International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org Volume 3 Issue 5ǁ May 2014 ǁ PP.08-15

Load Frequency Control of an Isolated Small Hydro Power Plant with Reduction in Dump Load Rating By Using Variable Structure Control

Ravindra Kumar Yadav[1], Dr. (Mrs.) Lini Mathew[2]
[1]*(Assistant Professor, Electrical Engineering Department, Bharat Institute of Technology, India)*
[2]*(Associate Professor, Electrical Engineering Department, National Institute of Technical Teachers Training and Research, Chandigarh, India)*

ABSTRACT *:In isolated hydro power plant the rating of dump load is equal to the rating of plant and the dump load is very costly. The rating of dump load can be reduced to 50 percent of its plant rating by having variable flow rate of water. The potential advantages of variable flow rate of water in isolated hydroelectric generation is discussed in this paper. The advantage of using multipipe system is discussed and the reduction in dump load rating with its transient response is also discussed. A variable structure controller is presented in this paper which shows significant improvement in the transient response with different step input change in load.*

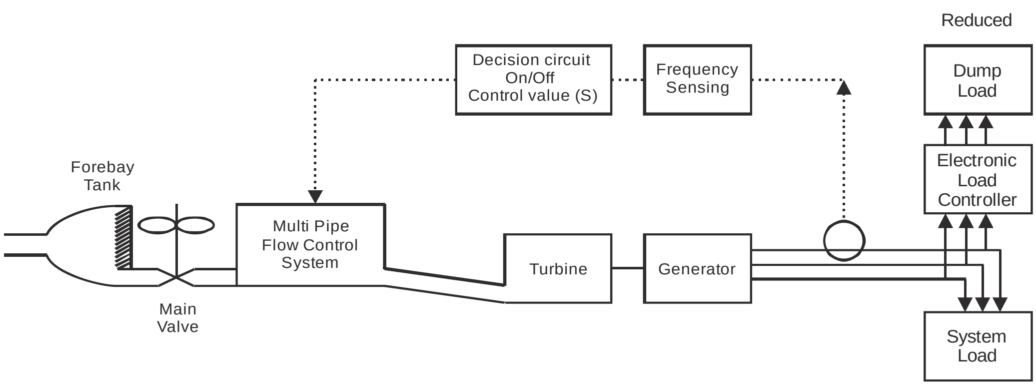
KEYWORDS: *Two Pipe System, Variable Structure Control, Dump Load, ON/OFF Control Valve.*

I. INTRODUCTION

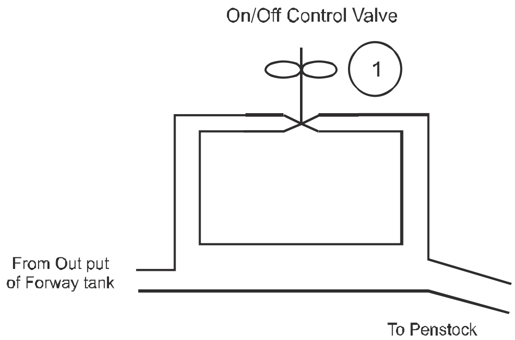
In isolated SHP plant water available at high head is brought to the power house through the penstock where it is converted to electricity by the use of electromechanical device and it leaves the plant through tail race with minimum energy back to the stream. The head of water of the water level in the forebay tank is maintained constant by diverting water through spillway to the stream. The flow rate through penstock is also constant; therefore the system generates constant power, as the generated Power (P) is proportional to Flow Rate(Q) and water Head(H).In isolated SHP plant the frequency fluctuation occurring due to change in active power load is generally controlled by using dump load and the rating of dump load is equal to rating of plant [1]. This technique is useful where there is hot water requirement; otherwise, it is waste of resource. The power wasted in dump load is considerable as the plant load factors in general are in the range of 40% to 60%. If the flow of water through the penstock can be regulated by some means then the excess water can be saved and transferred by channels of irrigation to the fields and system frequency can be maintained at desired level and the rating of dump load can be reduced [1].

II. TWO PIPE CONTROL SYSTEM

In this scheme, the penstock flow is controlled through two pipes as shown in Fig. 1, which results in reduction of dump load size to half of the plant rating and also of the gate valve. The dump loads are readily available up to certain rating and are very costly. Therefore this scheme can be used to control higher rating SHP plants by employing available dump loads which otherwise is not possible. In this paper the reduced size of the dump load is considered using Two Pipe System.



