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Variable Region Fuzzy Controller of ASVG based on Genetic Algorithm

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Abstract: Variable region fuzzy controller of ASVG based on genetic algorithm is proposed. In this method, the universe of discourse of the current loop fuzzy variables are converted, adopting genetic algorithm optimized proportional exponential contraction-expansion factor. The adaptive control of current loop is achieved. The adaptive fuzzy current controller with variable region of ASVG is designed using S-Function programming. The simulation experiment of ASVG is done. The simulation results show that compared with traditional PID control, ASVG based on variable universe fuzzy controller has the strong anti-interference performance and robustness. Quadergy is dynamically controlled, thereby the reliability of the power transmission system is improved and capacity is increased.

Key words: ASVG, fuzzy control, variable region, contraction-expansion factor

INTRODUCTION

Flexible AC transmission as a new technology in recent years can effectively improve the quality of power and it has obtained the rapid development. Compared with the traditional reactive power compensation device, the Advanced Static Var Generator (ASVG) as a new kind of flexible AC transmission system, has a fast response speed and more smooth adjustment feature. Due to the ASVG with excellent control performance and good compensation effect, it has become the current focus of research at home and abroad (Xue, 2012).

Generally, the ASVG through the voltage feedback of access point, use the traditional Proportional Integral Differential (PID) or the introduction of line Power System Stabilizer (PSS) auxiliary method to complete the control, but these ways are difficult to improve the dynamic stability and can't achieve the ideal performance (Mihallic *et al.*, 1996). The variable region fuzzy control based on traditional fuzzy control theory has many advantages such as: Don't need precise mathematical model, fast response speed, high precision, good robustness and so on. This study apply the variable region, adaptive fuzzy control which based on the genetic algorithm optimization into the current loop control of advanced static reactive power generator.

ADVANCED STATIC REACTIVE POWER GENERATOR CONTROL

Traditional PI control has a fast response speed but it also has some shortcomings in the dynamic

characteristics such as: High overshoot, long adjustment time and so on. However, fuzzy control as one of the branches of intelligent control has many characteristics such as: Strong robustness, easy to understand, simple operation, fast response speed, easy to fix, don't need system model. Because the fuzzy controller's input are error and error change rate in general, so it can be seen as a PD controller. Its dynamic characteristic is very good so it can reach steady state smoothly. Besides, its rise time and adjust time are very short. But its anti-interference performance is poor and it will produce static error at the same time. In order to enhance the ability of anti-interference performance and reduce the static error, the variable region fuzzy control and PI regulator are used in this study. Among them, the voltage loop requires good following performance, this study adopts PI controller and designs it as the typical type I system. In order to improve the system's ability to resist load disturbance and current fluctuations, current loop adopts the variable region fuzzy control. In this way, it has made the system response speed rapid, has a satisfactory control precision, easy to realize digital control and has a better control effect than traditional PI control. The structure of ASVG is shown in Fig. 1.

VARIABLE REGION FUZZY CONTROL

Theory of variable region: The essence of the fuzzy controller is interpolator (Li, 1998), fuzzy control which are obtained by interpolation function, whether it can fully close to real control function is depends on whether the distance between the peak point is sufficiently small and

