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Genetic Electromagnetism-Like Mechanism Based Power System Optimization Research

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To solve the problem of energy conservation with power system functioning, we researched intensively into the theory about hydrothermal power system energy-saving and the single-objective, multi-objective energy-saving regulation model building and optimizing approaches in this paper, surrounding the joint optimal regulation on hydrothermal power systems, in response to the complex space-time coupling between hydrothermal power systems with cascaded hydropower station, with a view to the rational and efficient utilization of hydropower resources and the saving of such non-renewable energy as coal. By building the compatibility conditions for hydropower station operation and the dynamic mathematical model of discarded water, a dynamic generating flow rate limit based optimal single-objective energy-saving regulation mathematical model for hydrothermal power systems is proposed. In response to the strong nonlinearity of built model, a genetic electromagnetism-like mechanism based energy-saving regulation model solution was proposed. This experimental study suggests that the genetic electromagnetism-like mechanism works in solving strongly nonlinear optimization problems. Thereby, power complemented with thermal power is an effective means to promote the power system efficiency and energy efficiency and to save non-renewable energy.

1. Introduction

As the most common form of clean power complemented with thermal power, hydrothermal power system plays a significant role in promoting the energy-saving and comprehensive economic efficiency of power system (Imani et al., 2013). According to the analysis of theory about hydrothermal power system energy-saving (Zhang et al., 2013), in order to bring complementary operation of hydrothermal power system into full play (El-Hana Bouchekara et al., 2016), the use of such non-renewable energy as coal should be minized on the basis of operating characteristics of hydropower station and thermal power plant (Wu et al., 2014), by making the most of interaction between hydropower and thermal power, provided that water resources are sustainable (Lei et al., 2014).

In power systems with cascaded hydropower station and thermal power plant, cascaded hydropower station can improve the utilization efficiency of hydropower resources through their recycling (Costanzo et al., 2014). It makes for the energy-saving operation of power system to bring the displacement of hydroelectric power into full play so as to promote non-renewable energy conservation (Wu et al., 2017). In this paper, energy-saving regulation model building and optimal model solution are investigated (Ning et al., 2013; Zhu, 2015), with a view to fully utilizing hydropower resources and saving such non-renewable energy as coal, on the premise of sustainable utilization of hydropower resources and on the basis of interaction between hydrothermal power systems (Mejbri et al., 2013).

To solve the problem of energy conservation with power system functioning, this paper researched intensively into the theory about hydrothermal power system energy-saving and the single-objective, multi-objective energy-saving regulation model building and optimizing approaches, surrounding the joint optimal regulation on hydrothermal power systems, in response to the complex space-time coupling between hydrothermal power systems with cascaded hydropower station, with a view to the rational and efficient utilization of hydropower resources and the saving of such non-renewable energy as coal. By building the compatibility

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conditions for hydropower station operation and the dynamic mathematical model of discarded water, a dynamic generating flow rate limit based optimal single-objective energy-saving regulation mathematical model for hydrothermal power systems is proposed. In response to the strong nonlinearity of built model, a genetic electromagnetism-like mechanism based energy-saving regulation model solution was proposed.

2. Dynamic Discarded Water Mathematical Model for Hydropower Station

2.1 Discarded water mathematical model for a single hydropower station

During operation, a hydropower station sometimes produces discarded water unavoidably due to the constraints of reservoir regulating characteristics, balanced distribution of hydropower resources, and other objective reasons. For a single hydropower station, discarded water means insufficient utilization of hydropower resources, which reduces the comprehensive economic efficiency of hydropower station. Thus, discarded water produced for subjective reasons during hydropower station operation should be minimized by improving the accuracy of hydropower resource forecast, making a reasonable regulation scheme, or other means. In order to fully utilize hydropower resources to improve the comprehensive economic efficiency of hydropower station, the water level of hydropower station reservoir is supposed to be the highest level, and the generating flow rate is then less than inflow rate and less than Q_{opt} and Q_{max}. In this case, considering Q_{max} as the discarded water limit will reduce the efficiency of water energy conversion into electric energy; considering Q_{opt} as the discarded water limit will cause an increase in total volume of discarded water but it can also improve the comprehensive efficiency of water energy utilization and the comprehensive economic efficiency of hydropower station. If Q_{opt} is less than Q_{max} in actual operation, it is still reasonable to take Q_{max} as the discarded water limit. Thus, Q_{opt} and Q_{max}, whichever is less, should be taken as the discarded water limit. The discarded water model for a single hydropower station can be formulated into:

$$\begin{aligned} & Z_{\mathrm{u}} = Z_{\mathrm{u,\ max}} \\ & Q_1 > \min(Q_{opt}, Q_{\max}) \\ & S = Q_1 \quad \min(Q_{opt}, Q_{\max}) \end{aligned} \tag{1}$$