(a)



(b)

Fig. 1 Block Diagram of Isolated SHP Plant with Two Pipe and Reduced Size Dump Load
(a) Proposed Two Pipe Flow Control System (b) Two Pipe Control System

In this scheme, a small section of penstock employs two pipes of equal diameter, one fitted with an 'ON/OFF control valve', as shown in Fig. 1(b). The water flow rate is equal in both the pipes when the control valve is fully open. The ON/OFF control valve is either fully open or closed depending upon the loading condition. If the valve is fully closed, the flow rate is reduced so that the power produced is reduced to half [2,6]. The water head is maintained constant by overflow of excess water through spillway to the diverting channel. The water from diverting channel is given to fields at higher altitudes. This method therefore reduces the size of the dump load to 50% of the normally required.The ON/OFF control valve is a motor operated valve which is either fully open or fully closed position. On receiving a signal it will change the state, though it is a major change in power but it will be considered as linear as it will occur in a sufficient long period of time. The dump load is a fast acting device and is in parallel with the load, while the ON/OFF control valve controls the input power to the turbine. Therefore, it is required that the frequency can be maintained at constant value by their devices when the system is subjected to small disturbances. To investigate the transient performance of the system a generalized simulation block diagram is developed by SIMULINK/MATAB is shown in Fig. 2[3]. The various cases of two pipe control schemes are considered for the study.

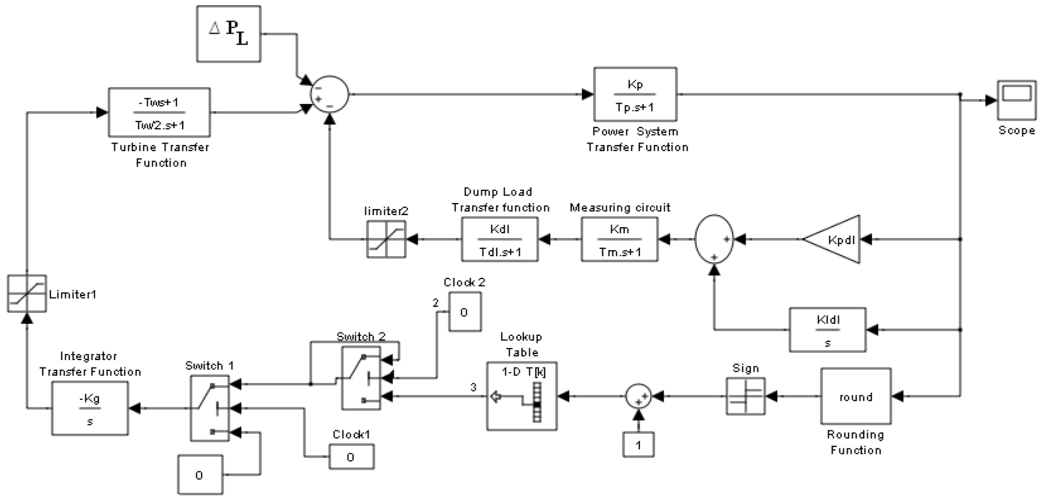


Fig. 2 Block Diagram of Proposed System of Two Pipe Control

III. PROPOSED VARIABLE STRUCTURE CONTROL

The use of integral control eliminates the steady state error for a step input and also improves speed of response of the system, while the peak overshoot is inversely proportional to the proportional gain, which is highly undesirable. The system transient response can be improved by increasing the proportional gain, but the system then exhibits steady state error in the absence of integral gain. A compromise in the controller is obtained by combining both proportional and integral gains as PI controller whose control law is given by:

$U(t) = K_{PX'}\, \Delta F + \int \Delta F\, dt$ …………(1)

It was observed that the compromise solution of using PI control does not eliminate the conflict between the static and dynamic accuracy [4,5]. This conflict could be resolved by employing variable structure controller. The control law of variable structure controller for conventional load frequency control is chosen as follows;

$U(t) = K_{PX}$ for $\Delta F > \epsilon$

$K_{1X} \int \Delta F \, dt$ for $\Delta F < \epsilon$ …………(2)

Where K_{PX} and K_{IX} are proportional and integral gain constants of the controller, while $\epsilon > 0$ is a constant.

