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Controlling and Analyzing the Behavior of a Pumped Storage Power Station with using Fuzzy Controller and two Linearization Methods- Dinorwig Power-Station

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Abstract-Regarding power distribution, engineers attempt to provide permanent electrical power solutions for consumers. In order to stabilize grid systems, power system should adapt value of generator outputs with demanded loads. On the other hand, it depends on operating voltage and frequency of the grid with low tolerance, or it should work at constant values in ideal condition. Moreover, economic restrictions lead to electric energy generation with low price and high quality. In fact, electric energy generation with low price and high quality makes pumped storage plants have a developed performance and a rapid responding to load changes. Therefore, designing improved controllers is necessary. The present paper intends to use non-linear model of Dinorwig power station, the model could be applied for simulation purposes. Finally, mixed logical dynamical model (MLD) has been presented for hydraulic part in order to determine differences and similarities and compare it with the linear model.

Index terms-Behavior analysis, Pumped storage plant, Linearization method

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1 INTRODUCTION

Physical features of the model

Dinorwig has two reservoirs and water flows between them. When water flows toward the lower reservoir, it enters a tunnel that categorizes volume of water into 6 parts, and then guides them to 6 separate hydraulic parts. A blade is installed on each of the generators and main runner of generators starts working, immediately after the interaction between water and blades. In fact, based on change of water velocity, torque is produced and it also changes in accordance with water velocity.

An oil- hydraulic servomechanism is used within the controller; its duty is to change position of guide vane in accordance with blade of the main runners.. In order to arrive at simulation, a changeable electrical load should be attached to the grid. Moreover, any change could be observed through governor and should produce a new signal for the guide vane. Physical features of the system shows that a non-linear model that changes based on time indicates the general features of the system.

Case study

The design includes six fuzzy rules; the rules have bee explained as follows:

Rule (1):

If $\Delta f$is optimal, *g* will also be optimal.

Rule (2):

If Δf is very small, *g* will also be very small position.

Rule (3):

If Δf is small, *g* will also be small position.

Rule (4):

If Δf is medium, *g* will also be medium position.

Rule (5):

If Δf is large, *g* will also be large position.

Rule (6):

If Δf is very large, *g* will also be very large position.

With regard to figures 1, 2, and 3, it is clear what kind of membership function and what kind of Universe have been used for $\Delta f, g,$ and $\frac{df}{dt}$. In order to compare fuzzy controller with PID controller, results of the previous researches on application of PID governor in systems with open loop have been demonstrated in figure 4.

