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Based on Fuzzy Hybrid Inverter Technology Solar Energy Application Research

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Abstract

The emergence of solar air conditioning, not only reduces energy consumption of the traditional air conditioning, but also decreases environmental pollution. However, the current market applications of solar air conditioning is not widespread, largely attributed to its internal control strategy has yet to be perfected. In order to achieve energy-efficient scheduling of solar air conditioning in the process of cooling, Firstly, the fuzzy control principle is introduced into the control procedure to solve the control threshold defined problem, the dynamic parameters of the air conditioner are adjusted dynamically to achieve the optimal balance between multiple operating frequencies and the energy-related parameters at the same time. Then, the finite states machine segmentation techniques is taken in advantage to make that solar energy stay in an optimal status in a finite number of states given at any time. Finally, the Kalman frequency stabilization technology is used to ensure the system operating in the most stable state sustainably. Experimental results show the energy efficiency and performance of the system are improved obviously. Energy consumption per unit of time has decreased by 7%, and the latency of the system meets the applicability requirements.

***Keywords**: inverter technology, solar air conditioning, fuzzy control, state machine region segmentation*

1. Introduction

With economic development, the living standards of people continue to improve, and the popularity of air conditioning is increasing at an alarming rate. However, when people pursue comfortable life, the needs of the oil, electricity and other energy are also increased. The traditional air-conditioning equipment function independently, leads to high energy consumption, and consumes large amounts of non-renewable resources. Moreover, during the cooling air, considerable number of the heat of condensation is emitted directly into the atmosphere, which will not only result in a large waste of energy, but will also pollute the surrounding environment. Therefore, in current situation with the energy increasingly scarce and the ecological environment continues deteriorating, how to significantly reduce the energy consumption of air-conditioning equipment and the environmental pollution is an urgent social need [1].

AC frequency control technology is the current developments in the field of electric drive key directions [2, 3]. With the wide application of microelectronic technology and modern control technology in the AC drive system, as a key component of AC variable speed system the inverter performance has been significantly enhanced. It plays an important role in the industrial sector as well as people living. With the development of high-quality microprocessor-controlled technology, inverter technology performance has gradually improved [4, 5]. Frequency control technology has a strong ability to control, high efficiency, quality and other advantages, and has a high energy-saving effect. Because the energy consumption of air conditioning systems accounted for a large proportion in the overall energy consumption of residents, the application of inverter technology integration with solar systems can reduce overall energy consumption, thus enhancing efficiency of the system and ensuring that the overall resident's consumption is minimized [6-8].

the temperature by the adsorption of solid adsorbent to the refrigerant, such as molecular sieve-water and activated carbon-methanol adsorption refrigeration. Now the absorption refrigeration technology is widely used, and it is analyzed as the objective in this paper [9, 10].

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2. Solar Absorption Refrigeration System

Solar absorption chillers heat water by solar collectors and provide corresponding heat medium water for the generator to ensure the chiller work smoothly, so as to complete the corresponding cooling effect [11]. It can be inferred from the experience that there is a positive correlation between the temperature of heat medium water and the performance of a chiller, and the cooling rate of the air-conditioning system is increased with the rise of temperature of heat medium water. A configuration diagram of the refrigeration system is described in Figure 1. Solar absorption air conditioning system can achieve a lot of functions, such as cooling in summer, heating in winter, and providing heat water for life throughout the year [12-14].

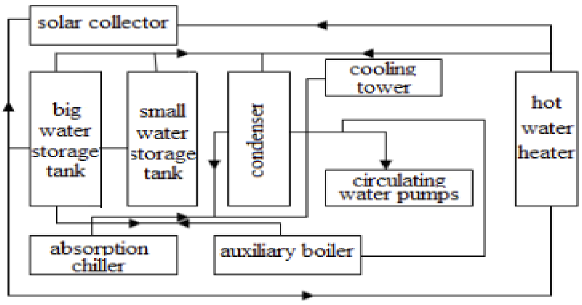

Figure 1. Operating Principle of Inverter Solar Air Conditioning and Refrigeration Systems

In air conditioning heating season heat medium water is mainly supplied by solar. When solar cannot meet the requirements, the auxiliary boiler is supplemented to ensure the enough quantity of heat. In non-air-conditioning heating season, the hot water heated by the solar heat collector is directly delivered to the water tank which is also called the life heat exchanger to heat the cold water in the tank. Some components in the inverter solar absorption air conditioning shown in Figure 1 are different from refrigeration system of compressors, such as variable frequency condenser, variable frequency circulating pump and auxiliary components of boiler. The air conditioning completes reasonable regulation of hydrothermal circulation through variable frequency condenser and circulating pump. It can be obtained from the analysis of Figure 1 that the solar variable frequency air conditioner combines the frequency control and conventional solar conditioning technology. Inverter is the key component of variable frequency solar air conditioning which controls the output power frequency and the operation of circulating pumps, condensers and other devices to ensure complete its cooling effect.