The examples considered in this paper need special attention in terms of controller gains. From the studies carried out, it has been observed that the control of generation depends upon system loading and load disturbance. In some cases the ON/OFF control valve starts operating along with continuous control by dump load after the peak deviation in frequency, before it reduced to zero, a steady state error occurs which is due to continuous and constant increase/decrease in generation and remains as long as ON/OFF control valve operate. Therefore the VSC law for conventional power systems has to be modified. The proposed VSC logic for an isolated SHP plant is given as:

$U(t) = K_{PX1}\,\Delta F + K_{1X1} \int \Delta F \, dt$ for $\Delta F > \epsilon$

$K_{PX2}\,\Delta F + K_{1X2} \int \Delta F \, dt$ for $\Delta F < \epsilon$ …………(3)

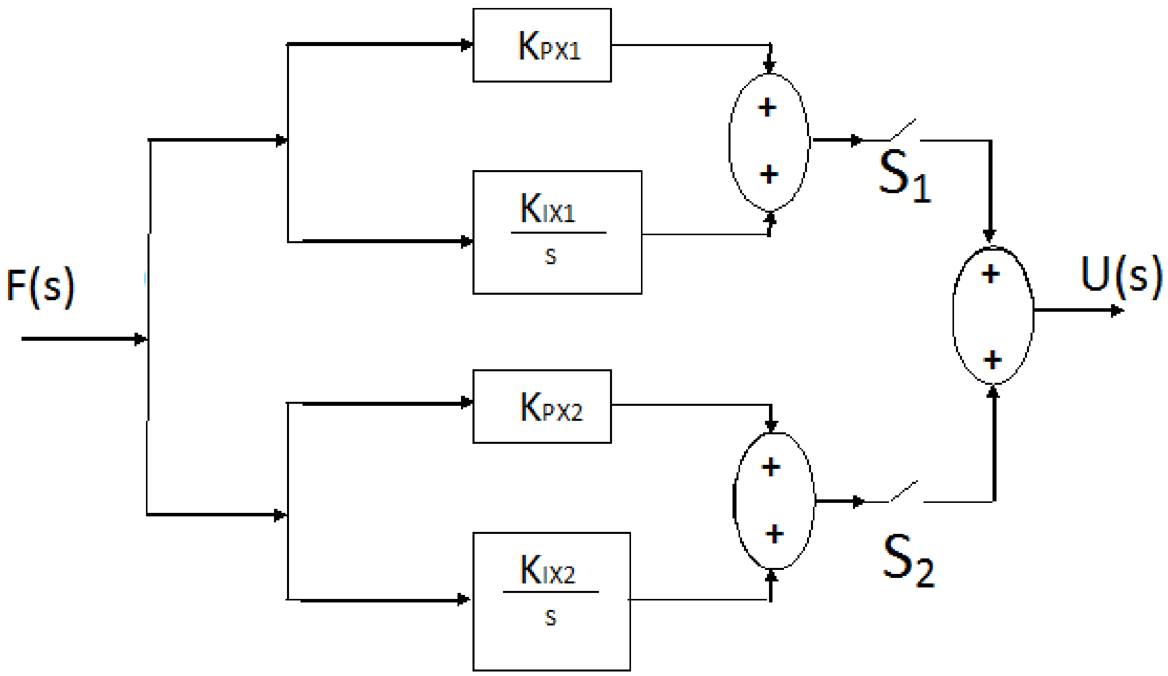


Fig. 3 Proposed Variable Structure Controller

The block diagram representation of the proposed variable structure controller strategy is given in Fig. 3 and switching table for S_1 and S_2 is given in Table 1.