Figure 1: membership function for Δf

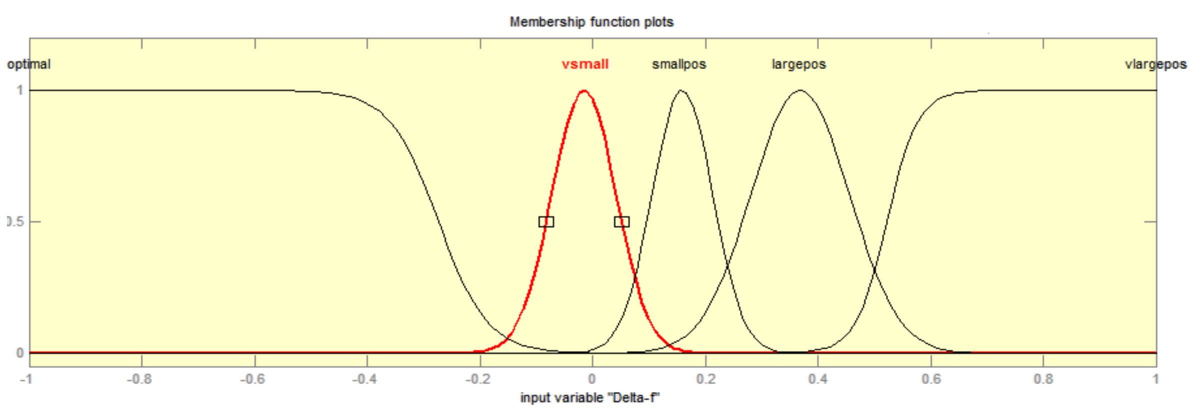


Figure 2: membership function of guide vane signal

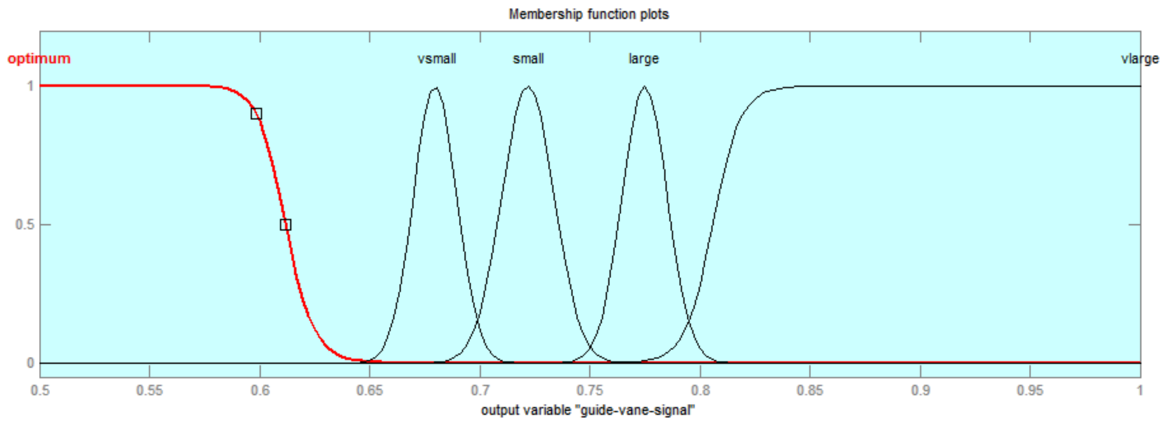


Figure 3: membership function for (df/dt)

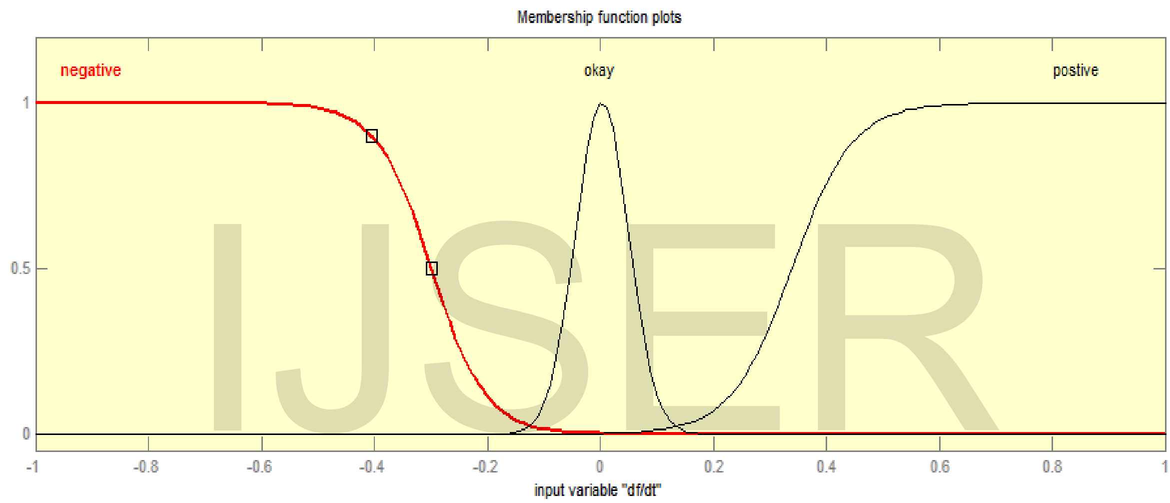
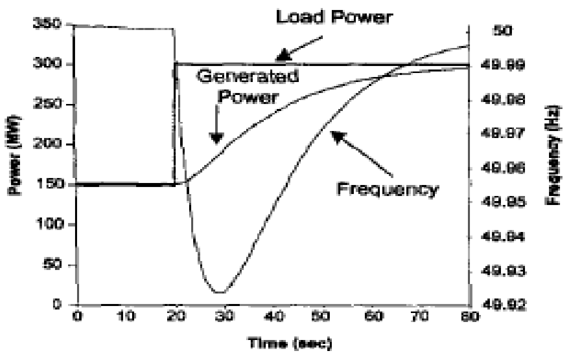


Figure 4: result of simulation for PID controller with increase of load up to 0.5.



