Application research on intelligent irrigation system based on frequency conversion technology and AGA in China

Huang Yeda[1], Xiao Yutian[1], Wei Wenqiang[1], Wu Yang[2], Zhai Qingzhi[1*], Zhu Xinzhi[3], Yang Shuo[3]

(1. *College of Information and Electrical Engineering, China Agricultural University, Beijing 100083, China*;
2. *State Grid Beijing Electric Power Company, Beijing 100031, China*;
3. *State Grid Hebei Electric Power Company, Hebei 050000, China*)

Abstract: Affected by the difference of natural environment, regional economic development and other factors, there are some problems in Chinese irrigation, including low water efficiency of irrigation and water shortage. What's more, most water pump motors are running under the mode of constant speed and constant frequency, which not only worsen this situation, but also make a great deal of waste of electricity and reduce the efficiency of electricity and water. To solve the problems above, this paper built an intelligent irrigation system by using information feedback technology and frequency conversion technology: first, according to the feedback information, the system can use adaptive genetic algorithm to get the optimal irrigation water allocation scheme of the current state in real time; second, the special frequency conversion technology, designed on the basis of the characteristics of irrigation, enable water pump motors to adjust the output water flow according to the optimal irrigation allocation scheme. Take the typical three-level canal system as an example which has rainfall during irrigation, this paper established an intelligent irrigation system and simulates its irrigation process, it is found that the system can reduce the total water consumption and improve the utilization efficiency of irrigation water and electricity. Therefore, construction and promote the intelligent irrigation system will be one of the way to develop Chinese irrigation.

Keywords: irrigation technology, intelligent irrigation system, frequency conversion technology, AGA

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1 Introduction

Agriculture is one of the pillar industries in China. Large irrigation area, which accounts for 33.22% (Editorial Committee of Chinese Yearbook of Agriculture, 2013) of the total irrigation area, plays an important role in the development of economic and agricultural production in China. However, large irrigation areas have been constructed for a long time, there exist the following problems: 1) water efficiency of irrigation is as low as 0.5 (Fang, 2013), which is far from the world's advanced level of 0.7 to 0.9; 2) Scientific irrigation strategy is lack, resulting the water shortage of 30 billion cubic meters annually in China; 3) pump motor are running at constant frequency mode, which makes the pump motor output constant power and flow. As a result, the pump motor can't fit the scientific water distribution scheme, which will cause the waste of power and water, and it also requires pump motor to have a great capacity, which will improve standards of transformers and other electrical equipment.

Irrigation water is transported and distributed by pump motor, and the consumption of power and water are the same trend. Therefore, the irrigation mode, consisted of unscientific water distribution scheme and constant frequency mode of pump motor, will not only waste a lot of water, but also caused a huge power consumption. It is

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* **Corresponding author: Zhai Qingzhi,** Master, Professor of College of Information and Electrical Engineering, China Agricultural University, 100083, China. Email: zhaiqz@cau.edu.cn.

a double reduction of resources efficiency. So it is necessary to make a scientific reformation in large irrigation area.

2 Intelligent irrigation system

There is a lack of scientific irrigation strategy of water in Chinese Large irrigation area. Mostly, time point and duration of water distribution time in the irrigation area are controlled by the operators according to their experience. Not only is it difficult to make efficient use of water resources, but also there may be a deviation between the amount of irrigation water and crop water demand. In addition, most pump motors are running at constant frequency mode, which makes the pump motor output constant power and flow, It can't match the real time water requirement of farmland, resulting in waste of water and electricity.

With the further development of frequency conversion technology, setting an intelligent irrigation system based on AGA and frequency conversion technology has become a technical choice to improve irrigation benefits.

2.1 Structure of the system

As shown in Figure 1, the steps of technical reconstruction in the large irrigation area can be divided into: 1) install CPU near the pump motor and transform the original motor with frequency conversion technology; 2) consummate the canal valves and configure various sensors.