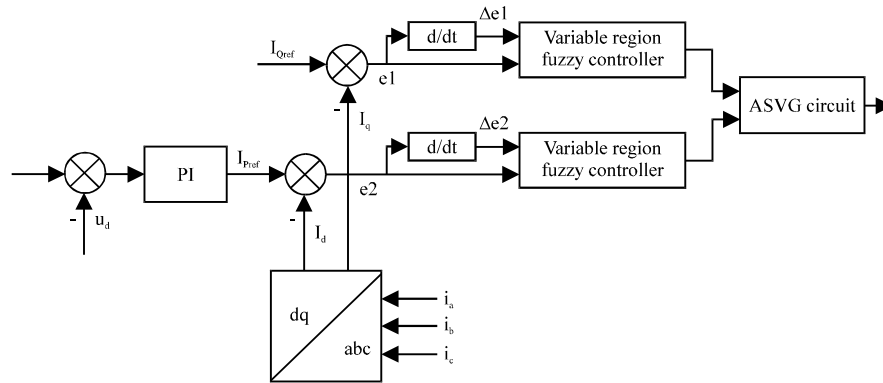


Fig. 1: Structure of ASVG

the control rules are enough. It is't real for fuzzy controller which rely on the domain expert knowledge to summarize the control rules. Thoughts of the variable region: Choosing the appropriate scaling factor at the premise of the fuzzy control rules are unchangeable, with error become smaller the initial region of the fuzzy controller will contract, or extend with error become larger (Li, 1997). Locally to see, the region's contraction is equivalent to the division of the fuzzy set of region is more close, the relative fuzzy language values of variables and the control rules are increased, it can simulate the ideal control function more accurately, so as to achieve the goal to improve the control precision. Assume that: the basic region of input variable $x_i (i = 1, 2, \dots, n)$ is $X_i = [-E, E]$ ($i = 1, 2, \dots, n$), the basic region of output variable y is $Y = [-U, U]$, $\{A_j\} \{1 \leq j \leq m\}$ is the fuzzy partition on the region of X_i , $\{B_j\} \{1 \leq j \leq N\}$ is the fuzzy partition on the region of y and fuzzy rules are:

$$\begin{aligned} \text{If } x_1 \text{ is } A_{1j} \text{ and } x_2 \text{ is } A_{2j} \text{ and } \dots \text{ and } x_n \text{ is } A_{nj} \\ \text{then } y \text{ is } B_j, \quad j = 1, 2, \dots, m \end{aligned} \quad (1)$$

where, set x_i , y_j are A_{ij} , B_j 's peak points of value, respectively. Theory of variable region is that the region of X_i and Y can change with the change of x_i and y , respectively. Set them as:

$$X_i(x_i) = [-\alpha_i(x_i)E_i, \alpha_i(x_i)E_i] \quad (2)$$

$$Y(y) = [-\beta(y)U, \beta(y)U] \quad (3)$$

In Eq. 2 and 3, $\alpha_i(x_i)$ ($i = 1, 2, \dots, n$) and $\beta(y)$ are contraction-expansion factors for the corresponding region.

Contraction-expansion factor for the variable region: In the process of variable region fuzzy controller's design,

the system need to improve the precision of control depends on the change of contraction-expansion factors. Contraction-expansion factors can be defined as changing regions' of control variables according to the current implementation of control index. It should meet the following conditions:

- $\alpha(0) = 0$
- α strictly monotone increase in scale of $[0, E]$
- $\forall x \in X$ meet $\alpha(x) = \alpha(-x)$
- $\alpha(\pm E) = 1$
- $\forall x \in X, |x| \leq \alpha(x) E$ is correct

For fuzzy control system of double input and single output, the input variables X and Y are often interrelated. Generally, take X for error e's region and take Y for the error rate of the ec's region. Therefore, $\beta(y)$ should be defined in $X \times Y$ that is $\beta = \beta(x, y)$, set $D = EC$, we can choose the Eq. 4 and 5 as contraction-expansion factors:

$$\beta(x, y) = \left(\frac{|x|}{E} \right)^{\tau_1} \left(\frac{|x|}{EC} \right)^{\tau_2} \quad (4)$$

$$\beta(x, y) = \frac{1}{2} \left[\left(\frac{|x|}{E} \right)^{\tau_1} + \left(\frac{|x|}{EC} \right)^{\tau_2} \right] \quad (5)$$

In Eq. 4 and 5, $0 < \tau_1, \tau_2 < 1$.

Design of current loop variable region fuzzy control:

Based on the theory of interpolation of fuzzy control, current loop of ASVG's fuzzy control can be expressed as a piece-wise interpolation function $F(x_1, x_2, \dots, x_n)$, the number of variable is n:

$$F(x_1, x_2, \dots, x_n) = y(x_1, x_2, \dots, x_n) = \sum_{j=1}^m \prod_{i=1}^n A_{ij}(x_i) y_i \quad (6)$$

The respective basic region of fuzzy controller's is completed through the corresponding effect of contraction-expansion factors. Under the initial region, $\alpha_i(x_i) = \beta(y) = 1$ and then $\alpha_i(x_i)$, $\beta(y)$ are changed with the change of input variable x_i and output variable y , respectively, so as to complete the region's conversion. The schematic diagram of variable region is shown in Fig. 2.

