Modeling and Fault Analysis of Canal Type Small Hydro Power Plant

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ABSTRACT:

In this paper, the simulation model of a typical canal type small hydroelectric power plant was developed through interconnection of models of various equipments of the plant under consideration in a MATLAB/Simulink based software environment. The various components of small hydroelectric plant like governor, Semi-Kaplan turbine, synchronous generator, exciter are being considered under modeling and simulation.. The aim is to study its behavior during phase to phase fault. This study helps in verifying costs and safety conditions, in selecting the best alternatives in the early phase of design and to determine the requirements of special protection devices to control over-current and under-voltage.

KEYWORDS – *Mathematical models, small hydro electric power plants, Fault Currents, Fault Voltages, Matlab/Simulink.*

I. INTRODUCTION

In Irrigation canal based Small Hydro plants, utilizing the heads available gives more or less constant power generation. But it is seen that the head available is almost constant whereas there are large variations in the discharge available. The power generation is completely dependent upon irrigation releases season wise through the canal which depends upon the crop pattern in the region. Power generation is for nine months as months of April, May and August are not considered since discharge is less than 1 cumecs.Modeling and simulation of small hydro power plant is valuable tool for planning power plant operations and judging the value of physical improvement by selecting proper system parameters. Earlier this was done for large or small hydro power plants. But for canal type small hydro power plants this study helps in verifying design of windings, costs and safety conditions. It also helps in verifying the parameters of control equipments like water level regulator, governor, exciter etc. and in determining the dynamic forces acting on the system which must be considered in structural analysis of the penstock and their support.

II. MATHEMATICAL MODELING

Generally differential equations are used to describe the various power system components. Study of the dynamic behavior of the system depends upon the nature of the differential equations.

Small System: If the system equations are linear, the techniques of linear system analysis are used to study dynamic behavior. Each component is simulated by transfer function and these transfer functions blocks are connected to represent the system under study.

Large System: Here state-space model will be used for system studies described by linear differential equations. However for transient stability study the nonlinear differential equations are used.

III. METHODS USED FOR MODELING FOR CANAL TYPE SMALL HYDRO POWER PLANT.

1.1 The generator model is derived starting from the basic circuit equations and the use of Park’s transformation.

1.2 Hydraulic turbine model includes both linear and nonlinear control methods. Nonlinear models are required where speed and power changes are large.

1.3 For governor, mathematical equations of ordinary differential equations representing the dynamic behavior are used. Here the regulator consists of two parts electrical (PID Controller) and electro-hydraulic parts

1.4 For exciters ordinary differential equations are used.

3.1.Mathematical Modeling of a Synchronous Machine:

The synchronous machine under consideration is assumed to have three stator windings, one field winding and two damper windings.

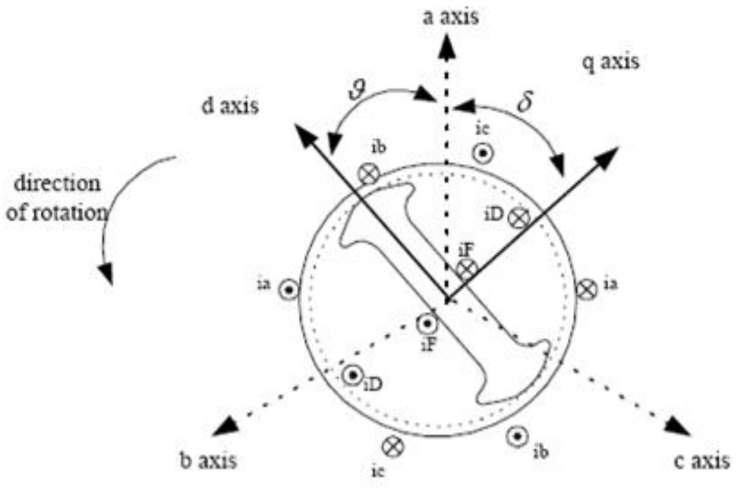

Fig. 1: Representation of a synchronous machine

Equation (1) is the generator voltage equation in the rotor frame of reference is described in Per-unit. The machine equation in the rotor frame of reference becomes.