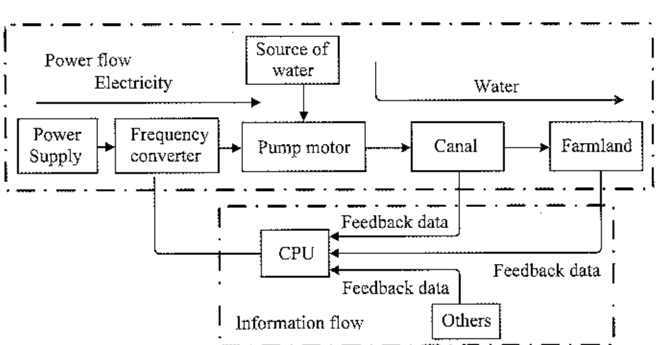

Figure 1 Intelligent irrigation system

When the Intelligent irrigation system is running, sensors can collect parameters of farmland and canal which can reflect water requirement of farmland. These parameters will be transmitted to CPU, and CPU adjusts irrigation strategy according to the feedback parameter. Then CPU adjusts frequency converter according to the new irrigation strategy. Pump motor will run at the control under the output signal of frequency converter, which can use irrigation water accurately and improve the water efficiency of irrigation and the utilization rate of energy.

2.2 Technology of the system

During the irrigation, irrigation strategies and water distribution scheme is needed, and they can be calculated by using adaptive genetic algorithm (AGA). According to the optimal water distribution scheme, the power and flow output of pump motor needs to be variable In order to realize water saving and electricity saving, the frequency conversion technology can meet this requirement.

Therefore, the intelligent irrigation system mainly uses the AGA and the frequency conversion technology.

2.2.1 Adaptive genetic algorithm (AGA)

Scientific irrigation strategy can scientifically and reasonably plan the water flow and water distribution time of each canal in the irrigation area according to the actual water demand of farmland, it can also shorten the whole irrigation period and reduce the leakage loss of the canals (Kang and Cai, 1996) which will increase water efficiency of irrigation. In order to find the optimal irrigation strategies and water distribution scheme quickly and accurately, an improved adaptive genetic algorithm (IAGA) (Xuan and Cheng, 2000) is used to optimize the model.

During the calculation, the superiority of adaptive genetic algorithm is that its fitness function, mutation rate and crossover rate can be changed according to the ratio of feasible solution in the process of calculation. The superiority makes the algorithm can avoid premature convergence in the early stage, move closer to the feasible solution domain quickly, and eventually converge to the optimal solution in the later stage. The specific operation is to introduce an adaptive penalty coefficient into the fitness function and introduce the Sigmoid function into the calculation function of mutation rate and crossover rate.

2.2.2 Frequency conversion technology

Before using frequency conversion technology, CPU and frequency converter are needed to be installed near the pump motor. CPU regulates the output voltage and frequency of the converter according to the current parameters. Thereby, the speed and the torque of the pump motor are controlled, then the water quantity of the farmland irrigation is controlled, so as to realize the effect of water saving and electricity saving.

There are two running models of frequency converter, including the model of fixed-voltage altering-current and the model of fixed-current altering-voltage. The power-saving effect of the former model is between 35.4% to 66.7% (Li, 2003), the latter model is between 37.3% to 82.6% (Li et al., 2003).

2.3 Factors affecting the operation of the system

The intelligent irrigation system can adjust the irrigation strategy and the water distribution scheme in real time by collecting different kinds of information, which can react to water requirement of farmland, so as to obtain the optimal water distribution scheme for the current irrigation area.

Factors, including water flow, pressure, soil moisture, weather, crop types, and canal topology, can react water requirements of crop. If the above-mentioned factors change during the irrigation period, then the optimal water distribution scheme and the actual optimal water flow will change. What's more, these feedback parameters need to be added into calculation in order to adjust the effluent of the water pump motor accurately.

3 Case study

3.1 Model of a canal system

Set up a three-level irrigation canal system which is shown in Figure 2, The head of the main canal connects with the water source; the end of the main canal is divided into the North Main Canal and the South Main Canal; the main canal, the north canal and south canal are respectively connected with some branch canals; in order to simplify the calculation and expression, the branch canals, which are connected to the main canal, is equivalent to be connected to a virtual main canal; sum up the flow of virtual main canal, the north canal and south canal, and it is equal to the flow of main canal.

