Advanced in Control Engineering and Information Science

Frequency-load control based on auto-tuning neurons for ship power station

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Abstract

The design of frequency-load controller greatly affects the performance of a ship power station. A common strategy to control frequency and load of the ship power station is to use speed regulator with a PI controller, these schemes require proper and continuous tuning, frequency and load of the diesel-generator are separately controlled, but frequency regulation and load distribution among parallel synchronous generators are interacted. A new parallel PID control technique based on auto-tuning neurons used as a modified hyperbolic tangent function is proposed in this paper, which specialized for frequency-load regulation of the ship power station. Simulation and experimental results show that proposed scheme can achieve an appropriate frequency-load control among parallel synchronous generators, and ensure their stable and economical performances.

Keyword: Ship power station; Frequency-load control; Controller design; PID; Auto-tuning

1. Introduction

It is well known that the use of PID controller is wide-ranging in control engineering and is acceptable for its simplicity in architecture [1]. Hence, PID controller is still widely used in ship power station even though many novel control techniques have been brought forward. In this paper, we focus on parallel synchronous generators. The frequency-load control of an interconnected ship power station plays an important role in parallel synchronous generators in accordance with load changes. Control action of the speed regulator is essential for maintaining system frequency and interchange of power at their specified values. Speed-frequency control system based on sliding mode control (SMC) scheme of the marine diesel-generator is introduced in [2], the SMC scheme consists of a speed regulator and an auxiliary loop incorporating current signal which is used to compensate for the influence of generator load current. [3] focuses on a control application of marine power management system (PMS) based on model free adaptive (MFA), MFA controller consists of a conventional governor and a feedforward current control.

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robust control scheme is introduced for the load-frequency control of an interconnected power system with uncertain parameters [4], the robust control is combined with the SVD technique and the Riccati equation approach. In fact, PMS controller is designed for single-variable control system; it doesn’t guarantee the stability and desired performance of interconnected ship power system.

At the present time, the same type of multiple diesel-generators usually operates in parallel to provide electricity for ship power system, how many parallel operations of diesel-generators depend on how much electricity on board. However, the capacity of the ship power station is small, its electrical parameters is vulnerable to disturbance with the external load changes, thus affecting the quality of power supply and resulting in abnormal electrical equipment on board [5]. Therefore, it is necessary to use automatic frequency-load regulator, it maintains that all the parallel operation of diesel-generators at rated frequency and rated voltage (within a certain deviation) in operating conditions; but also to ensure reasonable power distribution among parallel diesel-generators. Different adaptive control techniques have been proposed for the frequency-load control of interconnected power systems, such as variable structure controller [6], robust controller [7] and adaptive controller [8]. All the techniques discussed [2-8] are based on a centralized design approach, and don’t directly apply to interconnected ship power systems.

Ship power station usually consists of 3 sets of diesel engines and synchronous generators; its speed regulator based on PID algorithm controls the frequency and load of ship power station, power current reflects diesel-generator load. The above control strategy requires speed error signal and current signal, the former used to maintain the rate frequency, the latter used to feedforward control. On the other hand, the auto-tuning neurons have been used in control system design due to their powerful learning and adaptive abilities [9]. Adaptive PID controller based on auto-tuning neurons for MIMO systems has proposed [1].The main idea of these papers is that output nodes of the fully connected neurons are regarded as the PID control parameters.

This paper presents a novel methodology for design of frequency-load controller for multi-units interconnected ship power system. The proposed parallel PID control scheme is realized by introducing a modified sigmoid function used as the activation function of an auto-tuning neuron, where the function range and shape can be automatically adjusted on-line. Multiple PID work in parallel with the coupling control function, which can automatically control frequency-load of parallel synchronous generators. The proposed scheme can achieve an appropriate frequency-load control among parallel synchronous generators, and ensure their stable and economical performances.

2. Frequency-load controller design based on auto-tuning neurons

Ocean-going ship power system as an example, the system is equipped with 3 sets of the same type of the same capacity diesel engines (DE) and synchronous generators (G), the novel control system design shown in Fig.1. The ship power control system mainly consists of PC, auto-tuning neurons and parallel PID controller, each DE is equipped with an adaptive PID controller, which is connected with auto-tuning neurons. A simple architecture for the parallel PID controller tuning based only on the auto-tuning neurons, the gains of the parallel PID controller are directly tuned on-line by using these independent auto-tuning neurons.

Frequency regulating and power balance among parallel diesel-generators (DG) is completed by the adaptive PID controllers; PID output is converted into PWM signal and is transmitted to the governor, the frequency (speed)-load of parallel DG is controlled on-line auto-tuning neurons. Engine speed ($n_i$), frequency ($f_j$) and active power ($P_j$) ($j$=1,2,3) of generators through each transmitter into standard signals, as feedback signals input PC.
3. Frequency-load control strategy

Frequency stabilization and active power distribution of parallel diesel-generators (DG) depend on each DG speed characteristics, that is, the frequency-active power characteristic curve. In the regulating process of the frequency and load, the auto-tuning neurons utilize the relevant generators frequency and active power signals, the parallel PID controller gains are derived from the on-line tuning algorithms based on auto-tuning neurons. The parallel PID controller outputs PWM signals to each governor, the governor based on actuating motor acts on the fuel rack of diesel engine, to increase or decrease the amount of diesel engine fuel injection, consequently, to control the drive torque of generator, as a result, to maintain the constant frequency and adjust active power output of diesel-generators. The automatic control flow charts of bus frequency and generator active power are shown in Fig.2 (a) and (b)
4. Parallel PID controller based on auto-tuning neurons