Equation 6 can be written as:

$$y(x(t+1)) = b(t) \sum_{j=1}^m \prod_{i=1}^n A_{ij} \left(\frac{x_i(t)}{a(x_i(t))} \right) y_i \quad (7)$$

Equation 7 is a variable piece-wise interpolation function in which the number of variable is n . The fuzzy controller of variable region is an adaptive controller, its adaptive law is reflected on the contraction-expansion factors α and β . In the fuzzy controller of double input and single output, based on the theory of variable region, the design of fuzzy control system is shown in Fig. 3.

Among them, $x(k)$ and $y(k)$ are two respective input variables of fuzzy controller, $\alpha(x(k))$ and $\beta(x(k), y(k))$ are the contraction-expansion factors of the input variables, respectively, $\gamma(z(k))$ is the contraction-expansion factor of the output, $F(x(k), y(k), k)$ is the approximation function of the fuzzy controller.

The current loop of ASVG adopts the method of the variable region fuzzy control, the error e and variation de are inputs, $[-e, e]$ and $[-de, de]$ are respective regions and

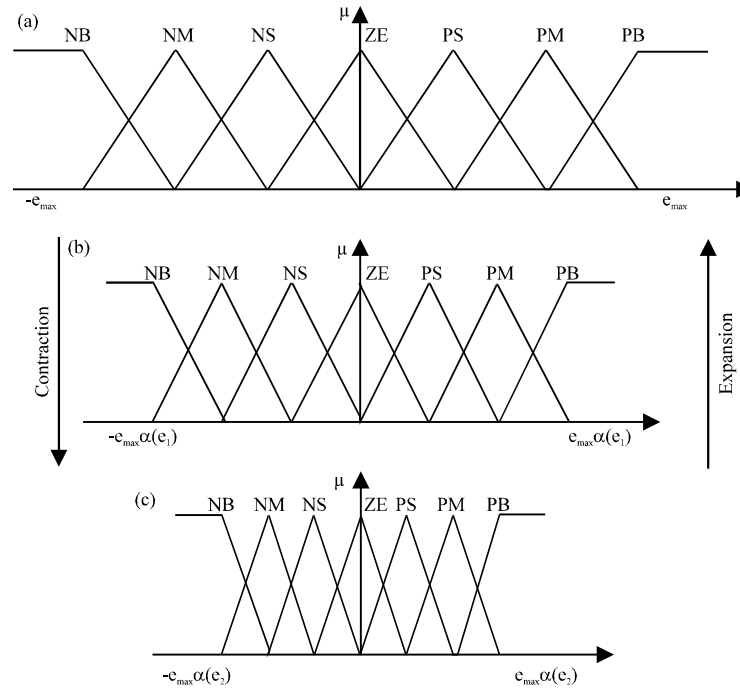


Fig. 2(a-c): Schematic diagram of variable region

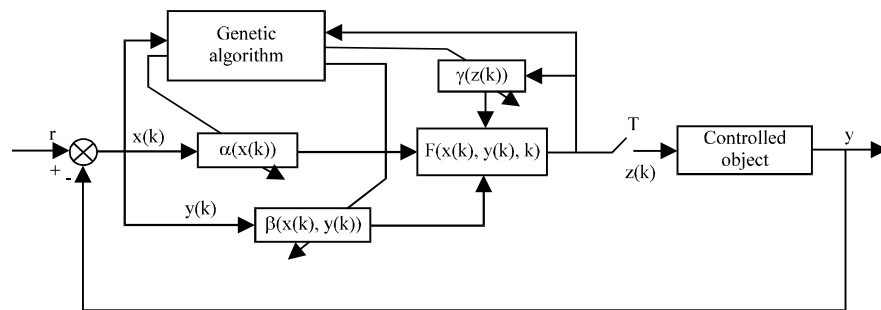


Fig. 3: Variable region fuzzy control system which optimized by genetic algorithm