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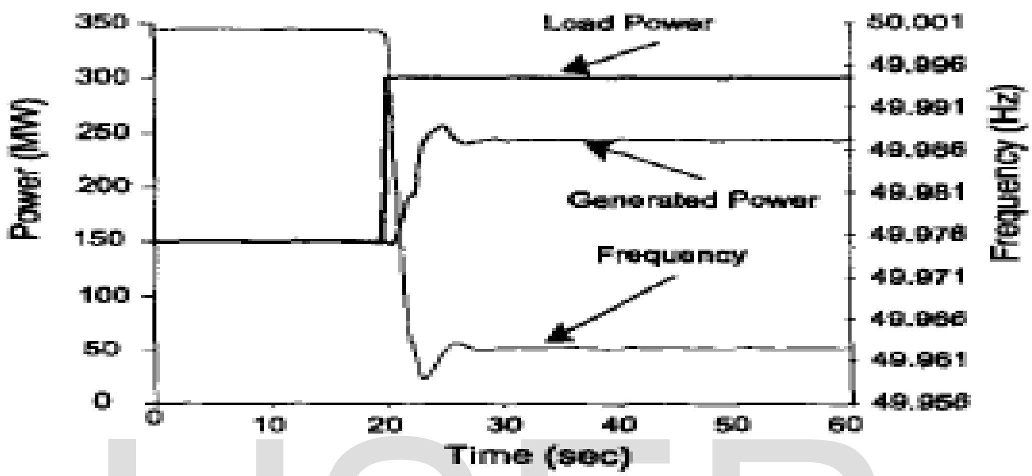
The generator has increased its output up to 295 MW after the passage of 60 seconds. However, the fuzzy controller cannot be adapted to this change of load I a perfect way. It is possible to decrease the highest value ofΔf. Figure 10 indicates the result of decreasing the highest value of Δf and the result of the simulation. Anyhow, g is not fired and it is needed to test new cases as well.

Figure 5: result of simulation for case study with increase of load up to 0.5



2 METHODOLOGY

In order to simulate case studies, system behavior should be analyzed under isolated load condition and head of the station should not exceed the average level. Moreover, load velocity change severely depends on loss factor.

2.1 Simulation of the single unit

In order to explain function of the system, main units are discussed. Required values of the mechanical power and grid frequency are adjusted based on 1pu. Load value equals 1 pu and the additional loadis added to it, after 500 seconds and model ability to follow the load is studied. It is assumed that the turbines can generate the required mechanical power for this load change, however, in practice; each unit has a limited output. Active grid power and then frequency decrease as a result of adding the extra load to the grid. The frequency drop continues up to 50 seconds so that the frequency will arrive at its lowest level (7.38 pu). The severe drop of frequency in the system could be harmful for the quality of the electric power.If grid stations could not compensate the frequency drop, it will lead to instability of the grid.

Figure 6: grid frequency with single unit

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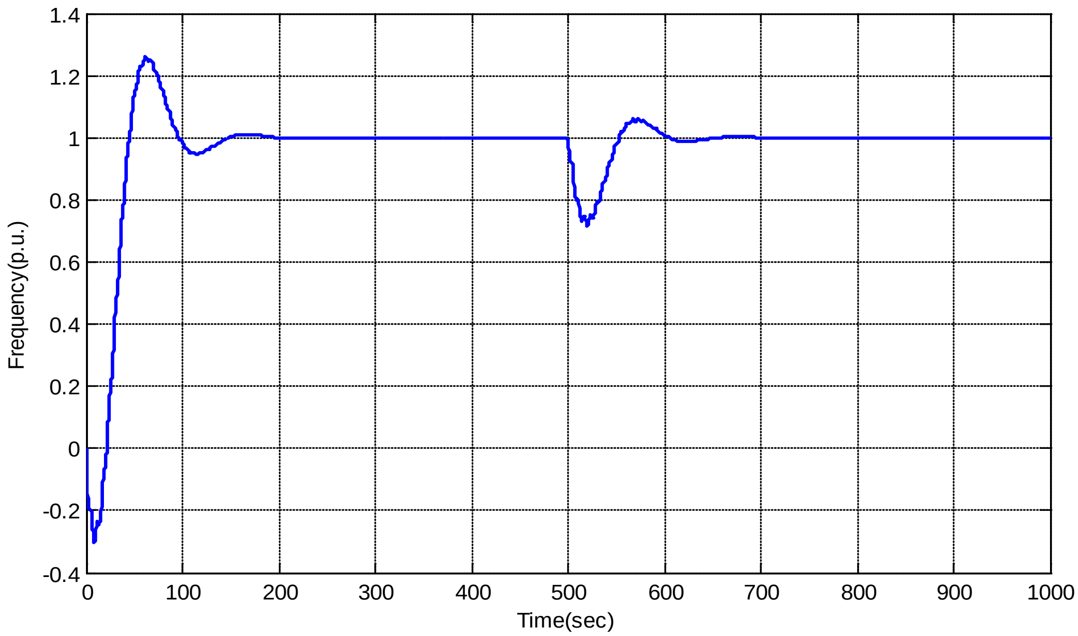


