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러프 셋 이론을 사용한 HVDC 시스템을 위한 적응 Granule 제어

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Adaptive Granule Control with the Aid of Rough Set Theory for a HVDC system

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Abstract – A proportional intergral (PI) control strategy is commonly used for constant current and extinction angle control in a HVDC (High Voltage Direct Current) system. A PI control strategy is based on a stactic design where the gains of a PI controller are fixed. Since the response of a HVDC plant dynamically changes with variations in the operation point, a PI controller performance is far from optimum. The contribution of this paper is the presentation of the design of a rough set based, fuzzy adaptive control scheme. Experimental results that compare the performance of the adaptive control and PI control schemes are also given.

1. Introduction

From the beginning of electric power history, DC transmission lines and cables have less expensive and more advantageous than those for three-phase AC transmission. As power generation and demand are increasing, in order to handle large bulk of power, we need utilize the savings that DC transmission offers. Not only it is used for long distance power transmission, also it is being used as a part of the AC network to enhance the stability of the system[1].

But the operation and control of HVDC links pose a challenge for the designers to choose the proper control strategy under various operation conditions[2]. The HVDC system traditionally uses PI controllers to control the DC current thereby keeping the current order at the required level. However, in controlling a nonlinear plant such as the fire angle of the rectifier side in HVDC system, the model controls such as fuzzy controllers show better performance to the dynamic disturbances than traditional PI controllers[3].

Generally speaking, fuzzy controllers show good control performances when systems are complex and cannot be analyzed using traditional methods. But we cannot obtain good control performances if fuzzy membership functions are inaccurate. When designing fuzzy controllers, it's difficulty to determine shapes of membership functions that are usually obtained by a large of try-and-error or experiences of the human being experts.

To circumvent the above problem, in this paper, we study a new approach to design an adaptive granule control with the aid of rough set theory in HVDC system. Compare with traditional PI controllers, the proposed approach show the optimal performance in a larger change area of the operation system, and need not have accurate dynamic model. Via the experimental study dealing with the rectifier side current control, the proposed approach also have more robust and online learning capacity.

2. HVDC System Model

A two pole point-to-point HVDC system has been simulated under the environment of MATLAB[5]. Each element on either side of the DC link and the transmission lines is represented in detail.

2.1 HVDC system model

Generally speaking, the HVDC system can be divided into four parts - generator side, rectifier side, inverter side and the load bus. In this paper, we only discuss about rectifier side. It's not necessary to illustrate each part in detail in our model. So, we assume the inverter side and the load to be voltage resource. The system shown in Figure 1 is re-divided into four segments - generator, transformer including one Y-Y connection type and one Y-△ connection type, the 12-pulse rectifier consisting of two 6-pulse bridges in series and voltage resource containing inverter side and the load bus[6].

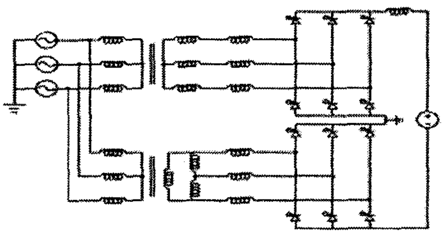


Figure 1 HVDC real model circuit

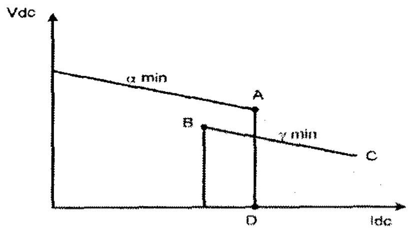


Figure 2 HVDC Control characteristic

2.2 Rectifier control system

The characteristic curve of voltage current control is operated through the constant voltage current control of a rectifier and a constant extinction angle control of an inverter in steady state, as show in Figure 2.

The constant voltage current control(AD) is the control that keeps the current of DC line uniform. The firing angle is adjusted with current error, to maintain the DC current constant. As shown in Figure 3, therefore, we use the firing angle as the output of rectifier current controller, whose inputs are current error and its derivative.

3. Proposed method of adaptive granule control design

The designed strategy of Fuzzy-PI controller based on Genetic Algorithms(GAs) has been applied[10].