3. Summary of Inverter Technology

The detection section mainly detects some factors like the voltage, current and temperature, and analyzes the boundaries of these factors to determine whether the corresponding maintenance should be done for system. The construction diagram of the inverter is shown in Figure 2.

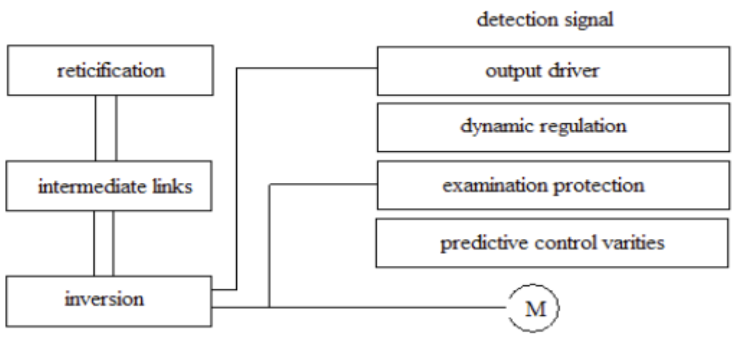

Figure 2. Inverter Structure

3.1. The Inverter in the Control

The core component of the inverter solar air conditioning system is GTO, an IMD VVVF drive system, as shown in Figure 3. The synchronous speed adjustment of the motor is realized by changing the frequency of the stator power, so that the real-time modulation of the speed is completed in the end. At the same time, it also can ensure minimum speed difference in order to maintain the inherent mechanical properties of the motor. GTO gates are used by frequency converters to turn off thyristors, so as to realize the inverter switching. Furthermore, negative gate turn-off pulse current route is used to update the main circuit current, cut unreasonable energy, and has advantages such as clear lines, low cost, high performance. Ordinary SCR has to analyze the fluctuations of operating frequency and load performance in order to instantly update inductance, capacitance and other parameters. While GrO only need to pass the gate turn-off signal with reasonable range and width to ensure the smooth operation of the overall circuit.

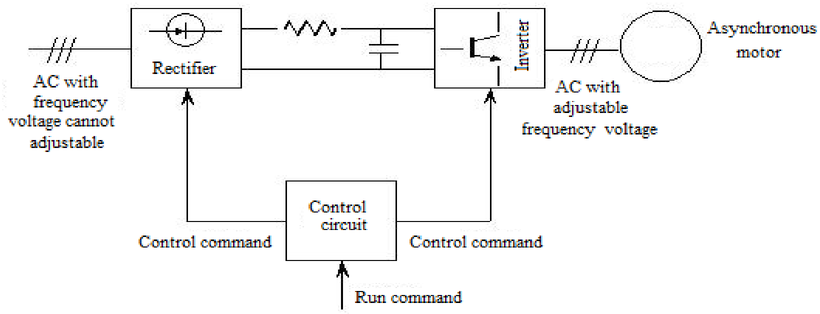

Figure 3. Variable Speed Drive System

3.2. The Mathematical Model of Variable Frequency Solar Air Conditioning

Besides several associated equipments, there are a set of power-driven system electrical machines, batteries and other supporting systems in the inverter of solar air conditioning. According to the need of temperature control, the various power sources, one of the causes of the inverter energy consumption, can switch between working alone and coordinate. Inverter energy consumption and the speed adjustment have a close relationship. The following mathematical model can be established to describe the adjustment process of inverter.

$$v(F)=\int_0^t f\,(\omega_e,T_e)dt \tag{1}$$

Wherein $f\,(\omega_e,T_e)$ represents the energy changes of point (ω_e,T_e) in the heating process of the inverter.

