Optimization Algorithm for Power Flow Calculation of Power System Considering Power Spring

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Abstract

With the popularity of intermittent and distributed renewable energy sources such as wind energy and solar energy, people are increasingly concerned about the stability of power systems. As a new type of voltage control device, electric springs can effectively suppress voltage fluctuations caused by changes in distributed generation power. Based on the analysis of the principle of electric spring voltage stability control, the optimization problem and control effect of non-critical load changes are considered. The calculation method of electric spring capacity is given, combined with immune genetic algorithm, an electric spring voltage control method based on immune genetic PI control is proposed, and the simulation is carried out with MATLAB/ Simulink. Simulation results show that the algorithm has good voltage regulation effect, thereby optimizing the calculation method of electric spring capacity.

Keywords

Immune genetic algorithm, Electric spring, PI control, Simulation.

1. Introduction

At present, distributed solar power generation is becoming more and more popular. "Spontaneous self-use, surplus electricity access to the Internet" makes every household a miniature solar power station. However, in remote rural areas, the impedance and resistance-to-inductance ratios of low-voltage power lines are relatively large, which will inevitably cause losses on the transmission circuit when transmitting active power. In order to ensure that the grid voltage amplitude is normal, the terminal voltage of the farmer household must be high when the farmer reverses the power supply to the grid, which leads to fault alarms and inverter shutdown protection, which affects the photovoltaic revenue. When the power grid draws electricity, there will be a low voltage at the end of the farm households, causing damage to household appliances.

In this case, we believe that a voltage regulator based on electric spring [1] technology can be used to solve this problem. Electric spring can automatically send or absorb power to maintain voltage stability, effectively overcome the unpredictable shortcomings of new energy power generation, is a new control idea.

With the rapid development of computer science, mathematics, control theory and information fusion, as an important analytical tool and research method, computer simulation technology has been widely used in various theoretical studies and engineering practice. In the major of electrical engineering, power flow calculation is a basic method to determine the steady-state operating state of a system given the power system network structure, parameters, and boundary conditions. However, due to the large number of calculation parameters, the process is complicated and tedious, not only the accuracy of the results of manual calculation is difficult to guarantee, but also the result changes when the parameters are changed also undergo complex calculations and the trend analysis is more difficult. The power system simulation module in MATLAB / Simulink is a model library specially used for power system simulation, which can be used for power flow calculation of the power system [2].

In this paper, a new control strategy is proposed, based on the improved genetic algorithm control method, so that the electric spring has a better regulation effect, when the non-critical load changes, the performance of the critical load has been kept stable. In this article, analysis of the working principle of the electric spring; based on the immune genetic algorithm, output the optimal PI control parameters; based on the electric spring, the capacity calculation method is given; the simulation model based on MATLAB/Simulink software is used to verify the proposed control The feasibility and effectiveness of the method.

2. Structure and working principle of electric spring

2.1 Electric spring structure

The main circuit part of ES-VR is composed of single-phase full-bridge inverter circuit, DC filter capacitor and AC filter inductor. In addition, ES-VR is connected in series with farm household electrical loads. The full-bridge inverter circuit includes four power tubes S_1, S_2, S_3 and S_4. The specific main circuit design is shown in Fig.1:

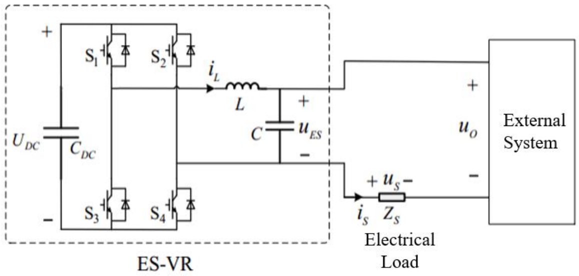


Fig.1 The main circuit design of the voltage regulator ES-VR

In the figure, the voltage of the farmer's electric load terminal is U_S, the farmer's electric load input current is i_S, the farmer's terminal grid voltage is U_O, the AC filter inductor current of the voltage regulator ES-VR is U_{DC}, the DC capacitor voltage of ES-VR is the output voltage is U_{ES}.