Table 1. Switching Table for Proposed VSC Scheme

Condition	S_1	S_2
$\Delta F > \epsilon$	1	0
$\Delta F < \epsilon$	0	1

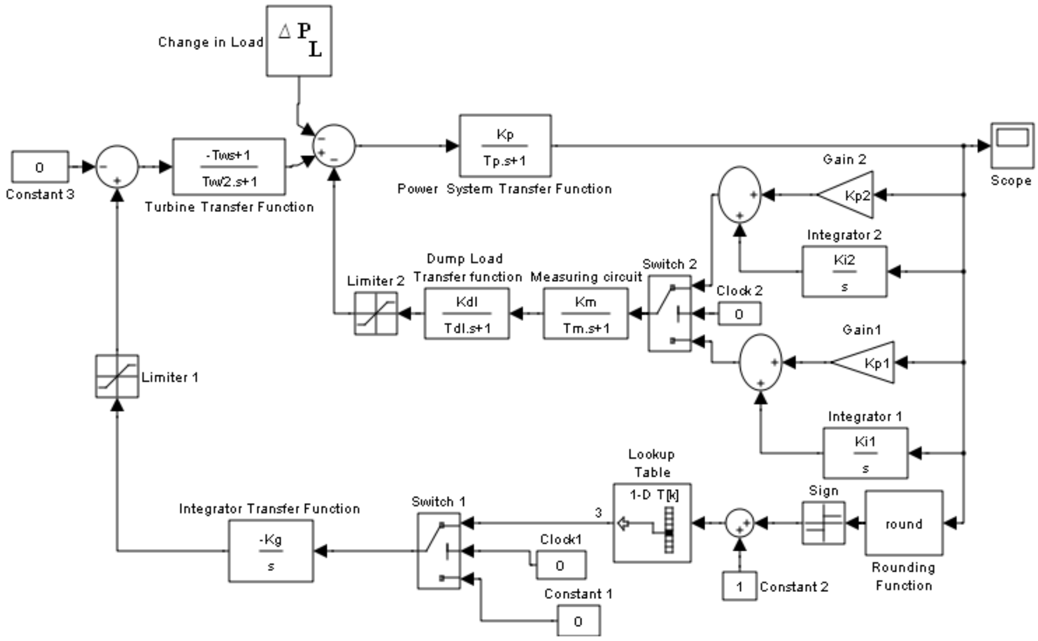


Fig. 4 Block Diagram of SHP with Proposed Variable Structure Controller

IV. SIMULATION AND RESULTS

Two Pipe Control

The transfer function block diagram of an isolated SHP plant with dump load and ON/OFF valve control used for simulation is shown is Fig. 2 the model is based on small signal analysis and the rate of increase or decrease of generation by the ON/OFF control valve is therefore taken as linear [7]. The parameters of the system considered for simulation are given in Appendix. The transient responses of the proposed system are investigated for unit step disturbances of ±0.0175pu(±21kW), ±0.02pu(±24kW) under different loading conditions. The ON/OFF control valve operation depends upon the initial loading of the system plus load disturbance. Therefore three cases have been investigated in two pipe control method.

Case 1.A

The load on the system if varies such that $0 \le P^0_L + \Delta P_L \le 0.5P_{LMAX}$ or $0.5P_{LMAX} < P^0_L + \Delta P_L \le P_{LMAX}$ then only the dump load varies between minimum and maximum limits and it maintains the frequency at the desired level. There will be no action of the ON/OFF control valve as the load is within limits of the dump load. The transient responses of the system for a step disturbance of ±21 kW in load is shown in Fig. 5. It has been observed in Fig. 5 that dump load varies its valve in accordance with change in load such that $\Delta P_{DL} + \Delta P_L = 0$, thereby bringing frequency back to its normal value i.e., ΔF to zero in about 60 sec.