The following mathematical model can be established to express the energy consumption while the inverter operating.

$$F\,(x)=FC=\int_0^t \Delta\frac{f\,(\omega_e,T_e)}{\rho}dt \tag{2}$$

The principle of inverter energy consumption: The energy consumed will change during the acceleration or deceleration process of inverter. A certain relationship exists between speed adjustment and energy consumption: Both of them has the parameter $\Delta f\,(\omega_e,T_e)$. If the change frequency of speed regulation increases, the $f\,(\omega_e,T_e)$ in formula 1 will change which will further cause the increase of $\Delta f\,(\omega_e,T_e)$. Then the parameter of $\Delta f\,(\omega_e,T_e)$ will become greater that lead to a greater result of formula 2, it means that the energy consumption of inverter is increased. The more frequently the inverter changes, the more obvious this contradiction is, which is another cause of the increase of energy consumption of inverter.

In order to verify the energy saving efficiency of inverter, daily energy consumption of the inverter is used as a measure standard, as follows:

Energy per day = energy consumption / 24 hours (3)

3.3. Membership Function

Membership function is the basis of the application of fuzzy control, the key point of using the fuzzy control appropriately is established the accurate membership function. Typical membership functions are trapezoidal membership function, triangular membership function, Gaussian membership function and the generalized bell-shaped membership function. Triangular membership function is made of straight line segments, and there is clear distinction between each two action. This paper uses the triangular membership function as the designed membership function. Taking the wide scope frequency of inverter into account, the domain of P is selected [1, 7], with the maximum 7 and the minimum 1. Similarly, the energy value changes is also chosen on the domain [1, 7], with the maximum 7 and the minimum 1, as shown in Figure 4.

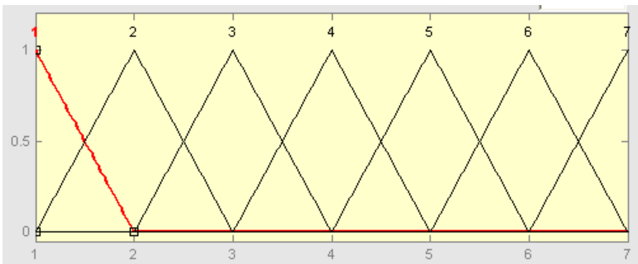

Figure 4. Input and Output Membership Functions

3.4. Fuzzy Control Rules of Energy Saving

Inverter control rules are the core of fuzzy logic control system. Number of rules is related to the division of fuzzy subsets of fuzzy variables. More finely divided more rules and longer running time of fuzzy controller, but does not represent the higher the accuracy of the rule base. The main idea of the fuzzy controller rule in this paper is:

a. When demand frequency T is relatively close to the inverter optimal operating point, maintain this status and no longer start other programs.

b. When demand frequency T is more or less than the certain value of inverter optimal operating point, make the inverter operate in the vicinity of the optimal point, and the remaining positive or negative frequency is provided by a motor.

c. When the frequency is greater than the maximum limit, shut down the inverter as far as possible so that to ensure safety of equipments

d. When the frequency is less than the minimum limit, try to turn off the inverter drive, let coasting.

Format is: IF Premise; THEN Conclusion：

a1：IF(T is 1) and(SOC is 1) then(output1 is 4)

…

a7：IF(T is 1) and(SOC is 7) then(output1 is 1)

…

g7：IF(T is 7) and(SOC is 7) then(output1 is 4)

The above method can complete optimization of the energy consumption of the drive to achieve the goal of energy saving control.

3.5. Finite State Machine Area Segmentation Technique

Finite state machine, also known as finite state automaton, referred to the state machine, is a mathematical model of finite number of states and actions between these states, like transitions and movements. The technology is composed by a finite number of states and migration between the states. At any given time, it can only in one of a finite number of states and can be used to describe the process of a control system. This technology ensures the inverter maintain an optimal state. Defining a five communication area:

$$M = (Q, \Sigma, \delta, q_0, F)$$

Wherein, Q represents a set of finite states, Σ expresses a set of finite events and δ is the mapping or transfer function from $Q \times \Sigma$ to Q. q_0 in Q is the initial state and $F \subseteq Q$ is the final states' set. Finite state machine has a variety of describing ways such as the state transition diagram. According to procedures of frequency control system, the processes include 13 states: reverse mold, pre-plastic, retraction, nozzle forward, injection, holding pressure, nozzle back, cooling, open mold, ejector, open the door, take the work pieces, closing, they can be expressed by a state diagram. The relationship between each two states can be represented by the state transition function. Workflow is divided into the following two steps

1) The procedure of the frequency control system consisted of n craft movement is a set contains 5 variables which denoted as $I = (Q, \Omega, \delta, q_0, F)$. Wherein Q represents a set of finite states of frequency control system action, $q_0 \in Q$ is the initial state and $F \subseteq Q$ is the final states' set. δ is the transfer function: $\delta : Q \times \Omega \to Q$, so $\delta(q,i)$ means that with the input $i \in \Omega$ the state of frequency control system is q.