The design of the main circuit is to control the voltage of the farmer's power load terminal to be within the prescribed range. When photovoltaic grid-connected farmers send electricity back to the grid and cause U_O to be too high, ES-VR absorbs reactive power to maintain the stability of the farmer's power load terminal voltage; when photovoltaic grid-connected farmers draw power from the grid (lack of photovoltaic output) and cause U_O to be low, ES-VR maintains stability by emitting reactive power.

2.2 Principle of PI regulator

In order to reduce the error of the DC voltage additional control circuit, a PI regulator is added to the circuit [3]. The PI regulator is a linear controller, which calculates the control deviation according to the given value and the actual output value, and forms the control amount by linear combination of the deviation ratio (P) and integral (I), thereby controlling the controlled object. Its transfer function is $G_{PI}(s) = K_P + K_i / s$. Once the system has a deviation, the proportional link (K_P) of the PI regulator will react to the deviation of the DC voltage additional control circuit system in proportion, and the integration link (K_i) will eliminate the steady-state error of the DC voltage additional control circuit system. The larger the value of K_P, the faster the adjustment, but excessive value will reduce the stability of the system and cause system instability. The smaller the value of K_i, the stronger the integral effect, but too small will result in a slower dynamic response.

2.3 Principle of PR regulator

In order to achieve signal-free tracking, the controller must include a model of the signal. The transfer function of the integral part of PI is $1/s$, so PI can only track the step signal without static error, and to achieve the errorless tracking of the AC sinusoidal signal, you need to use the PR controller. In order to accurately track the input signal, we added the PR regulator link to the ES-VR output voltage double closed-loop control circuit, and at the same time realized the phase control of the reference voltage [4].

The PR regulator is composed of a proportional controller and a resonant controller. Ideal PR controller. Next, when the gain tends to infinity, it can realize the tracking of the AC signal without static error. However, since the increase in gain will destroy the stability of the system, we use a quasi-PR regulator whose transfer function is:

$$G_{PR}(s) = K_P + 2K_i\omega_0 \frac{s}{s^2 + 2K_i\omega_0 s + \omega_0^{\ 2}}$$

The gain of the quasi-PR controller at the resonance frequency point is lower than that of the ordinary PR controller, and the system stability is better.

2.4 Principle of phase-locked loop

A phase-locked loop is a feedback circuit that uses an externally input reference signal to control the frequency and phase of the internal oscillation signal of the loop to achieve automatic tracking of the output signal frequency to the input signal frequency. The phase-locked loop is usually composed of three parts: a phase discriminator (phase comparator), a loop filter, and a voltage-controlled oscillator. The phase discriminator is used to discriminate the phase difference between the input signal U_i and the output signal U_O, and output the error voltage U_d. The noise and interference components in U_d are filtered by the low-pass loop filter to form the control voltage U_c of the voltage-controlled oscillator. It also acts on the voltage-controlled oscillator and pulls its output oscillation frequency f_0 to the loop input signal frequency f_i. When the value of f_0 and f_i are equal, the output voltage and the input voltage can maintain a fixed phase difference. At this time, the phase of the output voltage and the input voltage is locked Live, that is, the loop is locked [5].

3. PI control based on immune genetic algorithm

In order to make ES have better voltage regulation effect and can solve the control problem of time-delayed and nonlinear controlled objects well, this paper uses immune genetic algorithm. The conventional method of reasonable selection of parameter is to determine the value of the parameter K_P and K_i based on the adjustment experience, but this method has the disadvantage of taking too long and obtaining the parameter may not be the optimal value, which will affect the response speed and overshoot of the control system. Using the algorithm's global optimization feature to overcome the above shortcomings, an immune genetic algorithm is proposed to tune PI parameters online to further improve the control quality and achieve PI adaptive control [6].