This discarded water model of Formula (1) retains the advantage of forced discarded water strategy: hydropower resources are stored in the reservoir as many as possible. Besides, since the optimal generating flow rate Q_{opt}, determined according to the integrated compatibility conditions, reflects the coordinative relation between water head, head loss, and generating flow rate, it can coordinate water for power generation with generating capacity, conducive to promoting the comprehensive economic efficiency of hydropower station.

2.2 Discarded water mathematical model for cascaded hydropower station

According to the operating characteristic analysis of cascaded hydropower station, the inherent time-space coupling between hydropower stations makes it possible that the hydropower resources of upstream station are reused by downstream stations. If a dynamic discarded water model integrating the useful discarded water strategy for cascaded hydropower station with the dynamic discarded water strategy for single hydropower station is built, it would further tap the power generating potential of hydropower stations and raise their substitution effect in hydrothermal power system, promote saving of such non-renewable energy as coal, and improve the comprehensive economic efficiency of hydrothermal power system.
$Z_{u,i}$, $Z_{u,max,i}$, denote the reservoir forebay water level and allowable highest water level of hydropower station i; $Q_{opt,i}$ denotes the optimal generating flow rate depending on water head and head loss of hydropower station i; $Q_{max,i}$ denotes the allowable generating flow rate of hydropower station i; $\triangle E_i$ denotes the change in integrated output of hydropower station i. According to the mathematical model of dynamic discarded water strategy for single hydropower station and the basic principle of good discarded water strategy for cascaded hydropower station, the mathematical model of dynamic discarded water strategy for cascaded hydropower station can be formulated into (2).

$$\begin{aligned} & Z_{\mathrm{u,\ i}} \leqslant Z_{\mathrm{u,\ max,i}} \\ & Q_1 = \min(Q_{opt,i}, Q_{\max,i}) \\ & \Delta E < \sum_{i=i+1}^{N} \Delta E_i \\ & S = Q_0 \quad \min(Q_{opt}, Q_{\max}) \end{aligned} \tag{2}$$

Obvious from Formula (2), the built dynamic discarded water model for cascaded hydropower station allows for the coordinative relation between water for power generation and generating capacity during single hydropower station operation, the time-space coupling characteristic of hydropower station, and the hydropower resources recycling characteristics of cascaded hydropower station. This model can promote the reasonable utilization of hydropower resources and give play to the strong point of hydroelectric energy complementation in hydrothermal power system, by coordinating local interests with overall interests.

3. Case Study of the Genetic Electromagnetism-Like Mechanism Based Energy-Saving Regulation Model Solution

3.1 Analysis of the energy-saving regulation model optimization results

On the basis of genetic electromagnetism-like mechanism, energy-saving regulation models for hydrothermal power system using static discarded water strategy and dynamic discarded water strategy respectively are solved. The optimization results with these two different discarded water strategies (Table 1) are analyzed and compared from the output of hydropower station and the coal consumption volume and rate of thermal power plant. Figure 1 shows the total output of hydropower station and thermal power plant with distinct discarded water strategies. Obviously, the integrated output level of thermal power plant is relatively stable, whether with static discarded water strategy or with dynamic discarded water strategy, while that of hydropower station varies a lot with the changing load. Thermal power plant mainly shoulders the base load, and hydropower station is responsible for peak load regulation, which is consistent with the concept of energy-saving regulation. It reflects the coordination of substitution efficiency with balance efficiency during hydrothermal power system operation, saving such non-renewable energy as coal sufficiently.

Table 1: Optimization results for thermal plants with different water spillage strategies

Project	Unit	Water spillage strategies	Guigang	Qinzhou	Liuzhou
Average output	MW	D	416.55	397.56	238.66
		S	440.80	217.98	220.57
Daily output	A hundred million kWh	D	0.1000	0.0954	0.0347
		S	0.1058	0.1055	0.0368
Daily coal consumption	Ton	D	3075.0	2868.6	1195.3
		S	3235.7	3142.2	1260.0
Average rate of coal consumption	g/kWh	D	307.6	300.6	344.4
		S	305.9	297.7	342.4

(Note: D refers to dynamic discarded water strategy; S refers to static discarded water strategy.)

