



Optimal transient droop compensator and PID tuning for load frequency control in hydro power systems



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ABSTRACT

This paper presents an optimal method to tune the Proportional, Integral and Derivative (*PID*) controller for a hydraulic turbine coupled with the corresponding Transient Droop Compensator (*TDC*). The proposed methodology is based on the Desired Time Response Specification (*DTRS*) of the input guide vane servomotor that includes typical rate limiters and gain saturation in power plants. Therefore, the problem consists of adjusting both the parameters of the controller and compensator such as the time response remains close to the specified one. To avoid suboptimal solutions at local minimum points, it is necessary to solve the resulting non linear problem in two steps: (i) firstly, solve a linear programming (*LP*) to determine the values of *PID&TDC* block using state space representation to match the input and output time responses specifications and (ii) determine the final values of the *PID* and *TDC* parameters using the previous results in a new non linear programming. The proposed methodology has presented the advantage of tuning the *PID* coordinated with the *TDC* spending low computational time. The results show that the performance of the method covers a wide range of operating conditions of the system. Comparisons were also made with existing methods in the literature to show the effectiveness of the proposed methodology.

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Introduction

One of the most important roles in power system operation is to maintain a continuous energy power supply to the consumers considering quality and security requirements. This objective is achieved by matching the total generation with the total load by using the well known Load Frequency Control (*LFC*) [1], which is responsible to eliminate the frequency deviation and to maintain the active power flow in tie lines in specified values. As the power demanded by the loads change, the system can have several equilibrium points to operate in steady state. The *LFC* has to assure that the system dynamical behaviour, in the transition between the reachable equilibrium points, respect some requirements such as minimum oscillations. To achieve these tasks the Proportional and Integral (*PI*) controller has been widely used and recently the Proportional, Integral and Derivative (*PID*) controller has been studied to improve the results of the *LFC* design [2].

In terms of control techniques for the *LFC* design, the modern optimal control theory allows the calculation of the control system parameters with respect to a given performance criterion as

described in [3]. However, its feasibility requires the availability of all the state variables to generate the feedback signal, which is possible if the system state vector is observable from the area measurements [4,5].

The adaptive method is characterized by designing the controllers in order to make them less sensitive to changes in plant parameters and to non-modelled dynamics. The self-tuning controllers are designed to track the operating point of the system updating the controller parameters to achieve an optimum performance [6,7]. Despite the promising results achieved by adaptive controllers, the control algorithms are complicated and require on line system model identification. These efforts seem unrealistic, since it is difficult to achieve them [4].

The Robust control design approaches [8,9] have been tested in the *LFC* design and they allow utilization of physical understanding of power systems and to consider some uncertainties for the synthesis procedure. However, large model size and the elaborate organizational structure of power systems make their direct utilization on these systems too difficult.

Another class of methods for the *LFC* problem is the intelligent approaches using soft computing techniques as well as artificial neural network (*ANN*) [10], fuzzy logic [11–13], genetic algorithm (*GA*) [14,15], particle swarm optimization (*PSO*) [16,17] and bacteria foraging optimization [18].

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As well discussed in these references, the *LFC* regulator based on nominal system parameters values is certainly not suitable resulting in a degraded system dynamic performance and sometimes also in the loss of system stability. Thus, the design of a *LFC* with adequate performance requires the tuning of the controller parameters to maintain the frequency even under system condition variations. This problem becomes more important in hydraulic plants because the water starting time parameter (T_w) of the hydro turbine is dependent of the active load condition and also requires a Transient Droop Compensator (*TDC*) to minimize the inverse response characteristic. In addition, the load damping ratio (D) varies with the active load operating point leading the load and machine oscillations to other mode shape.

In the literature, it is possible to find some works that deal with the *LFC* control design considering hydraulic turbines. Ref. [19] considers the hydro turbine dynamics represented by a non minimum phase system and the generation constraints but it not considers the variation of T_w or D with the load. Work [16] used the non minimum phase system representation and it has considered the generation constraint but has not computed the variation of T_w and D with the active load condition. Article [20] had studied the effects of the variation of other parameters of the system to test the robustness of their method, although the parameters considered has not taken in account the variation of T_w and D with the load condition. In [21], the dependence of T_w with the load was considered, but the authors tested only the worst case scenario considering the value of T_w for the maximum load condition.