2) $q = (x_1, x_2, x_3, \cdots, x_n)$ is a collection of n craft movement states. Each movement can be described as $x_i \in \{T, L, P, V, n, S\}$, wherein T is the temperature, L is the location, P refers to pressure, V represents speed, n expresses rotational speed and S refers to the state.

According to the different states obtained by calculation, the above method divides the frequency control area to effectively avoid the evils of the communicating conflict and make a substantial increase in control accuracy.

3.6. Frequency Data Stability Control of Kalman Filter

In order to prevent data mutations and abnormal jitter, effective optimization control for frequency conversion data is needed. Kalman filter is linear minimum variance estimation with good filtering performance. When system noise and measurement noise are known, a mathematical model of the signal can be established to prevent data mutations and reduce noise. In addition, recursive algorithm is employed to design filter in the time domain by state-space method for estimating multi-dimensional stochastic process. There are two types of algorithms including continuous and discrete, in which discrete algorithm is easy to implement digitization. With the development of computer and computing technology, Kalman filter has gradually been widely studied and applied. A mathematical model for nonlinear systems with deterministic control can be described as follows:

$$\frac{dx}{dt} = f(x) + Cu + W$$
$$y = H \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + V \quad (3)$$

Wherein, $x = \begin{bmatrix} i_\alpha & i_\beta & \omega & \theta \end{bmatrix}^T$.

1) Discretization equation. The instant status can be predicated according to the previous status.

$$x_{k/k-1} = x_{k-1} + Ts[f(x_{k-1}) + Cu_{k-1}] \tag{4}$$

The predicated error is a result of state error and systematic error.

$$P_{k/k-1} = \phi_{k/k-1} P_{k-1} \phi_{k/k-1}{}^T + Q \tag{5}$$

The above two are the system predicated formula in EKF.

Ts is the sampling period, P represents the covariance matrix of x, and Q is the covariance matrix of W . $\phi_{k/k-1} = I + Ts \cdot F(t_{k-1})$

$$F = \frac{\partial f}{\partial x} = \begin{bmatrix} -\frac{R}{L} & 0 & \frac{\psi}{L}\sin\theta & \frac{\psi}{L}\omega\cos\theta \\ 0 & -\frac{R}{L} & -\frac{\psi}{L}\cos\theta & \frac{\psi}{L}\omega\sin\theta \\ M & N & -\frac{B}{J} & (i_\beta M - i_\alpha N) \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Wherein,

$$M = -1.5\frac{p^2\psi}{J}\sin\theta \ , \ N = 1.5\frac{p^2\psi}{J}\cos\theta$$

2) The reliability of measured value, the Kalman gain K, can be calculated through predication error and measurement error :

$$K_k = P_{k/k-1} H_k{}^T (H_k P_{k/k-1} H_k{}^T + Z)^{-1} \tag{6}$$

Where, Z represents the covariance matrix of noise measured V .

3) With the predicted value, the measured value and the reliability, the optimal estimate value of current state can be calculated.

$$x_k = x_{k/k-1} + K_k(y_k - H_k x_{k/k-1})$$

Optimal estimation error is:

$$P_k = P_{k/k-1} - K_k H_k P_{k/k-1} \tag{7}$$

Equation (5) to (7) are the fundamental formulas of EKF.

The selection of the noise covariance Q and Z is important for the initial value $P0$ of P, since they directly affect the filter and the convergence performance of EKF algorithm. EKF is an optimal estimation method, which is based on the predicted value and covariance, the current measured values and their covariance to estimate the current state. For the predictive value and the current measured value, a small amount of covariance will play a greater role in estimation process. As predicted value can be obtained by the previous state value and the system equations, the prediction error is result of joint action of the previous state and systematic errors.

The smaller $P0$ and Q, the greater the effect of $X0$ and the slower the estimates value converge to the actual value, but steady-state error will be reduced. The greater $P0$ and Q, the less the effect of $X0$ and the quicker the estimates value converge to the actual value, but steady-state error will be increased. Similarly, Z represents measuring error, the increase of Z which equals to the increase of measured noise will reduce the reliability of measured value thus slower the converge speed. And the decrease of Z which equals to the decrease of measured noise will increase the reliability of measured value thus accelerate the converge speed.

These two methods can effectively prevent logic confusion, timing conflicts, data mutation and other issues of frequency control caused by the conflict of unidirectional logical time domain, and causes a substantial increase in frequency control accuracy.