According to figure 6, settling time lasts for 650 seconds; settling time starts 150 seconds after increasing load. Final frequency equals 1.988 pn which is a desirable amount. Dinorwig has six units. Four units out of six should act at the peak time of energy consumption (10 am- 12am and 6 pm- 9 pm or during the weekend) to prevent from frequency drop in the grid. The other two units act as supporting power in emergencies. The real situation is simulated by collecting the four mentioned units. It should be noticed that each unit in the channel has its own way; therefore, different times for travelling and beginning time for water consumption have been used. Results of the simulation with four units and model schematic have been demonstrated in figures 7 and 8.

Figure 7: grid frequency with four units

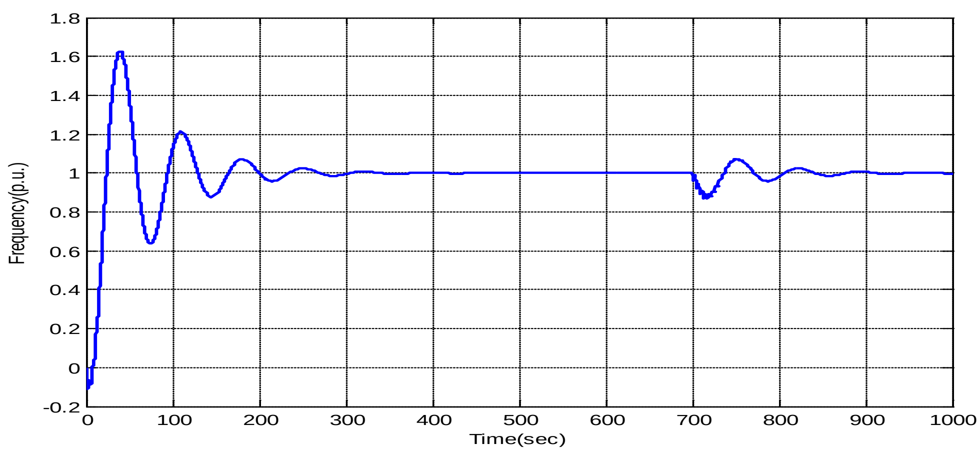
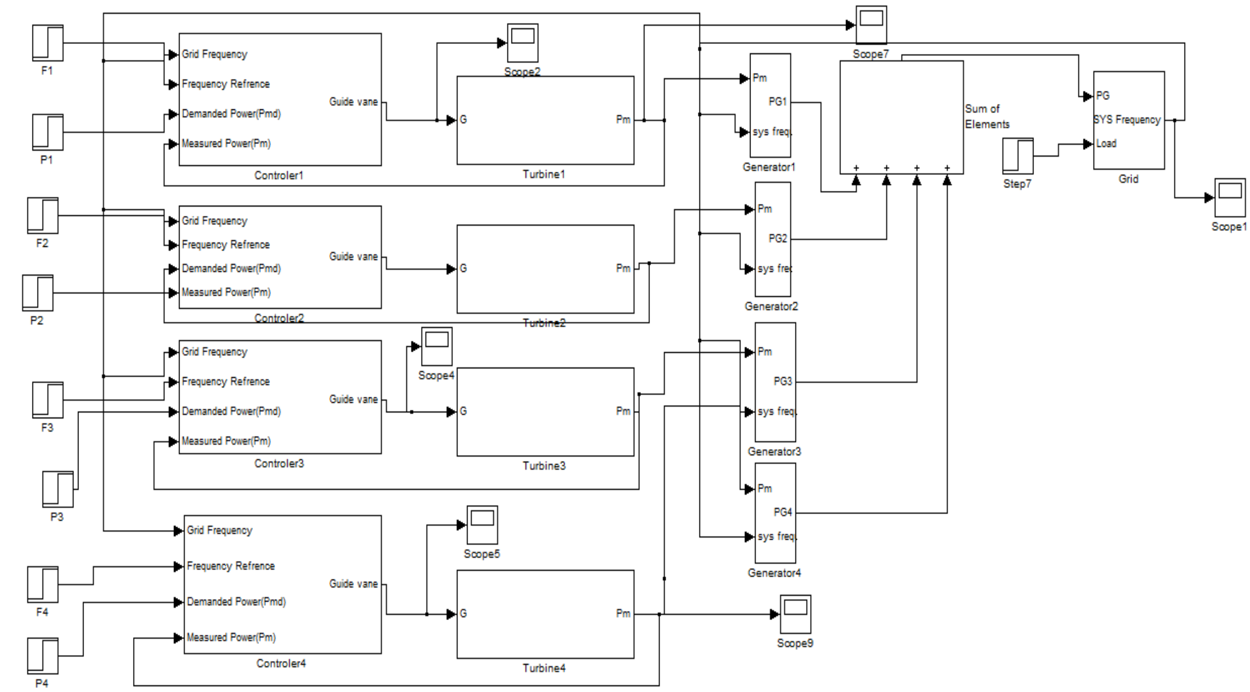