The block diagram of Fuzzy-PI controller that was designed is shown in Figure.3.[8][10]

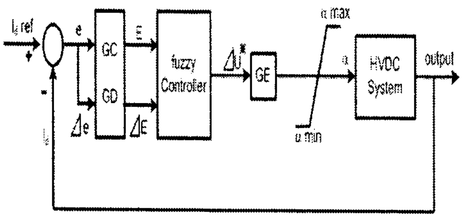


Figure 3 Block diagram of Fuzzy-PI controller

Here, the current error(e) and its derivative error(△e) are used to adjust the input variables(E, △E) by the scaling factors(GD, GE) that we can derive by means of the Genetic Algorithms (GAs).

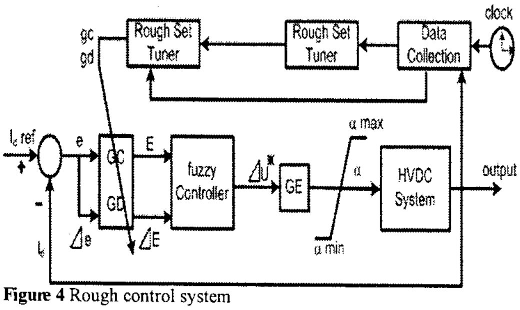


Figure 4 Rough control system

The proposed fuzzy-PI controller processes the input data by tuning the scaling factors (GC, GD, GE), whose output value is the firing angle. The parameters are set a fixed value preliminary, so materially speaking fuzzy-PI controller is non-time varying system .However, HVDC system is in time-varying system, the system operation parameters, input disturbance and operation target are varying momently. Due to the changes of performance index are not predictable, it is difficult to design the optimal time-varying controller of the determined program. In order to satisfy the demand of the parameters of fuzzy-PI controller to be tuned, adaptive granule control scheme is proposed (such as Figure. 4), In a word, the system clock is used to observe data collection and predict the overshoot, the undershoot, the rising time and IAE(Integral of the Absolute value of Error) of target. The result of data granulation is used to select the experiment result of optimal control rules, and then produce the adaptive parameters gc and gd. The case properties of being selected control rules have the closed property with the experimental result the constructed information granulation. Through selecting the suitable control rules, we can realize to tune the control parameters(gc, gd), so we can make the operation character of HVDC system optimal.

4. Implementation of Rough Control in HVDC System and Experimental Results

Section 3 describes the rough control scheme of the HVDC system simple. It consists of five components, i.e., fuzzy-PI controller, plant, data collection, rough set tuner and rough controller. General introduction of all components is presented in this section. Data collection that is the first step to apply rough control to the HVDC system is introduced in Section 4.1. After that, the rough set tuner, which establishes decision tables, is discussed in Section 4.2. Section 4.3 investigates the rough controller. Finally, The actual simulation of a typical HVDC system (plant) with a proposed fuzzy-PI controller with the aid of rough set theory is done in section 4.4. The rough controller performs the control on the adaptive fuzzy-PI controller, which in turn applies actual CC control onto the simulated HVDC system.

4.1 Data Collection

4.1.1 Selection of Suitable PI

Data collection monitors the plant, and samples real-time responses from the plant. We will define a performance index (PI) as"a functional relationship involving system characteristics in such a manner that the optimum operating conditions may be determined from it." Since optimum performance is based upon the IP used, the choice of a suitable PI for defining an optimum design (or an adaptive loop, as shown later) is a critical step to take. For that reason, only those most general interested and important characteristics, such as overshoot(Ov), undershoot(Us) rising time(Tr) and IAE, will be extracted and analysed by data collection, and used by both the rough tuner and rough controller.

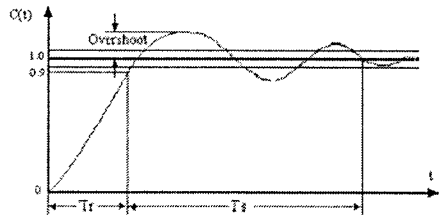


Figure 5 PIs of Id response defined from the step response

Figure 5 illustrates the PIs defined from the step response Id. These three values Ov, Us and Tr with the additional value IAE are corresponding to a pair of GC and GD. Time itself is measured relative to a clock, which measures durations in the context of information granules named early, on time, and late.

4.1.2 Multiple PIs and System Initialization

As we explained, one PI can be obtained from one pair of (GC, GD). To build an information system and perform our experiments, we need establish an initial decision system with multiple PIs. It is done by observing the step response Id from system with different controller gains (GC, GD). Ideally, we should initialize the control system with a large number of (GC, GD) pairs, which should be big enough to generate as many typical system step responses as possible.