$$\begin{bmatrix} v_d \\ -v_F \\ 0 \\ v_q \\ 0 \end{bmatrix} = \begin{bmatrix} r & 0 & 0 & \omega L_q & \omega kM_Q \\ 0 & r_F & 0 & 0 & 0 \\ 0 & 0 & r_D & 0 & 0 \\ -\omega L_d & -\omega kM_F & -\omega kM_D & r & 0 \\ 0 & 0 & 0 & 0 & r_Q \end{bmatrix} \begin{bmatrix} i_d \\ i_F \\ i_D \\ i_q \\ i_Q \end{bmatrix} - \begin{bmatrix} L_d & kM_F & kM_D & 0 & 0 \\ kM_F & L_F & M_R & 0 & 0 \\ kM_D & M_R & L_D & 0 & 0 \\ 0 & 0 & 0 & L_q & kM_Q \\ 0 & 0 & 0 & kM_Q & L_Q \end{bmatrix} \begin{bmatrix} \dot{i}_d \\ \dot{i}_F \\ \dot{i}_D \\ \dot{i}_q \\ \dot{i}_Q \end{bmatrix} \quad (1)$$

Where,

= Equivalent direct-axis Reactance
= Filed winding Self –inductance
= Self-inductance damper winding
= Equivalent quadrature axis reactance
= Self inductance of quadrature reactance
= Stator to damper winding resistance
=Stator to quadrature winding resistance
r = Stator winding current
= Field winding resistance
= resistance of d axis damper winding
= resistance of q axis damper winding
= armature current in the q direction
= Field current
= d axis damper winding current
= q axis damper winding current

IV. MODELING OF HYDRAULIC TURBINE AND GOVERNING SYSTEM.

4.1.Hydraulic Turbine Modeling

The representation of the hydraulic turbine and water column in stability studies is usually based on the following assumptions:

1. The hydraulic resistance is negligible.
2. The penstock pipe is inelastic and the water is incompressible.

3. The velocity of the water varies directly with the gate opening and with square root of the net head. The turbine output power is proportional to the product of head and volume flow.

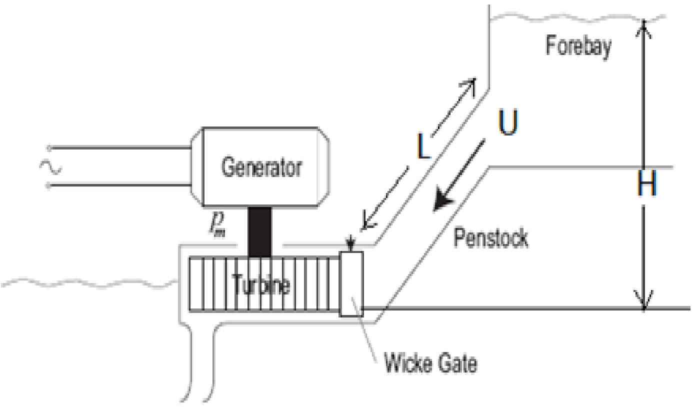

Fig. 2: A Typical Control System of Hydroelectric Plant

The velocity of the water in the penstock is given by

$$U = \quad G \quad H$$

Where

U = water velocity
G = gate position
H = hydraulic head at gate
 = a constant of proportionality

$$\frac{\Delta \square m}{\Delta \square} = \frac{1 - T_W s}{1 + 0.5\, T_W s}$$

Above equation represents the classical transfer function of a hydraulic turbine. It shows how the turbine power output changes in response to a change in gate opening for an ideal lossless turbine. Fig. 3 shows the mathematical model.

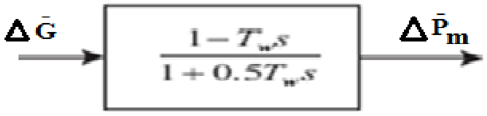

Fig. 3: Mathematical model of hydraulic turbine

4.2 Governor Modeling:

The basic function of a governor is to control speed and/or load. The primary speed/load control function involves feeding back speed error to control the gate position. In order to ensure satisfactory and stable parallel operation of multiple units, the speed governor is provided with a droop characteristic. The purpose of the droop is to ensure equitable load sharing between generating units. For stable control performance, a large transient droop with a long resetting time is therefore required. This is accomplished by the provision or a rate feedback or transient gain reduction compensation as shown in the figure.