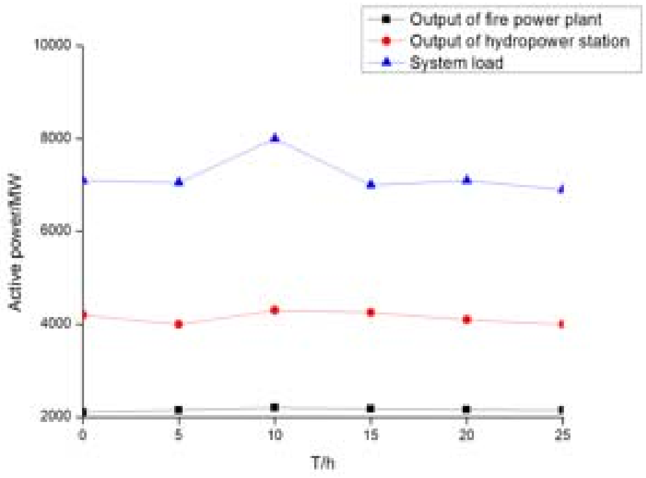
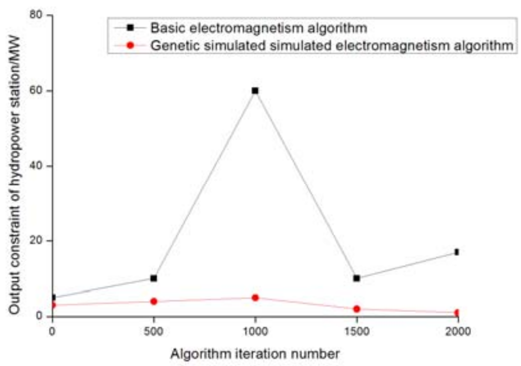


Figure 1: Power load, power generation of thermal plants and hydroelectric plants

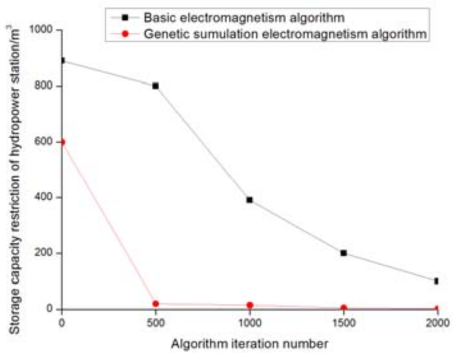
Seen from the effect of distinct discarded strategies on operating characteristics of hydropower station and thermal power plant respectively, both generating water head and generating capacity per unit of water of hydropower station using dynamic discarded water strategy are less than those of hydropower station using static discarded water strategy. It suggests that the water energy utilization efficiency of hydropower station using dynamic discarded water strategy is lower than that using static discarded water strategy. However, dynamic discarded water strategy can increase the total use of hydropower resources, with hydropower resource constraints satisfied, so as to raise the integrated output of hydropower station and promote the saving of such non-renewable energy as coal.

3.2 Performance analysis of genetic electromagnetism-like mechanism

Over genetic algorithm, electromagnetism-like mechanism has a significant advantage in convergence and efficiency of solving large-scale strongly nonlinear optimization problems. This paper focuses on the application of electromagnetism-like mechanism in optimal regulation of hydrothermal power system. For this reason, we only analyzed and compared the basic electromagnetism-like mechanism (BEL1V) and genetic electromagnetism-like mechanism (GAELM) in terms of optimization performance in energy-saving regulation model solving, in order to validate the effectiveness and superiority of genetic electromagnetism-like mechanism in solving large-scale strongly nonlinear optimization problems. Figure 2(a)-(d) show the changes in constrain violation of energy-saving regulation model during optimization with distinct algorithms; Figure 3 shows the changes in target function value of energy-saving regulation model during optimization with distinct algorithms.