$[-z, z]$ is the output z 's region. The output's region is changed with the input's region. The structure of the contraction-expansion factor can be built as follows (Pan and Song, 2008; Li *et al.*, 1997; Li, 1999; Park, 1994):

$$\begin{aligned} \gamma(e) &= w_1 \left[\frac{|e|}{r_e} \right]^{T_1} \\ \gamma(de) &= \frac{w_2}{2} \left\{ \left[\frac{|e|}{r_e} \right] + \left[\frac{|de|}{r_{de}} \right] \right\}^{T_2} \\ \gamma(z) &= w_3 \left[\frac{|z|}{y_z} \right] \end{aligned} \quad (8)$$

Five parameter values such as w_1, w_2, w_3, T_1, T_2 are optimized by using genetic algorithm. Appropriate objective function is established according to the control objectives of current loop and the optimal control performance of the fuzzy controller of ASVG system is realized. In the objective function of current loop, the time integral of absolute value of error is been added to improve its dynamic performance. The control flow chart is shown in Fig. 4.

The w_1, w_2, w_3, T_1, T_2 are optimized by using the following objective function which has a good dynamic performance and control output has a certain range:

$$J = \int (k_1 |e_w(t)| + k_2 u^2(t)) dt + k_3 t_u \quad (9)$$

The structure of contraction-expansion factors with the Eq. 9 has five parameters which need to be optimized such as w_1, w_2, w_3, T_1, T_2 .

Contraction-expansion factors of five parameters are optimized by using the genetic algorithm. The chromosome length is 5. Set fitness function as:

$$f = \frac{1}{J} \quad (10)$$

A new individual is created after selection, cross, Variation. The operation of basic variables of fuzzy control system depends on the time step k , set, respectively for $x(k), y(k), z(k)$. So, the variable region can be represented by the time function, set them as $X(x(k)), Y(y(k)), Z(z(k))$. With the process of optimization, the fuzzy subset region of input and output will changed accordingly. Set the changes of the subordinating degree function: A_i, B_j, C_{ij} as $A_i(x(k), k), B_j(y(k), k), C_{ij}(z(k), k)$. This makes fuzzy control rules as a set of dynamic rules $R(k)$:

$$R(k): \text{If } x(k) \text{ is } A_i(k) \text{ and } y(k) \text{ is } B_j(k) \text{ then } z(k) \text{ is } C_{ij}(k) \quad (11)$$

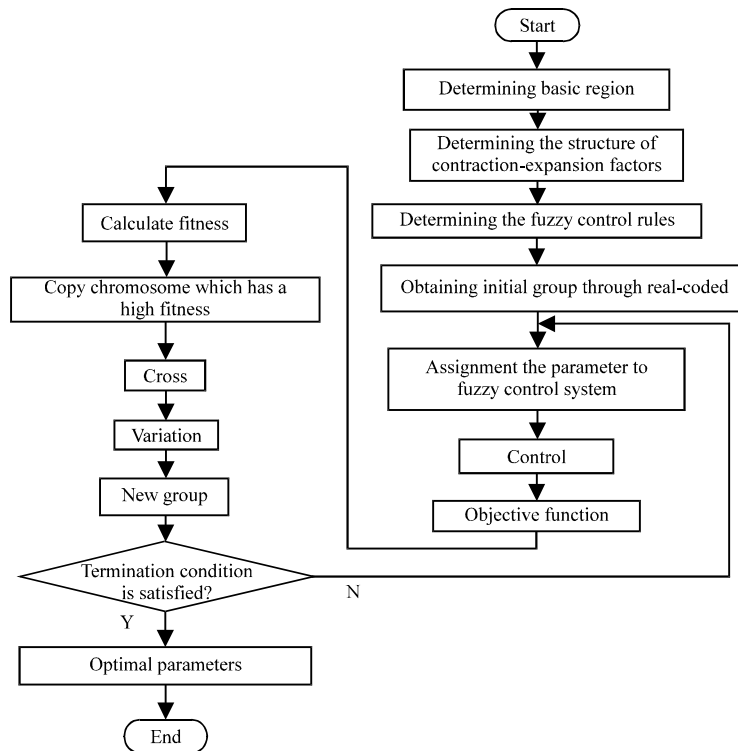


Fig. 4: Control flow chart of the variable region fuzzy control which optimized by genetic algorithm