Here,

ΔP_L Change in load

P^O_L Nominal load on the system

P_{LMAX} Maximum nominal load on the system

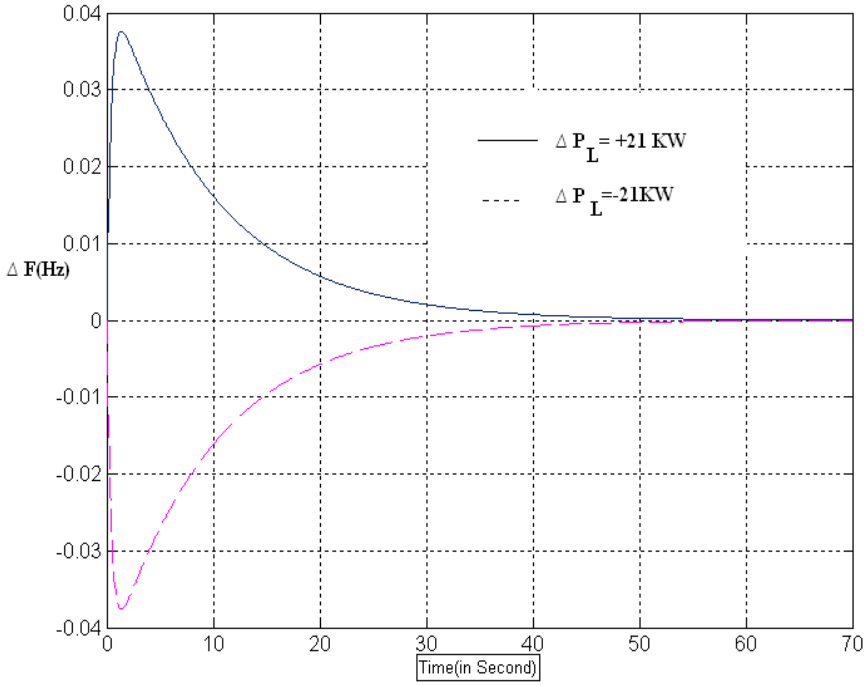


Fig. 5 Transient Response of System, Case 1.A, for Step Change in Load($\Delta P_L = \pm 21$ kW)

Case 1.B

In this case, the initial state of the ON/OFF control valve is 'open'. When the nominal load $P^0_L > 0.5P_{LMAX}$, and disturbance in the system occurs such that $0 \le P^0_L + \Delta P_L \le 0.5P_{L\ MAX}$, then the ON/OFF control valve closes to reduce generation by 50%. The transient response of frequency and dump load deviations with change in ON/OFF valve position of system for different step disturbances in load are shown in Figs. 6.

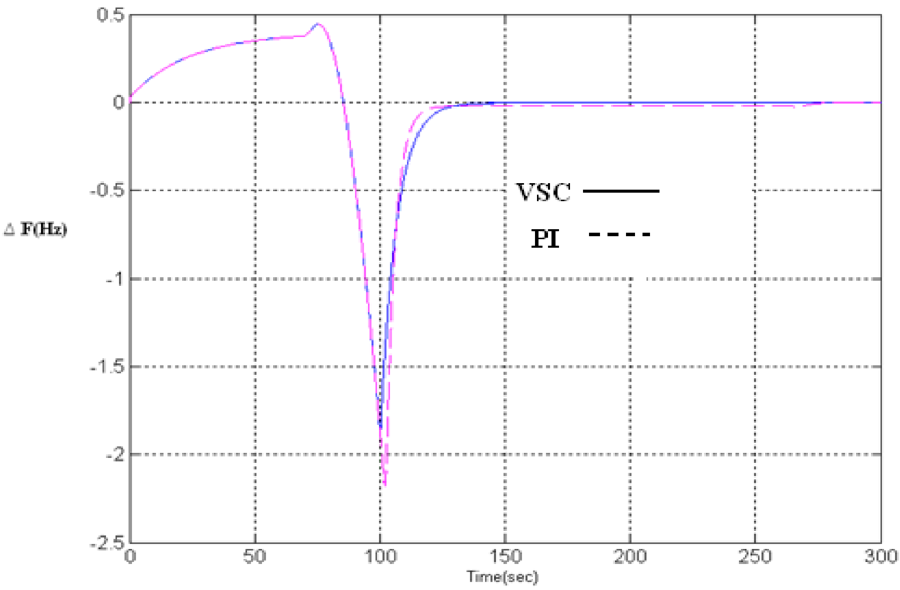


Fig. 6 Transient Response of System, Case 1.B, for Step Change in Load

It is observes that ΔF increases and attains a steady state value in about 50 sec as the dump load has already reached its positive maximum. The control logic starts closing the ON/OFF control valve at about 70 sec. as shown in Fig. 6, therefore, ΔF momentarily decrease and then increases sharply to a new steady state value and remains constant from 200 to 260 sec. This steady state error in ΔF is due to change in state of the

ON/OFF control valve and it exists till the valve reaches its final position. Once the ON/OFF control valve reaches its final position at 240 sec, then only the dump load controller will be acting and reduces ΔF to zero at around 300 sec. On the otherhand, the trasient response gets improved by using variable structure controller and frequency settles in almost 150 seconds.

Case 1.C

In this case, the initial state of the ON/OFF control valve is 'close'. When the nominal load $P^0_L \leq 0.5P_{LMAX}$ and the load disturbance occurs such that $P^0_L+\Delta P_L > 0.5P_{LMAX}$, then the ON/OFF control valve opens to increase the generation by 50% .The transient responses of such a system for unit step disturbances in load are shown in Fig. 7.