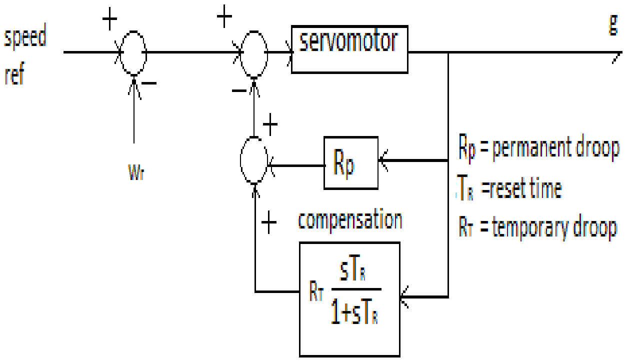

Fig. 4: Governor with transient droop compensation

4.3 Mechanical-hydraulic governor model:

The various components of Mechanical-hydraulic governor are; speed sensing, permanent droop feedback, computing functions, relay valve, gate servomotor and a dashpot used to provide transient droop compensation.

The transfer function of the relay valve and gate servomotor is

=

The transfer function of the pilot valve and pilot servo is

=

Where is determined by the feedback lever ratio; by port areas of the pilot valve and . Now from above two equations we have

= =

Where is the servo gain.

The transfer function of the dashpot is given by

=

The temporary droop is determined by the lever ratio, and the reset/washout time is determined by needle valve setting.

A block diagram representation of the governing system suitable for system stability studies is shown below.

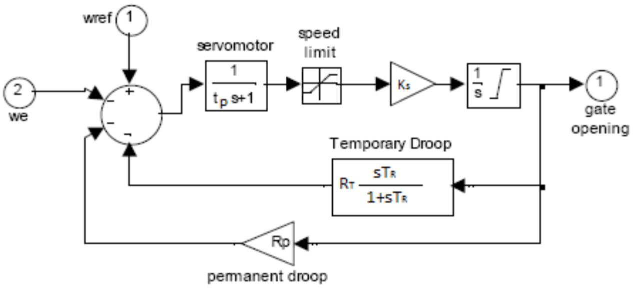

Fig. 5: Shows the Model of governors for hydraulic-turbines

V. EXCITATION SYSTEM MODELING:

The basic elements which form different types of excitation systems are the dc or ac exciters, rectifiers, amplifiers, stabilizing feedback circuits, signal sensing and processing circuits.

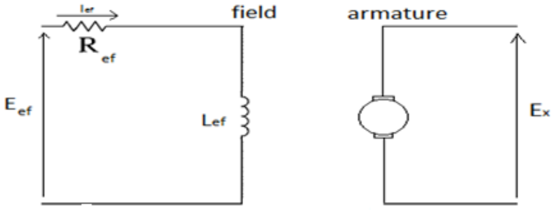

Fig. 6: Separately Excited DC Exciter

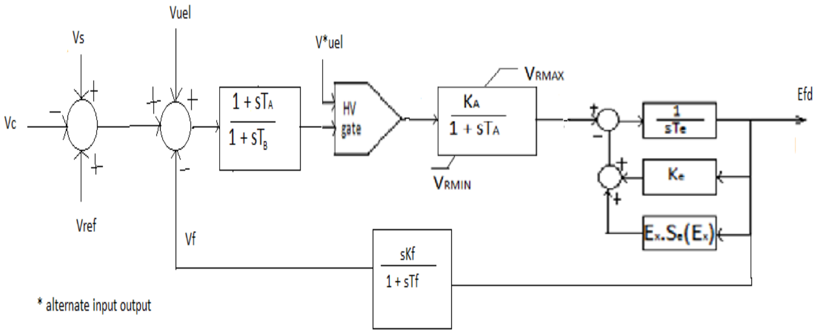

Fig. 7: Excitation system with stabilizing circuit

VI. SIMULATION MODEL DEVELOPED IN A MATLAB/SIMULINK SOFTWARE ENVIRONMENT.

The entire simulation system for the analysis of two-phase fault on canal type small hydroelectric power plant has been developed in a MATLAB/Simulink based software environment. Subsystems have been utilized in the simplification of a system diagram and the creation of reusable systems. Further, a subsystem is a group of blocks that is represented by a subsystem block. The entire simulation system contains three subsystems: first, the speed governor and servomechanism, in which turbine speed, dead zone, valve saturation, and limitation are all considered; second: the hydrodynamics system (HS), which consists of tunnels, penstock, and surge tanks; and third, the turbine generator and network, which has a generator unit operating in isolation. The combinations of three subsystems are shown in Fig. 8.

