Technique to Reduce Dump Load in Isolated Hydro Power Plant by Load Frequency Control

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Abstract

In this paper, a new technique for load frequency control is adopted in general the frequency is controlled by using a dump load, whose rating is equal to the rated power output of the plant. The new scheme proposed reduces the size of the dump load by controlling input power of the hydro power plant using on/off controls. The water flowing through the penstock is rerouted in smaller pipes, two or three fitted with motor operated valves. The opening or closing of the valves is achieved by on/off controls. The on/off control linearly raises or lowers the generation. A transfer function model for the system is developed with an on/off control logic. Finally, system transient’s performance is compared for the case of two –pipe (50% dump load) and the three-pipe (30% dump load).

Keywords: Mini Hydro Plant, Dump Load, Servo Motor On-Off Control

I. INTRODUCTION

In today’s world electrical energy is very essential and its availability plays a significant role in the upliftment of remote, backward or grid supply to the society. The demand and supply of consumer is increasing with the development of country linearly and now demand is increased to a larger value. Therefore many villages either have no electrical connection or getting rarely electric power only for few hours in a day from grid. The dependence on fuel and also on grid supply can be reduced by having stand-alone generations to meet the local requirements in these areas/locations. Some of these geographical areas have large number of small-hydro streams, which can be used for stand-alone power generation. The energy in flowing water of small streams can be tapped by small-hydro power plants. This clean source of power, therefore, plays a vital role in rural electrification in the case of developing countries. Moreover, small-hydro power has a huge, as yet untapped potential in most areas of the world and can make a significant contribution to future energy needs. Small-hydro power generation is already an effective and efficient proven technology, but there is considerable scope for research and development of controls for this technology. Most of the small-hydro plants do not require a dam or large water reservoir usually they require a weir.

The maintenance of system parameters like frequency, voltage, etc., within certain limits is essential for proper operation and efficient use of power produced. By eliminating the mismatch between generation and load the system frequency can be maintained constant. A conventional speed governor with supplementary integral control can be used to maintain the frequency constant both for grid connected and isolated mode operation. In general the generation control mechanism is not used due to prohibitively high cost; therefore, frequency is maintained by load management. In a standalone small-hydro generation system due to non-availability of storage facility, the total input has to be converted into electrical energy. Any variation in power demand is controlled by a resistive load called dump load. Since the input to the generator is essentially constant, the excess power due to decrement in load is dumped into the dump load. One of the main reasons for non-exploiting isolated small-hydro power systems in the higher capacity range is due to the limitation on the size of the available dump loads. It is also one of the reasons on the existing systems that the resources are not used to the fullest available capacity. In most of the sites of small-hydro plants it has been observed that the primary requirement of the local community is water for irrigation of agricultural land as their survival depends upon it. But if electricity is available, it will enhance the living standards by helping in better education, hospital, communication, facilities, etc. Once water enters the stream from tailrace, it requires power for pumping to the fields. Therefore, if surplus water is available before the entry to the penstock it can easily be diverted to the fields. In general, the load factor of small-hydro plants is less than 50%. Therefore, more than 50% water can be available as surplus if proper generation control strategies are employed instead of using dump load. A new control scheme is proposed in this paper by which the dump load is eliminated and frequency is maintained at the desired level.
II. DUMP LOAD IN SMALL HYDRO POWER PLANT

In a stand-alone small-hydro generation, the rated power is always generated subject to the availability of the source. Any variation in power demand is controlled by a resistive load called dump load. The dump load is a thyristor controlled heater load so that the actual load plus dump load is equal to the power generated at rated frequency. The system is proved to be cost effective when there is a hot water requirement. A PI controller generally is used with a six-pulse firing angle control technique for elimination of frequency fluctuations. A new case is discussed in which it consists of eight three-phase resistors (binary progression values) connected in series to control the power, and the dump load nominal power is chosen to be 30% higher than nominal load power.

III. PROPOSED MULTIPLE PIPE FLOW CONTROL (MPFC) SYSTEM

The generalized block diagram of the proposed system is shown in below fig 1. Here in this control scheme Multi pipe flow control system is connected to the turbine-generator set. From the forebay tank by valve ON/OFF mechanism water enter into the pipe. By Multi pipe flow control system flow of the water can be controlled. When there is system load is increase or decrease at that time there is deviation in frequency (i.e. frequency raise or lower) than at that time Dump load come into action and frequency is controlled by using a dump load, whose rating is equal to the rated power output of the plant.

![Block diagram of multiple pipe flow control (MPFC) system](image)

The proposed system can be categorized into two ways. The first one is a two-pipe control, and the second is a three-pipe control. In the case of two-pipe control, a small section of penstock employs two pipes of equal diameter, one fitted with a control valve as shown in below fig 2.

![Two-pipe single-valve control](image)

![Three-pipe single-valve control](image)

The water flow rate is equal in both the pipes when the control valve is fully open. The control valve is either fully open or closed, depending upon the loading condition. If the valve is fully closed, the flow rate is reduced to half and hence the power. The water head is maintained constant by overflow of excess water through spillway to the stream. This method reduces the size of the dump load to 50% of the amount normally required.