Figure 8: block diagram of four unitson-line



In this model, the additional loadis added in 700 seconds. Dominant feature of the response is its poor transient behavior. In order to explain this transient feature, controlling values of PID need to be discussed. The values are selected to provide balance for the same values under settling time. The settling time occurs 200 seconds after applying the extra load.

2.2 Stimulating fuzzy controller

It is predicted that performing fuzzy inference system will improve system response. Comparing PID with result of fuzzy controller, it gets clear that fuzzy system will have a critical improvement. The considerable item in the response of fuzzy logic refers to more desirable time increase.

In order to adjust the fuzzy controller, it is a challenging issue to be sure of suitability of fire signal for turbine blades; the reason is that frequency error signal decreases continuously. Although proper regulation of functions associated with responses would be very desirable, in this controller, it cannot have an acceptable response for various loads. Frequency responses have been demonstrated in figure 22 by applying the fuzzy controller. The most important effect of fuzzy application is its steady-state response when final frequency of the grid arrives at 1 pn. Another dominant feature of the response is its poor transient behavior. In order to explain the desirable features, it should be mentioned that in this fuzzy controller, the only inputs are frequency error and frequency drift. Figure 9 demonstrates schematic of fuzzy controller.

Figures 10 and 11 demonstrate the model response and frequency with values 1 pu and 2 pu. Moreover, the response relevant to high pressure turbine (in this case: 3 pu) has been indicated in figure 12.