For higher step disturbances in load, ΔF initially decreases and attains a steady state value (as the dump load attains its minimum limit) in about 50 sec. The control valve starts opening at about 70 seconds as shown in Fig. 7. It has been found that frequency momentarily increase and then decrease sharply to a new steady state value and remains constant from 200 to 240 sec as shown in Fig. 7. The integral action of dump load controller will further decrease the steady state error in ΔF to zero at around 300 sec.

Further, the trasient response gets settled in almost 150 seconds.

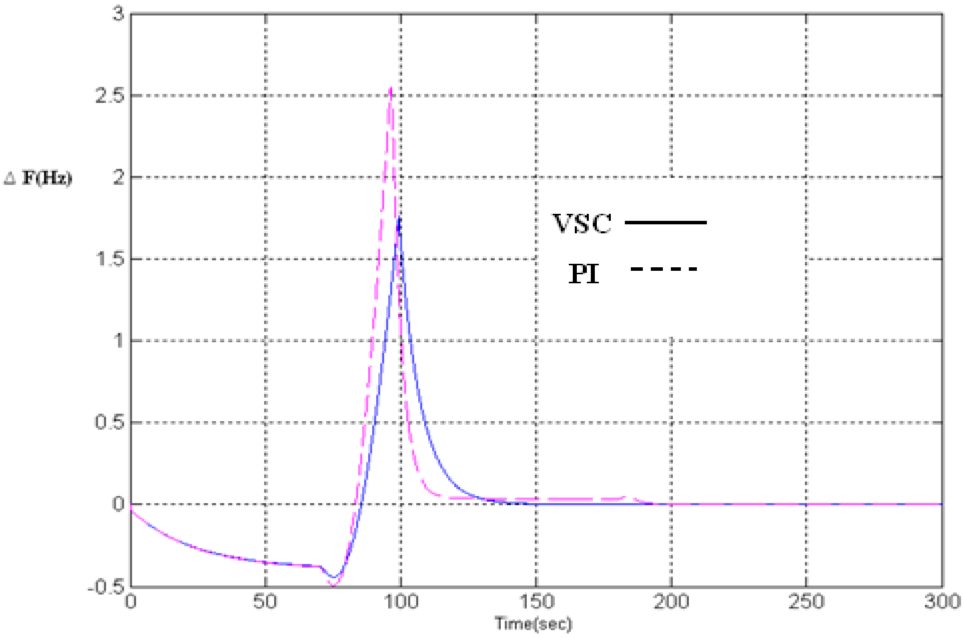


Fig. 7 Transient Response of System,Case 1.C, for Step Change in Load

Variable Structure Control

The transient responses of the system for cases 1.B and 1.C for step changes in load using PI controller and VSC are shown in Fig. 6 and Fig. 7. It has been observed that by using VSC, the transient responses have improved considerably as it causes reduction in peak deviation and steady state error (during transition of the ON/OFF control valve) [8].

The proposed VSC will not have effect on the performance of the system as in case 1A, because in this case $|\Delta F|_{peak} << \epsilon$. The value of parameters of the PI and VSC for various cases of the two pipe control scheme are given in Table 1.1

Table 1.1 Parameters of PI and VSC for two pipe control scheme.

Controller	Case	ϵ	K_{PDL1}	K_{PDL2}	K_{IDL1}	K_{IDL2}
Conventional PI	1.A, 1.B, 1.C	-	1	-	0.25	-
VSC	1.A, 1.B, 1.C	1.0	4.0	15.6	0.5	2.0

In this chapter, the transient behavior of an isolated SHP plant for reduced size dump loads using ON/OFF control valves in two pipe have been investigated. The optimum gain setting of dump load controller parameters K_{PDL} and K_{IDL} have been obtained. It has been observed that following a disturbance, if only the dump load controller regulate the power in such a way as to nullify the disturbance, then the transients of system frequency settles in 60 sec., on the other hand if it requires the operation of ON/OFF control valve along with dump load, then it has been found that the transient of the system frequency settle in 300 second. Finally, it can be concluded that the proposed scheme is very effective in frequency control of an isolated SHP plant following a small disturbance in addition to a reduction in size of load and saving of excess water due to variation in nominal loading.