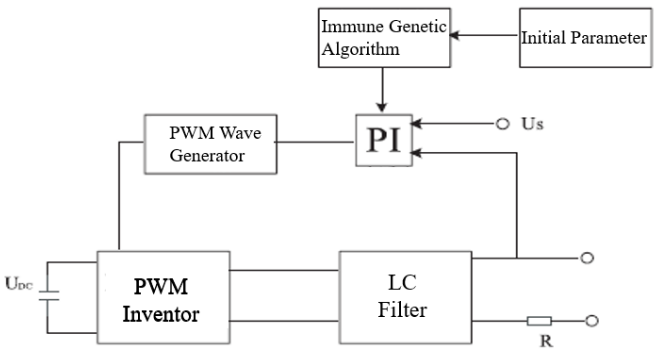


Fig.2 Structure diagram of electric spring voltage control based on adaptive PI control

The genetic algorithm was originally proposed by Hol-land in the United States. The basic idea of the genetic algorithm he talks about is to encode optimized parameters, and also to generate a certain number of individual initial populations as the selected questions to solve the problem. The selection condition of the genetic algorithm is to use the fitness function value, through the operation of selection, crossover and mutation to optimize from generation to generation, and finally the best solution that meets the required conditions will be obtained.

In this paper, the use of immune genetic algorithm can achieve multi-element optimization, the formula is:

$$ML(x,y)=|2I(x,y)-I(x,y)-I(x,y)|+2I|(x,y)-I(x,y)$$
$$-I(x,y)|$$
$$F(x,y)=\sum_{X=1}^{N} \quad \sum_{Y=J-N}^{J+N} ML(x,y), ML(x,y) \geqslant T$$

Because the calculation of the data gain function in the self-adjusting PI controller is complicated, in order to achieve the ideal control goal, there is a way to reduce the average error in the integrated unit of the degraded ratio, the average error can be avoided, the formula is

$$C(\varphi T)=C(\varphi(T-1))+C(T)$$
$$C(T)=WC_1(T)+WC_2(T)+WC_3(T)$$
$$C_1(T)=\|\Delta I\|-\|\nabla I(P(T))\cdot N(T)\|-\|\Delta I(P(T))\cdot N\|$$
$$C_2(T)=\sum\|P(T)P(T-1)\cdot N(T-1)\|, I=L,R$$

In the formula, W is the integral discrete coefficient; L is the driving value of calculus; C1, C2 and C3 are the fluctuation limit, integer fluctuation limit and data transmission items of integer unit data respectively. Therefore, the immune genetic algorithm can be used to adjust the calculus unit. And the individual algorithm is only for data, so it can be directly applied to the calculus unit. The formula is:

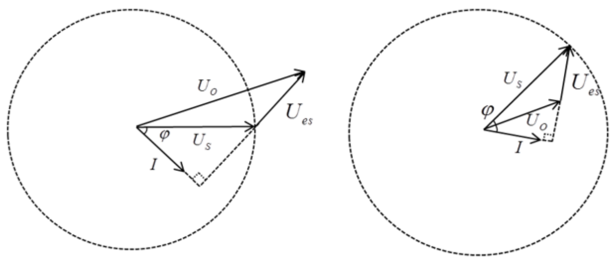
$$K_P=K\{1+K_0[1-EXP(-\left(\frac{e}{R}\right)^2/\alpha_p^2)]\}$$

$$K_i=K\{K_P+K_0EXP(-\left(\frac{e}{R}\right)^2/\alpha_p^2)\}$$

In the formula, K_P and K_i respectively represent the proportion and inverse proportion of the integral unit and K_0 represents the actual integral function, and the immune genetic algorithm is used to adjust the proportional unit to ensure that the calculated data in the loop has no target error. The integral unit is adjusted to avoid the average error, and the immune genetic algorithm is used to adjust the differential unit to solve the transmission error in the calculation process. This optimizes the self-tuning PI controller. Finally, for the value of PI, in order to ensure the accuracy of the data, simulation calculations are also required.

4. Calculation method of electric spring capacity

The vector diagram is as shown in the two compensation cases:



(a) The grid voltage is higher than the rated voltage (b) The grid voltage is lower than the rated voltage

Fig.3 Voltage vector diagrams in different situations

The formula for calculating the rated power P_S of ES is

$$P_S=U_S I\cos\varphi \Rightarrow \varphi=\arccos\frac{P_S}{U_S I},$$

where U_S is the rated voltage of critical load, I is the circuit current and φ is the power factor angle of critical load.

According to the vector diagram, we can know that $U' = U_S \sin\varphi$.

Therefore, the calculation formula of electric spring voltage can be defined as

$$U_{ES} = \sqrt{U_0^{\ 2} - (U_S \cos\varphi)^2} - U' = \sqrt{U_0^{\ 2} - \left(\frac{P_S}{I}\right)^2} - U_S \sin\varphi,$$

where U_0 is the grid voltage.