(a)



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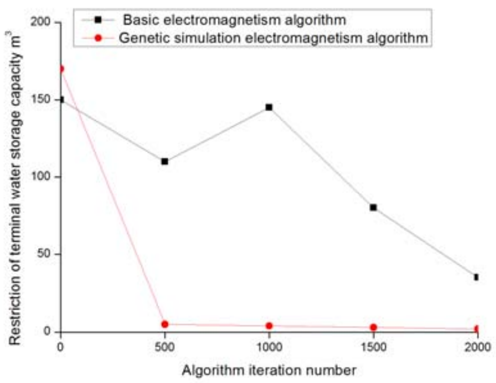
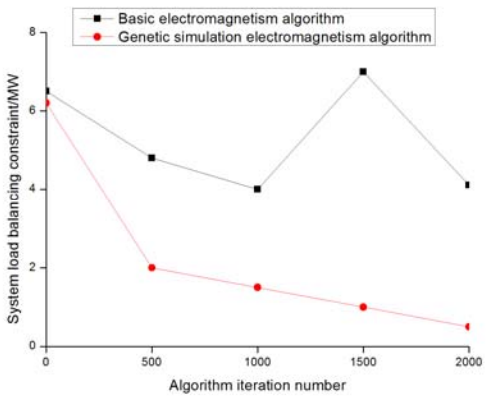


(c)



(d)

Figure 2: Constraint violations of optimization process for different ELM

Known from the changes in constraint violation of energy-saving regulation model during optimization with two electromagnetism-like mechanisms, the constraint violation of hydropower station output during optimization with basic electromagnetism-like mechanism cannot decrease with the increase in algorithm evolutional algebra. Although the reservoir storage, end reservoir storage, and load balance constraint violations are decreasing with the increase in algorithm evolutional algebra, the decrease speed is low and this decrease stagnates in the later stage. It is hard to satisfy constraints. During optimization with genetic electromagnetism-like mechanism, since electromagnetism-like mechanism and genetic operator are fully utilized, the constraint violation decreases rapidly and constraints are satisfied when the algorithm reaches termination conditions.

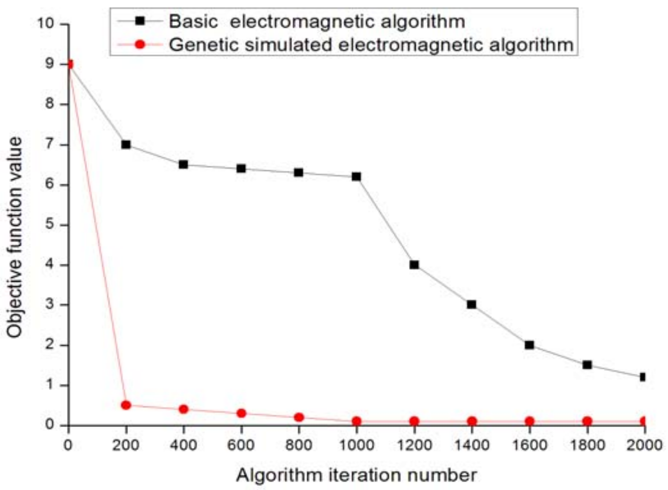


Figure 3: Objective function values of optimization process for different ELM

From the changes in target function value during optimization shown in Figure 3, the search performance of basic electromagnetism-like mechanism is poorest, and its target function value decreases mildly during optimization; in contrast, the optimization performance of improved electromagnetism-like mechanism is much higher, thanks to the improvement in charge quantity calculation, stress calculation, and global optimizing strategy, but this optimization stagnates in the later stage, due to the limitation of local search; genetic electromagnetism-like mechanism takes advantage of electromagnetism-like mechanism, as well as crossover operator and mutation operator in preventing the algorithm being trapped in local optimum, so its optimization performance is the best.

4. Conclusions

In this paper, on the basis of theory about energy-saving regulation of power system, the building and solving approaches for single-objective energy-saving regulation model of power system were studied and the energy-saving regulation model was solved with genetic electromagnetism-like mechanism, for the purpose of fully utilizing hydropower resources and saving such non-renewable energy as coal. In response to the strong nonlinearity of built energy-saving regulation model, genetic electromagnetism-like mechanism was used for model solving.

The analysis of optimization efficiency and constraint satisfaction level suggests that genetic electromagnetism-like mechanism could solve the energy-saving regulation model. The comparison between basic electromagnetism-like mechanism and genetic electromagnetism-like mechanism suggests that genetic electromagnetism-like mechanism, superior in both solving efficiency and solving accuracy, be applicable to solve large-scale optimization problems.

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