4. Simulation

4.1. Experimental Environment

In order to test feasibility and effectiveness of solar air conditioning energy-saving scheduling method based on hybrid inverter technology, the simulation experiment is employed to detect the technology. Meanwhile, in order to measure advantages and disadvantages of the hybrid inverter technology, the scheduling methods described in literature [4] and [6] are regarded as comparison models. The total system latency and energy consumption are adopted as measurement indicators, the specific simulation environment are shown in:

Table 1. Experimental Environment

Configuration Information	Illumination intensity
System	Window XP
RAM	2G
Hard disk	180G
CPU	3.0G
Simulation software	VC++

4.2. Analysis of Experimental Results

Figure 5 and 6 show the changes of total time delay and energy consumption in different ways, as the inverter frequency increases.

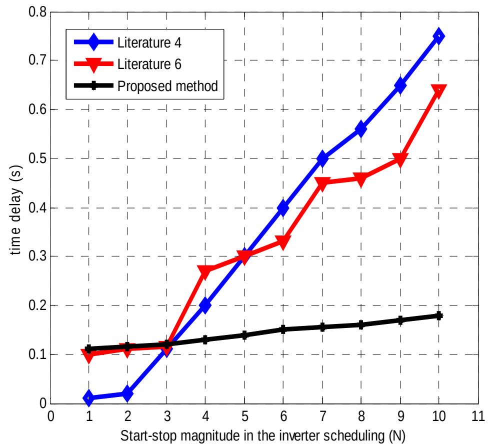

Figure 5. Delayed Results of Different Algorithms

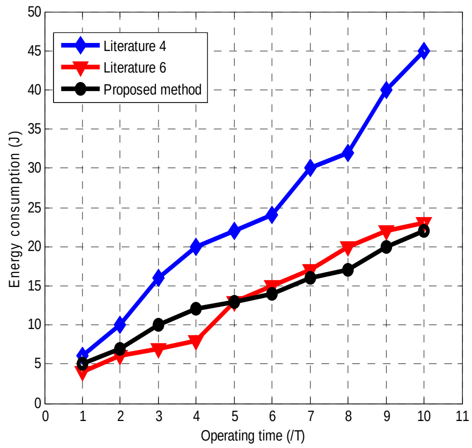

Figure 6. Energy Consumptions of Different Methods

It can be seen from Figure 5, compared to literature [4] and [6], with the increase of start-stop magnitude in the inverter schedule, the approach used by the essay has little delay variation, and has been maintained within 0.2 seconds or less, the maximum delay is 0.7 seconds in the literature [4] and [6] as the drive frequency increases.

In the energy consumption (see Figure 6), the method is closer literature [6], but it still can be seen that the consumption is slightly lower than the method described in literature [6]. With the passage of time, the energy consumption in literature [4] is growing.

According to synthesis algorithm described in the previous section, simulation experiments for the inverter system are carried out. Assuming that each node has an inverter, weight value are 0.6 and 0.4. Energy consumption of each drive unit is fixed (energy for per unit is 1). Energy consumption difference among the proposed algorithm and algorithms in literature [3] and [8] is shown in Table 2.

Table 2. Implementation of the Mandate

number of tasks	time and energy consumed by proposed algorithm	time and energy consumed by algorithm in literature [3]	time and energy consumed by algorithm in literature [8]
50	46, 180	48, 175	45, 183
100	89, 351	90, 350	89, 354
1000	870, 3565	878, 3558	887, 3593

Comparing to the other two algorithms, the proposed algorithm better balances performance and energy consumption of inverters which make task implementing without influencing the performance. At the same time, weight value changes make the adjustment of scheduling algorithm flexible.

5. Conclusion

In order to achieve solar energy air conditioning and refrigeration process scheduling, from the perspective of control, in this article, we introduced fuzzy control theory to the inverter control system of solar air-conditioning to dynamically adjust the work dynamic parameters of air conditioning. Then, making solar energy is given a finite number of states in the optimal one at any time by using the finite state machine segmentation techniques. Finally, the use of Kalman frequency stabilization technology to ensure energy-efficient scheduling of solar air conditioning system operating is in the most stable state and sustainable. Simulation results show that: in the proposed method, the system's energy consumption per unit of time decreased by 7%, the latency of the system also meets the requirements of the application, which indicates the energy-saving effect is more obvious increase. In conclusion, it proves that the method in the solar energy-efficient scheduling achieved good results, as well as provides a theoretical perfect reference for s refrigeration control technology of solar air conditioning.

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