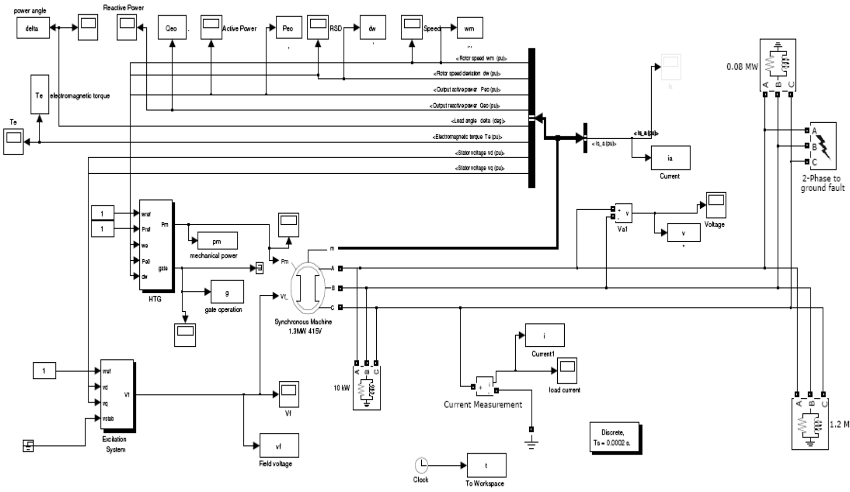

Fig. 8: Working model for canal type hydro power plant

A typical canal based hydroelectric power plant with a Kaplan turbine, as shown in Fig. 7 reflects the Canal Type Small Hydro Power Plant in Bathinda Punjab run under Punjab Energy Development Agency (PEDA), and hence all the data of this plant are used to simulate study the effect of two-phase fault. Therefore, all of these simulations are performed for different time conditions. In addition, the influences of changing different parameters of pressure water supply system, turbine speed governor PID gains, as well as surge tanks were analyzed. The simulation results are all in per unit system and the required data are below

6.1 Turbine and Governor Data

h = 2.10
= 2.74
= 3
ω = 93 rpm
ηt = 91%
= 1p.u.
= 0.07
=0.05
= 3
= 0.10
= 3.26
=0.02
=10/3
=0.01
=0.97518
=-0.1
=0.1

6.2 Exciter

= 1
= 1
and = 0.00001,
0.00001
= 0.08
= -15
= 7.3
=0.87
=200
=0.02
=1
=0.03
=1
=1.2911

6.3 Synchronous Generator

=1.3 MW
=415V
f =50
=0.911
=0.408
=0.329
=0.580
=0.350

=0.3
=0.7
=0.035
=0.033
=0.03
H =1
P =4
=1

VII. CONCLUSION

In this case, synchronous generator is connected to the load through a transmission line as shown in Fig.8. Initially the load is 1.2MW on the generator. At 10.5 seconds, disturbance is created by putting phase-phase fault for 0.2seconds. The values of the governor, exciter, synchronous generator and hydraulic turbine are same as given before. The corresponding results for current and voltage are shown below:

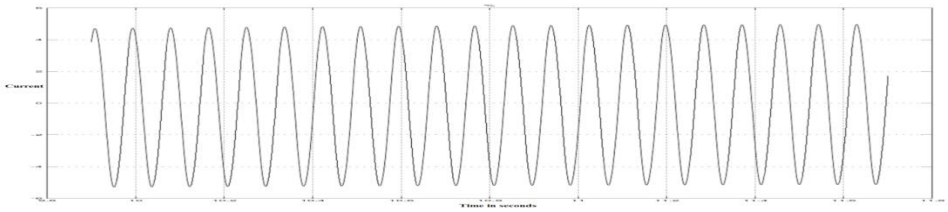

Fig. 9: Current under normal condition

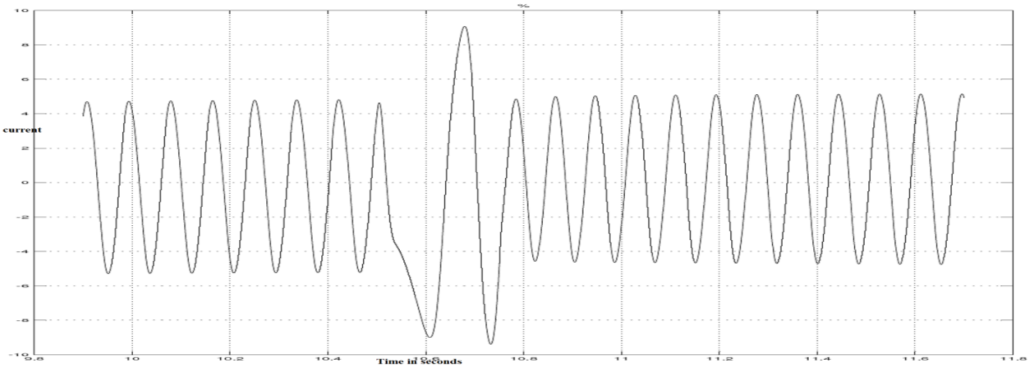

Fig. 10: Current under fault condition

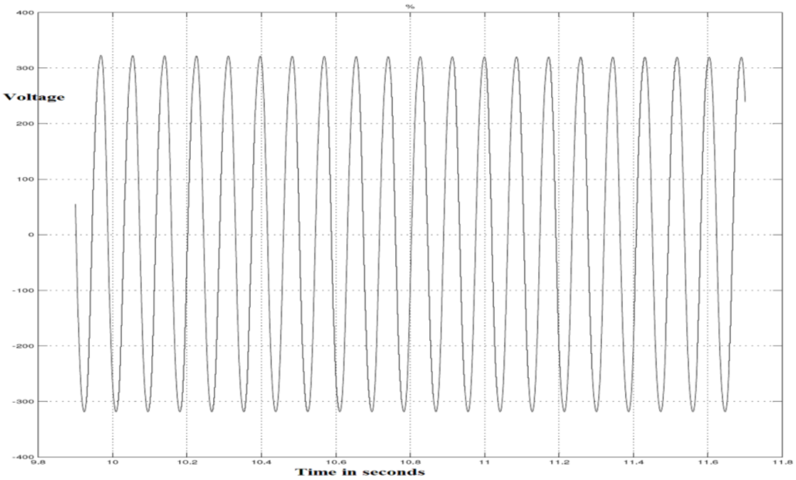

Fig. 11: Voltage under normal condition

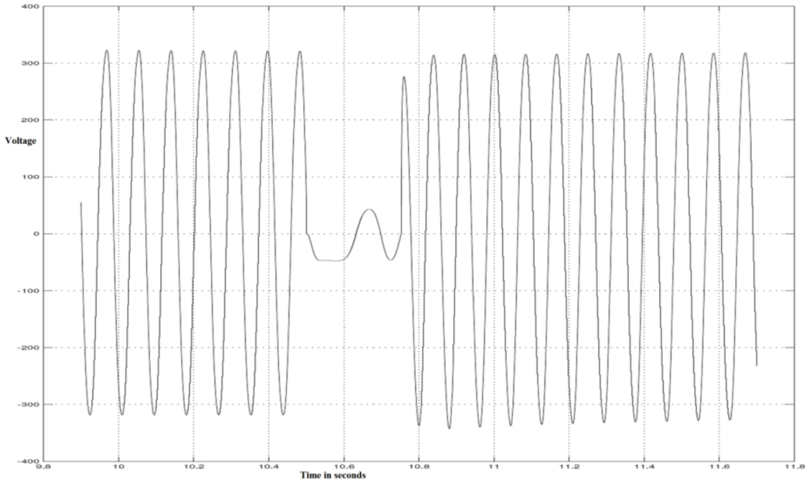

Fig. 12: Voltage under fault condition

Table -1 Experiment Result

Quantity	Without fault	With fault
Current (amp)	5	9
Voltage (V)	325	40

When the plant was connected to its load, there has been an immense change in current and voltage during the fault, armature current increases sharply and terminal voltage reduces drastically. as it is convenient from the table. The peak overshoot has raised from 5 to 9 amperes. While the voltage has been dropped from 325V to 40V. After fault clearing, the variations of terminal voltage and armature current characteristics are very similar. Finally, due to increase in armature current and terminal voltage, electrical power increases and becomes constant after approximate 2.5 seconds after the fault clearing. So from these results we come to the point that the generator winding should be of such a design so that it can bear this current. Also steps should must be taken to avoid under-voltage which will otherwise cause a lot of problems while being in parallel operation with other generators. At last results were handled to Punjab Energy Development Agnecies (PEDA) Chandigarh to take the corrective measures from the results if there will be such type of frequent faults.

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