Figure 9: fuzzy logic controller

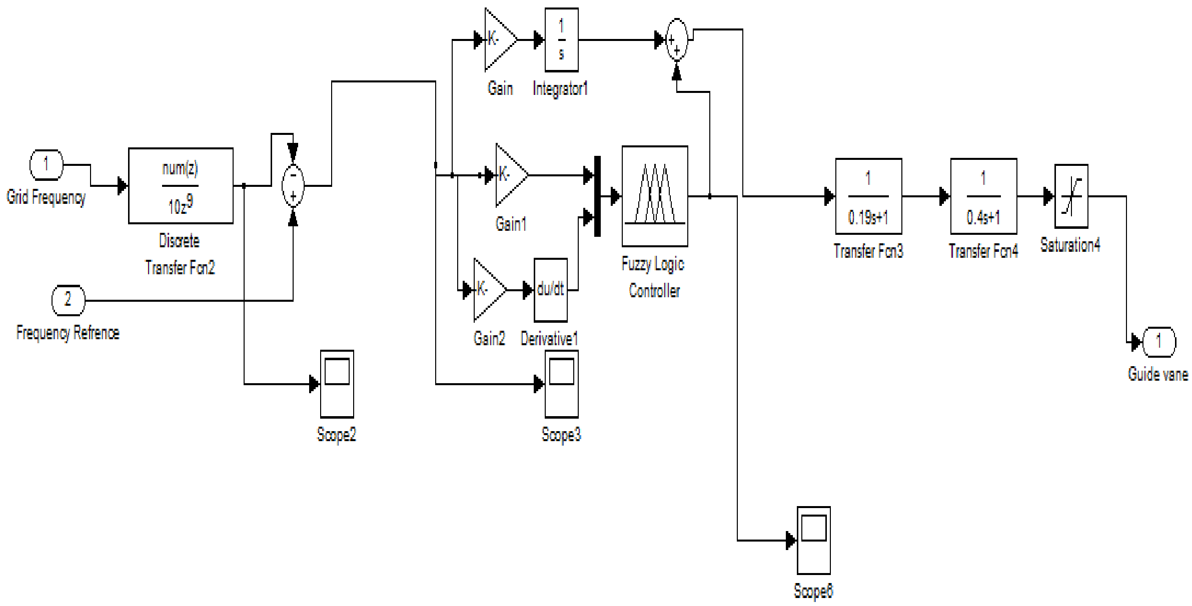


Figure 10: frequency response of linear model (head+ 1 pu)

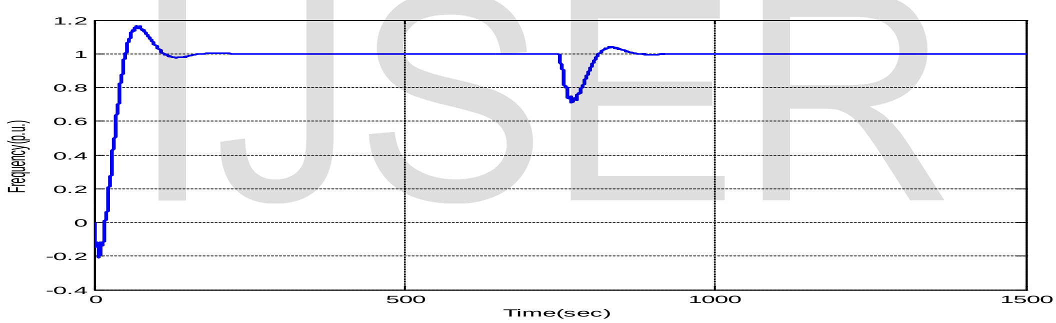
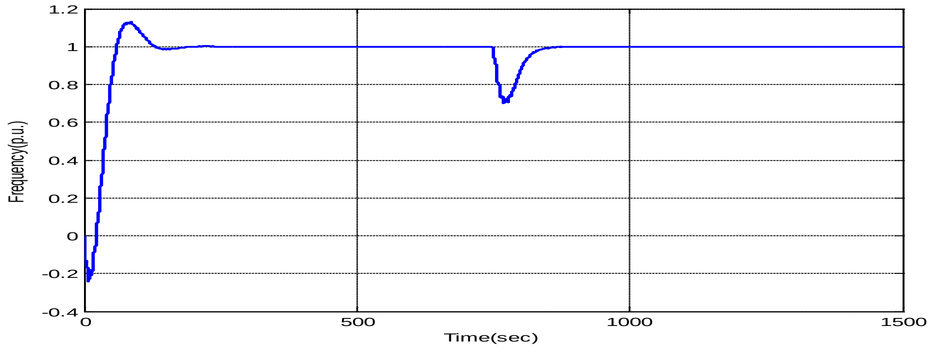
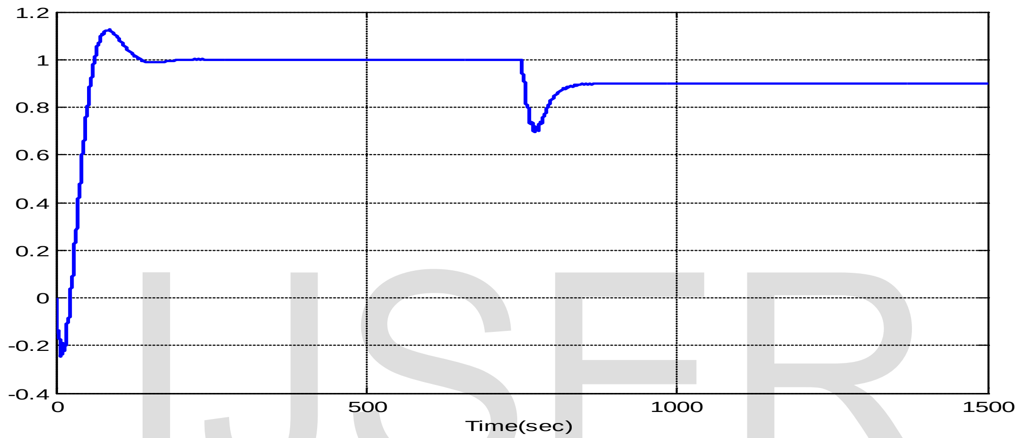