The electric spring capacity is $S_{ES} = U_{ES} I = \sqrt{U_0^{\ 2} I^2 - P_S^{\ 2}} - U_S \sin\varphi$ and the equivalent impedance of the circuit is $Z_{eq} = Z_{ES} + Z_S$, where Z_{ES} is the equivalent impedance of the electric spring.

From the circuit diagram, we can get

$$\frac{Z_{ES}}{Z_{ES} + Z_S} U_0 = U_{ES}$$

We make $r = \frac{U_0}{U_{ES}} = \frac{U_0}{U_0 - U_S}$, then we can get $Z_{ES} = \frac{Z_S}{r-1}$ and $Z_{eq} = \frac{Z_S U_0}{U_S}$ .So the current expression is $I = \frac{U_0}{Z_{eq}}$.

5. Simulation verification

In order to verify the working performance of the electric spring, the simulation model of the entire system is built in Matlab / Simulink [7], and the optimal parameters K_P=5 and $K_i = 30$ are output by the immune genetic algorithm. The set circuit parameters are shown in the following table:

Tab.1 Some parameters of the simulation circuit

Item	Parameter value
Farm household load reference voltage /V	110
DC voltage given value at both ends /V	80
Frequency /Hz	50
K_P	5
K_i	30
User line resistance /Ω	15
User line inductance /H	0.05
DC capacitance /F	2×10^{-3}
Transmission line resistance /F	1.0

In the simulation, we verified the voltage regulation capability of the electric spring by simulating the working conditions during the day. photovoltaic current, farmer's load voltage, The waveform diagram of the effective current value and the effective voltage value of the grid voltage of the farmer's terminal is shown in Fig.4.

In the process of increasing the active power injected into the feeder by the photovoltaic grid-connected system, the farmer's load voltage has only a sudden pulse, which basically remains unchanged; The waveform diagram of Fig.4 also shows that the voltage of the PV grid-connected terminal increases in amplitude during the period of 0.15s-0.3s, while the farmer's load voltage and load current only have slightly larger and slightly smaller amplitudes at 0.15s and 0.3s, respectively. After a period of vibration, it immediately returned to its original amplitude.

It is known from Fig.4 that when the photovoltaic power increases, the electric spring reacts quickly, the ES output voltage increases, absorbs reactive power, and is in an inductive working mode to suppress the farmer's load voltage with photovoltaic power. Changes have maintained the stability of the farmer's load voltage.

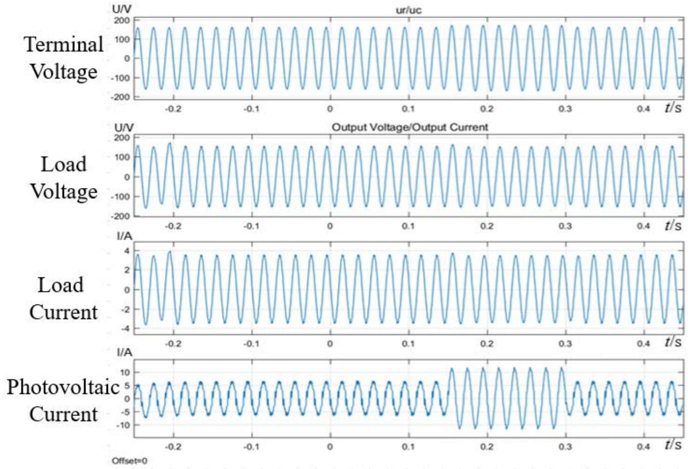


Fig.4 Voltage and current changes during simulation

From the above simulation results, the conclusion is consistent with the theoretical analysis.

6. Conclusion

In order to improve the voltage regulation capability and stability of ES, this paper uses an immune genetic algorithm to optimize the calculation of the power spring capacity. The simulation results of the power spring can be seen: The PI control proposed in this paper can effectively solve non-critical load changes the voltage of the entire system is unstable; the immune genetic algorithm used in this paper has the advantages of short controller adjustment time and strong anti-interference ability. In general, the algorithm control adopted in this paper has a good optimization effect on the capacity calculation of ES.

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