Dc} & m_{Df} & l_{DD} & m_{DQ} \\ m_{Qa} & m_{Qb} & m_{Qc} & m_{Qf} & m_{QD} & l_{QQ} \end{pmatrix} \begin{pmatrix} -i_a \\ -i_b \\ -i_c \\ i_f \\ i_D \\ i_Q \end{pmatrix}$$

By parks transformation method, we obtain

$$\begin{pmatrix} U_d \\ U_q \\ U_0 \end{pmatrix} = C \begin{pmatrix} U_a \\ U_b \\ U_c \end{pmatrix}$$

Where,

$$C = \begin{pmatrix} \cos\theta & \cos(\theta - \frac{2\Pi}{3}) & \cos(\theta + \frac{2\Pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\Pi}{3}) & -\sin(\theta + \frac{2\Pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

Now, the voltage and flux equations of dq axis is given by

$$\begin{pmatrix} U_d \\ U_q \\ U_o \\ U_{fd} \\ U_{Dd} \\ U_{Qd} \end{pmatrix} = \begin{pmatrix} r_s & 0 & 0 & 0 & 0 & 0 \\ 0 & r_s & 0 & 0 & 0 & 0 \\ 0 & 0 & r_s & 0 & 0 & 0 \\ 0 & 0 & 0 & r_s & 0 & 0 \\ 0 & 0 & 0 & 0 & r_s & 0 \\ 0 & 0 & 0 & 0 & 0 & r_s \end{pmatrix} \begin{pmatrix} -i_a \\ -i_b \\ -i_c \\ i_{fd} \\ i_{Dd} \\ i_{Qd} \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Psi_a \\ \Psi_b \\ \Psi_c \\ \Psi_{fd} \\ \Psi_{Dd} \\ \Psi_{Qd} \end{pmatrix} + \begin{pmatrix} -\omega\Psi_q \\ \omega\Psi_d \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

Here, $U_o = U_{Dd} = U_{Qd} = 0$

As the generator and motor are two forms of synchronous machine, the equivalent motor can be obtained by changing the current reference direction

When the motor and generator pair is running steadily, then

$T_{eM} = -T_{eG}$

When the torque acting on the rotor is unbalanced then, the unbalanced torque

$\Delta T = T_m - T_e$

The rotor speed changes the unbalanced torque equation. The equation of rotor motion

$$J\frac{\omega_m}{dt} = T_m - T_e$$

When we use inertia time constant

$$\frac{2H}{\omega_0^2} S_B \frac{d\omega_m}{dt} = T_m - T_e$$

The motor power angle can be expressed as

$\delta = \omega_m t - \omega_0 t + \delta_0$

By solving the above equations, we get

$$\frac{d\delta_M}{dt} = \frac{d\delta_G}{dt} = \omega_0 \Delta\omega_m$$

Thus, the motor and generator pair mechanical modellingis given as following block diagram.

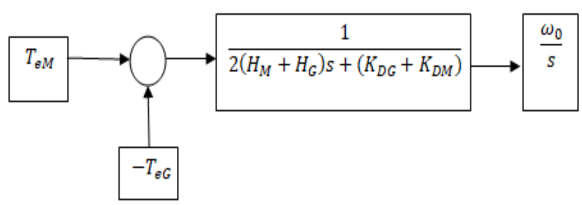

Fig.3 Mechanical Model of Motor Generator Pair System

III. SIMULATION MODEL

SPECIFICATIONS FOR HYDRO THERMAL POWER PLANT

Table -.1 Specifications of Hydro Thermal power plant

Names	Abbreviations	Values
Frequency bias	B_i (pu MW/Hz)	1
factor in area-Regulation constantin area	R_i (Hz/pu MW)	2.4
T12	coefficient of synchronization	0.0707
a12	power coefficient by synchronization	1
F	system frequency (Hz)	50
T_w	inertia time constant of Water (s)	2
Tm	starting time constant (s)	8
D	damping coefficient	1

P is the power flow in tie line

P_G is the total area power generation;

Pl (f) is the total area load, which is a function of frequency;

H is the total inertia of the system,

f is the nominal frequency of the system

H $_i(\frac{df}{dt})$ is the accelerating or decelerating power of each area

The values of the PI controller were obtained by the trial and error method and the values are given by

$K_p = 1.7$

$K_I = 0.25$

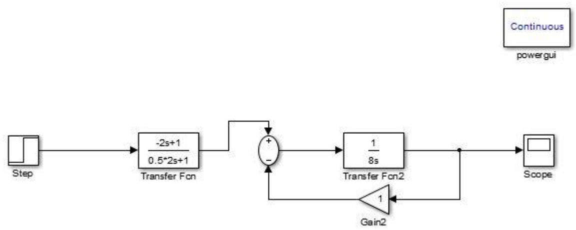

Fig.4 Simulink block for hydro thermal power plant without convectional PI controller:

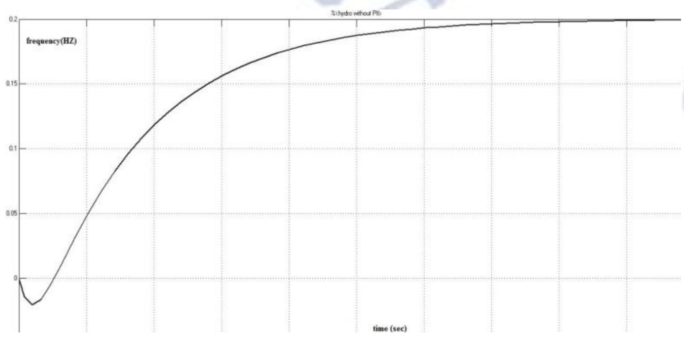

Fig.5 Results For Hydro Thermal Power Plant Without Convectional PI Controller

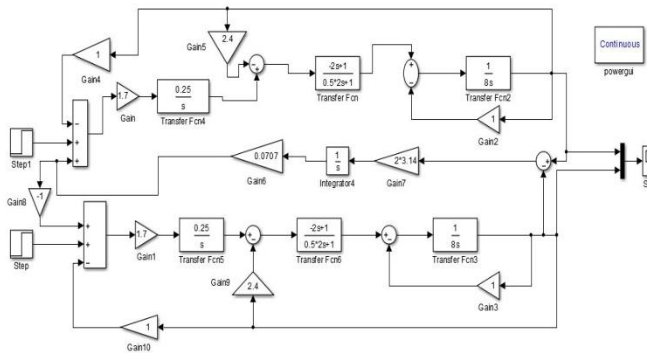

Fig. 6 Simulink Block For Hydro Thermal Power Plant with Convectional PI Controller

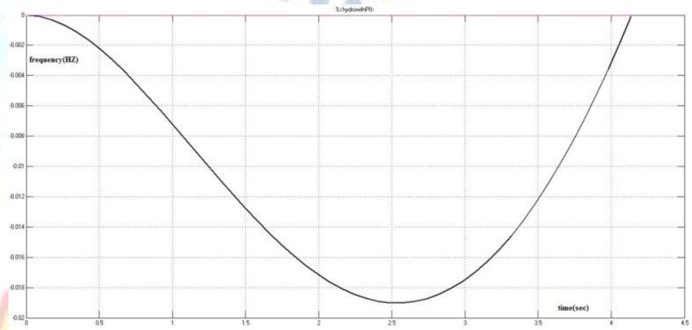

Fig.7 Results For Hydro Thermal Power Plant with Convectional PI Controller

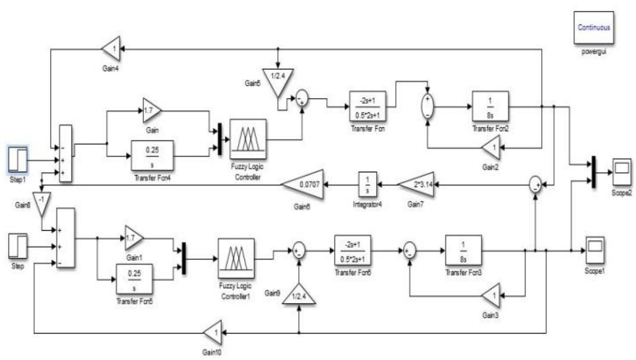

Fig.8 Simulink Block For Hydro Thermal Power Plant with Fuzzy Logic PI Controller

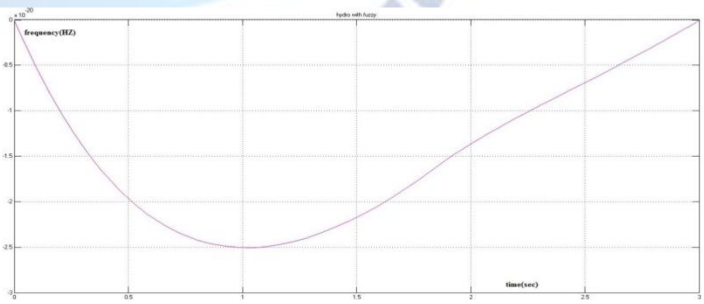

Fig.9 Results For Hydro Thermal Power Plant with Fuzzy Logic PI Controller

The simulations results suggest that fuzzy logic controller yields better results when compared to conventional PI controller when all the above figures 5, 7 and 9 are analysed. Convectional PI controller is one equation whereas Fuzzy controller is based on the rules. Fuzzy controllers are easy to implement, but they are relatively hard to tune i.e., what kind of membership functions are to be taken, how to set-up their parameters etc.., Fuzzy Logic Controllers, when well designed, can behave like a nonlinear controller or even like a set of linear PID controllers that operate differently according to the stimuli or inputs. Fuzzy controllers are useful in any control system with a strong non-linear plant, where small change of the manipulated value changes parameters of the plant or even its dynamics.

The most important thing is usage of renewable source (water) for the production of electricity. Because of this, usage of fossil fuels is reduced to some extent. Finally, due to all the mentioned parameters above, the fuzzy logic PI controller can be used as an advanced controller for providing load frequency in such single area and two area hydro electrical power plants.

COMPARISON RESULTS:

	Hydro without PI controller	Hydro with PI controller	Fuzzy with PI controller
Over shoot Values (%)	2	2.5	1
Settling time (seconds)	40 sec	4.1 sec	3sec

Convectional PI offers high settling time when compared to fuzzy logic controller due to oscillatorybehaviour in transient period. The oscillatory behaviour is reduced in fuzzy logic controller as shown in above table and so settling time reduces.

IV. CONCLUSION

The present paper is the comparison of the convectional PI controller with Fuzzy logic PI controller. The variation of the load in one area and multi area is also verified by the simulation results. The parameter values are not changed in both convectional PI and Fuzzy logic controllers.The simulations results suggest that fuzzy logic controller yields better results when compared to conventional PI controller. Convectional PI controller is one equation whereas Fuzzy controller is based on the rules. Fuzzy controllers are easy to implement, but they are relatively hard to tune i.e., what kind of membership functions are to be taken, how to set-up their parameters etc.., Fuzzy Logic Controllers, when well designed, can behave like a nonlinear controller or even like a set of linear PID controllers that operate differently according to the stimuli or inputs. Fuzzy controllers are useful in any control system with a strong non-linear plant, where small change of the manipulated value changes parameters of the plant or even its dynamics

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