In this paper, we first select the center values GC*=0.04 and GD*=0.008, or denoted by (GC*, GD*)=(0.04, 0.008). With the center values and assuming that GC=1/4 • gc • GC* and GD=1/8 • gd • GD* (gc, gd are the factors of GC, GD), we obtain a group of initial values of (GC, GD) by taking different parameters gc and gd. The distributions of gc and gd are drawn in Figure 6. The X-axle is the series number and the Y-axle is the values of gc or gd. With the initial set of (GC, GD), we then simulate the HVDC and all responses are recorded. As we know, for each unique combination of GC and GD, we will get one step response Id. It is a manual process. Of course, the final set of step responses obtained in this way does not include all possibilities. However, the sampling is good enough to reflect the important features of PI around the center (GC*, GD*).

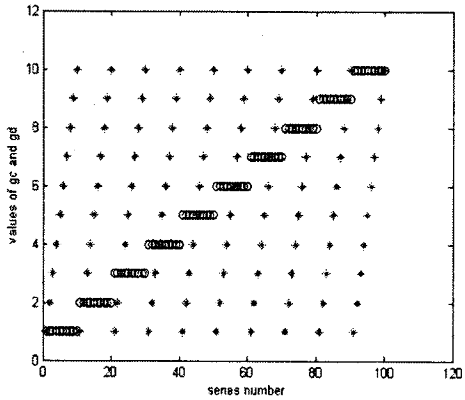


Figure 6 Distribution of the values of gc and gd in our simulations

4.2 Rough Set Tuner

In this section, we will deal with the simulation of the roughset tuner. The main functions of a rough set tuner comprise data granulation and decision table construction Values of PIs, which are the final results of the tuner, are the essences of adapting the parameters of fuzzy-PI controller.

4.2.1 GranulatePIs

In data collection, PIs (such as Ov, Ust, Tr and IAE) are used to characterize the step response Id. When all or some of PIs are collected, they are fed into sensors by the rough tuner to be granulated. There are four sensors, denoted as v1... v4, in which v1 is overshoot sensor, v2 is undershoot sensor, v3 is rising time sensor and v4 is IAE sensor.

These relationship functions for granular computation are made by a series of initial optimal values inquired by genetic algorithms (GAs). Before applying rough tuner system, we got a pair of optimal scaling factors (GC*, GD*, GE*) by GAs. And also we got a large number of PIs around the optimal scaling factors (GC*, GD*) introduced in section 4.1.2. The overshoot v1, undershoot v2, rising time v3 and IAE v4 take the division the collected data into the determined optimal parameters (GC*, GD*) for granular computation.

4.2.2 DecisionTable

The first step to establish a decision table is to characterize responses from the system for different controller gains, which has been done by data collection and data granulation. For each observed step response (i.e. Id is our case), we decide in the decision table the correction factors for both proportional and integral gains, which adjust the controller parameters in order to improve the performance. Controller parameter values (GC and GD) are inserted in a decision table by using a form of pattern recognition. Each decision value indicating a change in GC and GD is a judgment about the controller performance from a measured step response, and the observed response is compared to an ideal response. A decision table is constructed with four condition attributes: v1 for granulation of overshoot measurement, v2 for undershoot granulation, v3 for rising time granulation and v4 for IAE granulation. Sample rows from a rough controller tuning information table are given in Tables 1 and 2.

Table 1 Decision table for GC

	v1	v2	v3	v4	gc
1	-7	1	3	4	1
2	1	4	2	2	1
3	5	3	1	2	1
4	9	3	1	2	1
5	10	5	1	1	1
6	11	5	1	1	1
7	11	7	1	1	1

Table 2 Decision table for GD

	v1	v2	v3	v4	gd
1	-7	1	3	4	1
2	1	4	2	2	2
3	5	3	1	2	3
4	9	3	1	2	4
5	10	5	1	1	5
6	11	5	1	1	6
7	11	7	1	1	7

4.3 Rough Controller

In this section, we consider a method to determine changes in the system controller gains. There is a rule-firing algorithm to direct our choice of system controller gains (GC, GD), which is described as follows:

Step 1. Let x, v1, v2, v3, v4, a1, a2, a3, a4 be an experimental value observed during actual operation of a control system, sample decision system condition sensors for a sample control rule D(S), and sensor values from decision system table (U, V{d}, A), respectively. Let s be defined as a sum s = (v1(x) - a1) + (v2(x) - a2) + (v3(x) - a3) + (v4(x) - a4), where x is an input value (e.g. observed overshoot, undershoot, rising time, or IAE) evaluated with sensor vi in V (for example) to produce a particular value ai.