The discrete-form of PID can be given as

\[ u(k) = u(k-1) + K_p [e(k) - e(k-1)] + K_i e(k) + K_d [e(k) - 2e(k-1) + e(k-2)] \]  

(1)

Where \( K_p, K_i \) and \( K_d \) are the proportional gain, the integral gain and the derivative gain, respectively.
From [1], the auto-tuning neuron is given by

$$ O = h(x) = \alpha \left[1 - \exp(-\beta x)\right]/\left[1 + \exp(-\beta x)\right] $$

(2)

Where $O$ is the output of neuron; the activation function $h(x)$ is a modified hyperbolic tangent function, $x$ is the input of the neuron; $\alpha$ is the saturated level, and $\beta$ is the slop of function. The output range and the curve shape of $h(x)$ in an auto-tuning neuron are determined by two adjustable parameters $\alpha$ and $\beta$.

The cost function $J$, as follows:

$$ J(k + 1) = \sum_{j=1}^{n} e_j^2(k + 1)/2 \rightarrow \min $$

(3)

e$_j$ is the difference between the $j$th actual output ($y_j$) and $j$th desired output ($y_{dj}$), that is, $e_j=y_{dj}-y_j$.

Using the chain rule of differentiation, the adaptive law is given by

$$ \frac{\partial J}{\partial \alpha_j} = \frac{\partial J}{\partial y_j} \frac{\partial y_j}{\partial u_j} \frac{\partial u_j}{\partial o_j} \frac{\partial o_j}{\partial \alpha_j} ; \quad \frac{\partial J}{\partial \beta_j} = \frac{\partial J}{\partial y_j} \frac{\partial y_j}{\partial u_j} \frac{\partial u_j}{\partial o_j} \frac{\partial o_j}{\partial \beta_j} $$

(4)

From (3), we obtain

$$ \frac{\partial J}{\partial y_j} = -e_j $$

(5)

Furthermore, from (1), we have

$$ \frac{\partial u_j}{\partial o_j} = \begin{cases} e_j(k) - e_j(k-1) & \text{if } l = 1 \\ e_j(k) & \text{if } l = 2 \\ e_j(k) - 2e_j(k-1) + e_j(k-2) & \text{if } l = 3 \end{cases} $$

(6)

when $l=1,2$ and $3$, the output of auto-tuning neuron is $K_{pj}$, $K_{ij}$ and $K_{dj}$, respectively.

From (2), we have

$$ \frac{\partial o_j}{\partial \alpha_j} = \frac{o_j}{\alpha_j} ; \quad \frac{\partial o_j}{\partial \beta_j} = \frac{\alpha_j x_j}{2} \left(1 + \frac{o_j}{\alpha_j}\right) \left(1 - \frac{o_j}{\alpha_j}\right) $$

(7)

Combining (4)-(7), the steepest descent method is written as

$$ \alpha_j(k + 1) = \alpha_j(k) + \mu_j e_j \frac{\partial u_j}{\partial o_j} \frac{\partial o_j}{\partial \alpha_j} \text{sgn} \left[ \frac{\partial y_j}{\partial u_j} \right] $$

(8)

$$ \beta_j(k + 1) = \beta_j(k) + \mu_j e_j \frac{\alpha_j x_j}{2} \left(1 + \frac{o_j}{\alpha_j}\right) \left(1 - \frac{o_j}{\alpha_j}\right) \text{sgn} \left[ \frac{\partial y_j}{\partial u_j} \right] $$

(9)

Where $\mu_j$ is a small positive scalar for the $l$th auto-tuning neuron.

5. Simulations results

Typically, ocean-going ship power stations are using the same specification of the same type of diesel-generators; consequently, the control strategy applies constant-frequency and power-equalization method, the control flow charts are shown in Fig.2. The integrated signal ($\Delta e$) of power difference ($\Delta P$) and frequency difference ($\Delta f$) is applied to control diesel-generators, as shown in Fig.1, that is $\Delta e=\Delta f+\Delta P$. 

The control accuracy is $|\Delta f| \leq 0.2$Hz and $|\Delta P| \leq 3\%-5\%P_N$; if $\Delta e < 0$, then increasing the engine speed; if $\Delta e > 0$, then decreasing the engine speed.

The hardware-in-the-loop system consists of two CUMMINS diesel engines and two STANFORD synchronous generators, where the rate power $P_N=50$kw, the rate speed $n_N=1800$rpm and the rate frequency $f_N=60$Hz. The control system is realized by SIEMENS S7-300PLC, STEP7, DEIF PPU, PC and MATLAB. The simulations and results are shown in Fig.3, initialization parameters of frequency-load control system: sample interval $T_s=0.1$s, time constant $T_c=1.5$s and delay time $\tau=1$s; $K_p=1$, $K_i=1$ and $K_d=1$; $\alpha=1$, $\beta=0.15$; load disturbance is $10\%P_N$.

![Fig. 3. the simulation result of frequency-load control of parallel diesel-generator](image)
6. Conclusions

Novel auto-tuning neurons for parallel PID controller have been applied to frequency-load control of ship power station in this paper. The parallel PID gains are not fixed, but can be automatically adjusted by steepest descent method. According to the $\Delta e$ size, PWM is automatically selected. From the simulation result, it is obvious that frequency-load adjustment process will not produce fast and overshoot phenomenon.

Acknowledgements

This work is supported by China Ocean Shipping (Group) Company (COSCO) Research Project under Grant 2010-1-H-002.

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