On the other hand, by using variable structure control it has been found that the dynamic performance improves both in terms of peak deviation as well as in terms of steady state error in ΔF along with reduction in settling time.If it requires the operation of ON/OFF control valve along with dump load, then it has been found that the transient of the system frequency settle in 300 sec in two pipe control with PI control while with variable structure control it settles in only 150 sec. Similarly if the SHP plant is old and gets renovated/ upgraded for higher capacity, the transient performance of this system for same loading conditions, disturbance and gain values have been investigated. A considerable improvement in the performance has been observed.

APPENDIX

A.1. Rating and the Data of the Typical Example Studied

A 1200 kW isolated SHP plant is considered for simulation. The nominal load on the system, generator inertia constant and system frequency are taken as 1000kW, 5 sec and 50 Hz respectively. Based on the head of water, the valve of Tw varies from 1.0 to 2.0 sec. Typical valves of Tw for low, medium and high head plants are 1.0, 2.0 and 4.0 second respectively. Based on the combination of ON/OFF control valve, servo motor controlled valve and dump load, two new frequency control techniques are proposed in this thesis. These techniques are further divided into cases based on initial conditions of the system.

A.2. Reduced Dump Load With ON/OFF Control Valve

Calculation of power system parameters of typical example is given below:

The initial load on the system is 900 kW while the maximum load on the system could be 1000 kW. In order to meet the gap between generation and load, the dump load will contribute a load of 100 kW. The power system parameter for this condition is given as:

$D= ((P^{O}_{L}+P^{O}_{DL})/P_{R})/F^{O} = ((900+100)/1200)/50=0.01667$

$K_{P}=1/D =1/0.01667=60$, $T_{P}=2H/F^{O}*D=2*5/50*0.01667=12$

A.2.1 Two Pipe Control

The power system constants depend on initial loading condition and generation conditions. The values of power system constants for various cases of two pipe control are in Table A.1.

The parameters of dump load controller and ON/OFF control valve are given by:

$K_{DL}=0.41667$, $T_{DL}=0.05$, $K_{PDL}=1$, $K_{IDL}=0.1$, $K_{M}=1$, $T_{M}=0.02$ Sec., $K_{G}=0.0075$ Sec.

The values of Limiter-1(ON/OFF control valve) and Limiter-2 of Fig. 2 are given in Table A.2.

Table A.1 Power System constants for Two Pipe Control

Operating load	$\Delta P^{O}_{L}+\Delta P_{D}$	D	K_P	T_P
>500	1000	0.01667	60	12
<500	500	0.00833	120	24

Table A.2 Typical Loading and Lower and Upper Limits of Limiters

Case	Initial load(p.u)	Dump load(p.u)	Limiter 1(p.u)	Limiter 2(p.u)
1.A	0.75	0.0833	-0.41667 to 0	-0.833 to 0.333
1.B	0.433	0.4	-0.41667 to 0	-0.4 to 0.0167
1.C	0.4	0.01667	0 to 0.4167	-0.1667 to 0.4

REFERENCES

[1] Doolla, S, Bhatti, T.S, “Load Frequency Control of an Isolated Small-Hydro Power Plant With Reduced Dump Load”, IEEE Transaction on Power System Vol. 21 Pages 1912-1919, November 2006.

[2] F. Ardanuay, J. Wilhelmi, J.I. Perez, “The Potential Advantage of Variable Speed Hydroelectric Generation”, IEEE Transactions on Energy conversion, Vol. 21, Pages 569 – 574, June 2006.

[3] Ansel A, Robyns B., “Modelling and Simulation of an Autonomous Variable Speed Micro Hydropower Station.” Mathematics and Computers in Simulation, Vol. 71, No. 4, pp. 320-332, June 2006.

[4] A. Kumar, O. P. Malik, and G. S. Hope, “Variable structure system control applied to AGC of interconnected power system,” *IEE Proc. Part C*, vol. 132, No. 1, pp. 23-29, 1985.

[5] Z. Al-Hamouz and Y. Abdel-Magid, “Variable structure load frequency controllers for multiarea power systems,” *International Journal of Electric Power and Energy Systems*, vol. 15, No. 5, pp. 293-300, 1993.

[6] F. Ardanuay, J. Wilhelmi, J.I. Perez, “The Potential Advantage of Variable Speed Hydroelectric Generation”, IEEE Transactions on Energy conversion, Vol. 21, Pages 569 – 574, June 2006.

[7] R.C. Bansal, T.S. Bhatti, “Small signal analysis of isolated hybrid power systems”, Narosa Publishing House, Ne w Delhi.