As already described, the revised works have not been dealing with variation of both parameters T_w and D along the active load condition. It is also common in literature to tune the *PID* controller separately from the transient droop compensator. Seeking for a faster and more efficient methodology for Load Frequency Control (*LFC*), this paper presents the development of a novel control design approach named Desired Time Response Specification (*DTRS*) technique based on the input guide vane servomotor (*IGVS*). This feature results in the following advantages:

- (i) the action of the *IGVS* device is specified for having smooth movements without physically impact in the gate. It must be emphasized that this specification is part of the control design process, and the same desired output behaviour may be applied to hydraulic power plants with different capabilities;
- (ii) one of the main advantages of the proposed methodology is that the proportional-integral and derivative gains of the *PID* controller, the dash-pot constant and temporary drop of the *TDC* are tuned together. This approach results in a lower stabilization time with reduced impact on *IGVS*;
- (iii) the *PID* and *TDC* can be tuned considering different operational point conditions, where both the water time delay (T_w) and load damping (D) vary together in a large range;
- (iv) the performance of the *DTRS* method is suitable to operate interconnected power systems, even for abrupt changes in load conditions;
- (v) as the *DTRS* design is to specify just the time response of a physical variable, it allows different analysis without deep knowledge in control techniques.

Standard *LFC* design

This section presents the standard *LFC* by using the *PID* controller for a hydro turbine with transient drop compensator (*TDC*). Considering small deviation of the frequency, the turbine and the corresponding speed governor control can be represented as a

linearized block diagram. Fig. 1 shows the block diagram of control for an isolated hydro turbine power system.

where:

- T_R Dash-pot constant or Reset time in sec;
- R_t Temporary droop parameter. R_t can range from 0.01 to 1.2;
- R_p Permanent governor speed regulation parameter. R_p is usually equal to 0.05;
- Δ_{TC} Represents the output of the transient compensator or the gate servo input (pu-Mw);
- T_G Speed governor time constant in sec;
- Δ_{GV} Speed valve of the governor (pu-Mw);
- $\frac{1}{R}$ Droop characteristic (pu-Mw/Hz);
- T_w Water starting time in sec;
- Δ_{PL} Active power load perturbation (pu-Mw);
- Δ_{PG} Active power generation (pu-Mw);
- T_{ps} Power system time constant $T_{ps} = \frac{2H}{Df}$, $f = 60$ Hz ;
- H Machine inertia in sec;
- D Loading damping ratio (pu-Mw/Hz);
- Δ_{FR} Frequency variation (Hz);
- K_{ps} Power system gain (Hz/pu-Mw); $K_{ps} = \frac{1}{D}$;

$X_{GV}^{open, close}$

The speed valve limiter;

$X_{CV}^{open, close}$

The position valve limiter.

A supplementary control action must be used to maintain the nominal value of the frequency. The (*PID*) controller has been investigated for this task. In order to reduce the noise effect the *PID* design can be set as:

$$PID(s) = K_p + \frac{K_i}{s} + \frac{K_D \cdot s}{1 + s \cdot T_D} \quad (1)$$

Where K_p , K_i and K_D are the proportional, integral and derivative gains, respectively. T_D is the derivative filter constant that is used to avoid the noise effect. The design of any supplementary controller for a one machine system is the best place to begin an evaluation of the *PID* controller. After that the global performance is assessed for a two machine system.

As well known, the hydro turbine having a positive zero resulting in a non minimum phase characteristic leading to inverse output of the turbine. For this reason, the system may become unstable for traditional gains. Then, a Transient Droop Compensator (*TDC*) should be included in the speed regulator to improve the stability of the plant. Usually, the *TDC* parameters have been calculated as proposed in Ref. [1]:

$$R_t = [2.3 - 0.15(T_w - 1.0)] \cdot \frac{T_w}{2H} \quad (2a)$$

$$T_R = [5.0 - 0.50(T_w - 1.0)] \cdot T_w \quad (2b)$$

Proposed *PID* and *TDC* tuning

The proposed formulation has five variables that need to be determined at the same time, K_p , K_i and K_D of the *PID* controller and T_R and R_t of the transient droop compensator. In this work, the derivative filter constant (T_D) is considered equal to 0.01 as suggested in [22]. For the application of the proposed methodology, the standard representation of Fig. 1 should be redrawn as shown in Fig. 2. It can be seen that the new third order block includes the droop characteristic, *PID* and *TDC*.

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