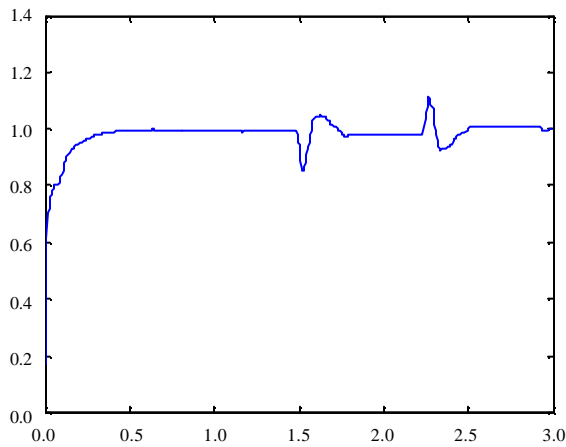


Fig. 5: System bus voltage of fuzzy control of ASVG access point

When $k = 0$, Eq. 11 is initial fuzzy control rules. Control function will changed with the changes of regions, it can be written as follows:

$$F(x(k), y(k), k) = \sum_{i=1}^p \sum_{j=1}^q A_i(x(k), k) B_j(y(k), k) Z_{ij}(k) \quad (12)$$

By the previous theory, we can see: The monotonicity of $R(k) (k > 0)$ is guaranteed by the monotonicity of $R = R(0)$, the effectiveness of the control function $F(x(k), y(k), k)$ is ensured.

By using the theory of variable region, the design of fuzzy controller reduced the reliance of prior knowledge of control domain experts. The basic region will contract with the change of the controller input error. As a result, new fuzzy control rules will derived from the initial fuzzy rules and it will greatly improves the performance of the control system.

SIMULATION OF ASVG

In order to verify the feasibility of this study, the corresponding modules based on the above theoretical analysis are established by using the MATLAB software, the simulation experiments are done. The ASVG adopted dq direct axis current control strategy. The ASVG simulation system mainly includes: Three phase AC power, reactive power load part, reactive current detection module, control module and the inverter circuit part. Specific parameter is: Three-phase voltage source: 10 kV, 50 Hz, the ratio of transformer: 10 kV: 380 V, active load: 50 kW, PWM switching frequency: 12 kHz, DC side capacitor: 4000 μ F; the output filter: The

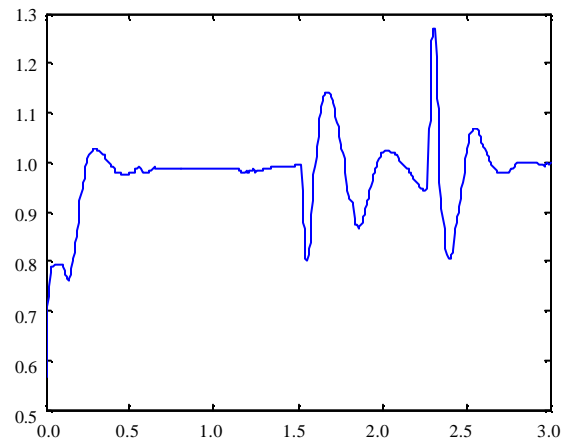


Fig. 6: System bus voltage of PI control of ASVG access point

equivalent impedance: 0.2, filtering inductance: 2 mH, filter capacitor: 10 μ F, three-phase current source with the initial phase angle of 90° is join into the load side between 1.5-2.5 sec.

The voltage of ASVG access point can be got according to the simulation model. Figure 5 and 6 show that: In the simulation time of 3 sec which joining in the three-phase current noise source between 1.5-2.5 sec, power system voltage has no obvious fluctuation and it well maintained the system voltage's stability and balance of the device access point, because of the access of ASVG device of the variable region fuzzy control and fast track compensation.

CONCLUSION

In this study, the variable region fuzzy control which based on genetic algorithm optimization is applied into the ASVG's current loop control. When power system waving, it effectively suppressed the voltage fluctuation, improved the anti-interference ability of the power system and robustness and eventually realized the reactive power compensation. This is an effective, fast and stable control scheme for the nonlinear, strong disturbance and time-varying uncertain systems.

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