Figure 11: frequency response of linear model (head= 2 pu)



12: frequency response of linear model (head= 3 pu)



3 DISCUSSION AND RESULTS

3.1 Change in response

As the responses indicate, when for units work at the same time, change of behavior occurs and disturbs the station performance. Investigating the changes and their resource is necessary. Since many causes bring about a change of behavior, it is difficult to explain the reason of the event occurrence. However, the possibility of following reasons should be studied:

1. When the system works with four units, the system gets more sensitive to parasites and power change.
2. When the system works with four units, the guide vane is in a completely open situation. This state could influence water pressure and provide the opportunity for change of some of the parameters.
3. Poor connection point of the units could increase the changes.

3.2 Effect of adjusting velocity gain

The system gets steadier with change of gain from 0.0001 to 0.0004 in the system controller. In other words, with increase of the gain value, error signals increase up to four times and mechanical powercould improve the unsteadiness margin.

3.3 Impacts of controller gains

Primary values of controller gains equal k_i= 0.187 and k_p=0.13. In order to evaluate PI gains, the values have a four- fold increase. The results indicate that the new controller has a more undesirable unsteadiness. However, another factor makes engineers select lower gains. The mentioned factor is business requirements. Moreover, increase of gains leads to increase of response velocity. Therefore, the gains should be selected in a way that leads to achievement of goals. The result of system investigation in different values of k_p approves that decreasing the gain does not influence steady-state of values, however, applying the gain will have a desirable response.

3.4 Impact of MLD

The application of MLD shows that considering more factors and parameters in linearization processes leads to more correct linear responses. An investigation into MLP model indicates that number of active units and amount of power plant pressure severely influence responses. Furthermore, in comparison with other developed methods of linearization, MLD is more sensitive to PID controllers of gain. Therefore, adjusting process needs more concentration.

4 CONCLUSION

The present paper presents a special method of simulation related to Dinorwig pumped-storage power station. The simulation could be done via Matlab and Simulink software or other power distribution software such as d SPACE. The simulation is useful and it could increase power plant efficiency. The advantage of modeling method is that it could provide more information for power plants. The information indicates mutual acts among different parts of the system. The present paper confirm that correctness of the whole model associates with the parameters. In the case of Dinowig power station that velocity and output power are relatively high, nonlinear model is more accurate. The advantage of linear model is that controller parts could systematically be adjusted via Bode diagram; however, the adjusting process is sensitive to governor inputs.For instance, a little disturbance in power, brings about new values of PID gain, in other words, the controller should be adjusted based on starting time and moving time of the wave. Although system performance is disturbed with the adjusting process of the linear system, the advantage is that it is easy to determine its stability and operating condition. According to the theory of electric power distribution, it is clarified that frequency change in the grid depends on change of the active power; moreover, voltage change in the grid is in accordance with the change of the active power.The present paper emphasizes the active power. Impact of all machines, and the relation between grids and loads nature are complicated issues presented in modeling electric power system. Consequently, simple model of the grid has been studied in the project. The project has assumed that effective factors on system transient behavior are constant. A linear model has been prepared for the power system. Since comparing with the total power generated in the grid, the electric power generated in Dinorwig is smaller, using this linear model is acceptable. However, non-linear model is used in the simulation to achieve more accuracy. The applied controller consists of two loops including power and frequency controllers. In order to adjust PID controller, test and error methods have been used, moreover, the obtained gains have indicated similar simulations. In some of the developed power stations, digital controllers with PLC programming will be used at different states to have more flexibility. The actuator model which is responsible for the movement of the guide vane will be introduced via time constants. Applying the averaging filter is suggested to limit undesirable filters; moreover, frequency analysis is needed to recognize the value of this filter.

The following fuzzy controller advantages are the main motivations for performing the governor in the project.

1. The fuzzy controller is the best options for managing nonlinear systems features.
2. The fuzzy controller presents a response with little increase of time and a very little overshooting.
3. Fuzzy controller is the best choice for systems that include parasites.
4. Fuzzy controller has more stability.
5. There is a high sensitivity to low change in the load value and input (in this case: frequency).

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