In the three-pipe system, the penstock flow is regulated through three longitudinal small sections of pipes as shown in figure 3. Two pipes are fitted with control valves with each pipe having 30% of flow rate under maximum rated load conditions. The third pipe has 40% of the flow rate under all conditions. The role of control valve and maintenance of water head are the same as for the two-pipe case. This method reduces the size of the dump load to 30% of the amount normally required, assuming minimum load of 10% contributing to power house demand and some emergency needs. The decision of the time for on or off for the control valve, when the load increases or decreases, plays a vital role in the system dynamics. To understand the dynamics, a transfer function model is developed for the system along with the dump load and on/off controller.

Fig. 4 shows the transfer function block diagram of an isolated small-hydro power plant with dump load and on/off valve control. The model is based on small signal analysis, and the rate of increase or decrease of generation by the control valve is therefore taken to be linear. The dump load consists of a resistive load with six-pulse control technique. The first-order transfer functions are due to delay in firing of the thyristors and monitoring of the system frequency. The integral gain KID eliminates the frequency deviations by varying the dump load from nominal value within limits of minimum and maximum value of limiter2. As the load increases, frequency will decrease and the dump load will also decrease to maintain the frequency constant (ΔF=0).
If $\Delta PD$ reaches the lower limit but frequency deviation is negative, i.e., the frequency is lower than the nominal value, the control valve is activated to “on” position increasing the generation $\Delta PG$ by 50% and 30% of maximum rated load in two-pipe and three-pipe control, respectively. It is vice versa when the load decreases. The system damping (load frequency characteristics) is given by

$$D = \frac{(P_L + P_D)}{P_R}$$

The system gain constant and time constant are given by

$$K_P = \frac{1}{D}$$
$$T_P = \frac{2H}{f^2D}$$

$KP$ and $TP$ will therefore have different values (two in two pipe control and three in three-pipe control), depending upon nominal loading. $PR$ is the power capacity of the small-hydro power plant. The velocity of water in the penstock is given by

$$V = \sqrt{2gh}$$

The time taken by water to travel the penstock under ideal condition is given by

$$t_p = \frac{l}{\sqrt{2gh}}$$

Where $tp$ is the length of the penstock, and is the available head of the water (also $l>h$). $TW$ represents the delay of water in the penstock and is proportional $Tp$; therefore

$$Tw = k*Tp$$

The value of $T_w$ lies between 0.5 and 4.0 s, depending upon the head (low, medium, or high). The numerator term (zero) in the penstock turbine transfer function indicates the increase or decrease in generation is momentarily opposite when the control valve is opened or closed, respectively. The effect is more as head increases.

Where,

<table>
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<th>Abbreviation</th>
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<tr>
<td>$H$</td>
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<tr>
<td>P.u.</td>
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<tr>
<td>$KD$</td>
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<tr>
<td>$KID$</td>
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<td>$PID$</td>
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<td>MPFC</td>
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<td>$Ta$</td>
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<td>$TM$</td>
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<td>$\Delta F$</td>
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<td>$\Delta PG$</td>
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<td>$\Delta PL$</td>
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The details of the control logic are shown in fig. 5, and the functional flow chart of the input valve controller is given in fig 6. The settling time is passed as the threshold value for all the switches. Implementation of such control logic is quite possible with low-cost analog/digital circuits.
IV. SIMULATION RESULTS AND DISCUSSION

A. Case A: Two Pipe Control Scheme

IF there is disturbance in normal system condition and change in load condition the load $\Delta PL$ varies such that

$$0 \leq PL^0 + \Delta PL \leq 0.5 \text{ PL max}$$

or

$$0.5 \text{ PL max} \leq PL^0 + \Delta PL \leq \text{ PL max}$$

Here only the dump load will vary between minimum and maximum value so as to maintain the frequency constant, and there will be no action of the control valve. This is depicted by transient responses of the system.

Here in this case operating load is greater than 500 Kw

1) Gain constants
- $KD = 60$
- $KID = 0.1$
- $KPD = 1.0$
- Limiter 1: upper limit: 0 & lower limit: -0.41667
- Limiter 2: upper limit: 0.333 & lower limit: -0.833

2) Time Constants
- $Tp = 12$
- $Tw = 1.0$
- $T\alpha = 0.05$
- $TM = 0.02$
- Initial load = 0.75
- Dump load = 0.0833
- $PL^0 + PD^0 = 1000 \text{ Kw}$
- $D = 0.01667$
B. Simulation Results

Fig. 8: Transient response of $\Delta F$ for various step changes in load $\Delta P_L$

Fig. 9: Dump load response of $\Delta P_D$ for various step changes in load $\Delta P_L$

C. MATLAB Simulink model

Fig. 10: MATLAB Simulink model

Here in this case operating load is greater than 500 Kw.

1) Gain constants
   - $K_D = 60$
   - $K_{ID} = 0.1$
   - $K_{PD} = 1.0$
   - Limiter 1: upper limit: 0 lower limit: -0.41667
   - Limiter 2: upper limit: 0.333 lower limit: -0.833

2) Time constants
   - $T_p = 12$
   - $T_w = 1.0$
   - $T_\alpha = 0.05$
   - $T_M = 0.02$
   - Initial load = 0.75
   - Dump load = 0.0833
   - $P_{L0} + P_{D0} = 1000$ Kw
   - $D = 0.01667$

D. Simulation Results

Fig. 11: Transient response of $\Delta F$ for various step changes in load $\Delta P_L$
This is depicted by transient responses of the system for a step disturbance of 21 kW, as shown in figure. It is observed that the frequency and dump load deviations $\Delta F$ and $\Delta PD$ vanish in about 60 s.

REFERENCES