Step 2. Let n, m be the number of GC, GD rules, respectively. Let si, 1 = i =n, sj, 1 = j = m be sums of the form introduced in step 1 relative to n rules for GC and m rules for GD, respectively. Then let mgc, mgd be functions defined as follows as follows:

mgc: s1, ..., si, ..., sn -> i such that gc[i] = min(s1, ..., si, ..., sn)

mgd: s1, ..., sj, ..., sm -> j such that gd[j] = min(s1, ..., sj, ..., sm)

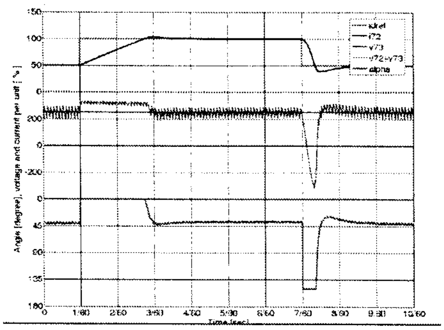
In other words, mgc, mgd each finds the index (i, j) of the smallest sum, which identifies the premise of a rule, which is closest to the measured condition during the operation of a controller.

Step 3. Let GC, GD be the current values of proportional and differential coefficients. Then compute GC=1/4 • GC* • gc[i] and GD=1/8 • GD* • gd[j].

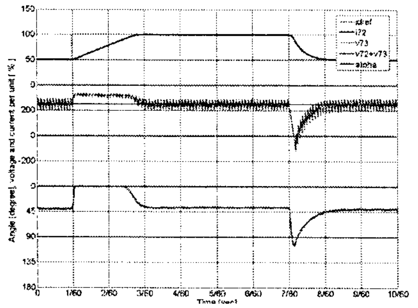
At this point, it should be observed that variations of step 3 of the rule-firing algorithm are possible. First, it has been found that it is helpful to change GD only if the percent of overshoot exceeds some k (e.g. k=0.1). Second, performance of the controller can be improved by constituting a population that will evolve. Such refinements of this algorithm are outside the scope of this paper.

4.4 Experimental Results

In this part, the fuzzy-PI adaptive granule controller is compared with PI controller in the same case. as shown in Figure 7.



(a)



(b)

Figure 7 (a) PI control (b) Fuzzy-PI adaptive granule control

Table 3 Compare Self-tuning Fuzzy-PI With Fuzzy-PI

	Fuzzy-PI adaptive granule control	PI
$J=\int_{0}^{t} \lvert e(\tau) \rvert d\tau$	J=1.1038	J=1.1323
rise time	1401 * dt	1403 * dt
overshoot	0.5545%	3.7330%
undershoot	-1.3016%	-21.661%

*note: dt = 0.25[sec]/15000[sample]

After comparison of self-tuning Fuzzy-PI controller with Fuzzy-PI controller, we know that the self-tuning Fuzzy-PI controller has better performance in terms of overshoot and undershoot, as shown in Table 3. Not only the overshoot and undershoot are decreased in self-tuning Fuzzy-PI controller, and also the performance index and rising time in self-tuning Fuzzy-PI controller are smaller.

5. Conclusion

In the paper, we have successfully proposed a rough control scheme, intended to improve the performance of a HVDC transmission system. Rough sets are used to measure system performance, extract features from the measurement of performance index PI, granulate obtained features, establish rough decision system, and fire suitable decision rules to control HVDC system and achieve better performance.

In addition to the theoretical analysis of our rough control scheme, we have also implemented the rough control scheme and completed the construction of the simulation environment successfully. We have exploited experimental results to establish a decision system, which guides us to obtain the optimal control parameters.

Finally, the performance of the fuzzy-PI adaptive rough control scheme have been demonstrated, when the HVDC system is in the single control mode, by applying it to the constant current control of the fuzzy-PI adaptive granular controller. The result shows many improvements by the rough control scheme, as compared with the conventional HVDC control scheme. It lead us to draw the conclusion that the rough control scheme performs in a manner comparable to or even superior to the classical PI control, when it is working under some control models, for example, the constant current control model.

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