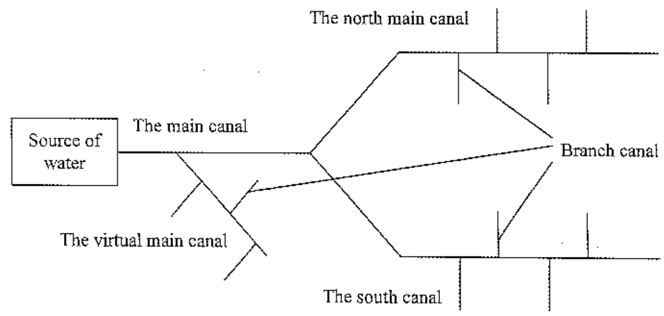

Figure 2 Model of three-level irrigation canal system

Objective function, which is aimed to minimize the total water leakage loss in the whole irrigation area, is established as follow:

$$\left.\begin{aligned} &Min\ \ S = S_{bu} + S_{bd} + S_{nu} + S_{nd} + S_{xu} + S_{xd} \\ &S_x = \sum_{i=1}^{T} f\left(A_x, m_x, q_{xi}, l_x, t_x\right)\left(x = bu, nu, xu\right) \\ &S_y = \sum_{j=1}^{P_y} f\left(A_{yj}, m_{yj}, q_{yj}, l_{yj}, t_{yj}\right)\left(y = bd, nd, xd\right) \\ &S = f\left(A, m, q, l, t\right) = \frac{\left[A \cdot l \cdot q^{(1-m)} \cdot t\right]}{100} \end{aligned}\right\} \quad (1)$$

where, *bu*, *bd*, *nu*, *nd*, *xu*, *xd* is the code of the north main canal and its branch canals, the south main canal and its branch canals and the virtual main canal and its branch canals; *S* is mean water leakage loss during irrigation period, m^3; *A*, *m*, *l*, *t* respectively means the canal bed permeability coefficient and index, canal length and water distribution time; *i* is mean serial number of water distribution period; q_{xi} means the actual flow when the distribution period is *i*; *j* is mean the serial number of branch canal; *P* is mean the quantities of branch canal.

When AGA is used during the calculation, its fitness function is constructed by addition, shown by Equation (2):

$$F(x, c(p)) = 1/[f(x) + c(p) \cdot P(x)] \quad (2)$$

where, *f*(*x*) is mean the objective function, as shown in the Equation (1); *P*(*x*) is mean the penalty item, which is established according to the constraints; *c*(*p*) is mean the adaptive penalty coefficient(Gan and Peng, 2009; Wang and Xiu, 2012; Tessema and Yen; Houck and Joines, 1994); *p* is mean the proportion of feasible solutions in the current generation.

When setting crossover rate and mutation rate, Sigmoid function (Ouyang et al., 2003; Wang and Cao, 2002; Sha et al., 2004) can be used which has a good balance in the linear and nonlinear behavior. According to the Sigmoid curve, the value of crossover rate and mutation rate of individual is adjusted nonlinearly between the average fitness of the population and the maximum fitness of the individual.

3.2 Parameter setting

AGA is used to optimize the actual water distribution. The design flow of the main canal, the north main canal and south main canal were 27, 14 and 8 m^3/s; the values of permeability coefficient A and water permeability index m of all canals are 1.9 and 0.4 (Wang and Xiong, 1993). The water demand of farmland is 0.09 m^3 in the irrigation area, and each water distribution period is 12 hours. The value of parameters of branch canal of the main canal, the north main canal and the South main canal is equal to that in document (Wu, 2016). The population of genetic algorithm is set at 80. The upper and lower bounds of crossover rate are 0.8 and 0.6, and that of mutation rate are 0.05 and 0.005. The termination condition of the algorithm is that the number of iterations is 20000.

3.3 Result analysis

3.3.1 Results of routine operation of the system

After optimization, the water flow of branch canals of the main canal is shown in Figure 3a, where the ordinate corresponds to the canal number of branch canal as well as the width of the shaded rectangle is the length of the water distribution time and the height of the rectangle corresponds to the value of flow; the water flow of the main canal is shown in Figure 3b, where the vertical coordinate is the water flow volume of the head of the main canal and the shadow area is the total water input of irrigation area.

Figure 3b shows that, after irrigation water distribution optimization, the water flow of main canal is smooth and even can be kept constant in some continuous water period, which reduce the adjustment times. The water flow of canals is close to their design flow, the time to finish the irrigation target is short. Therefore, the optimized water distribution scheme calculated by AGA is useful.

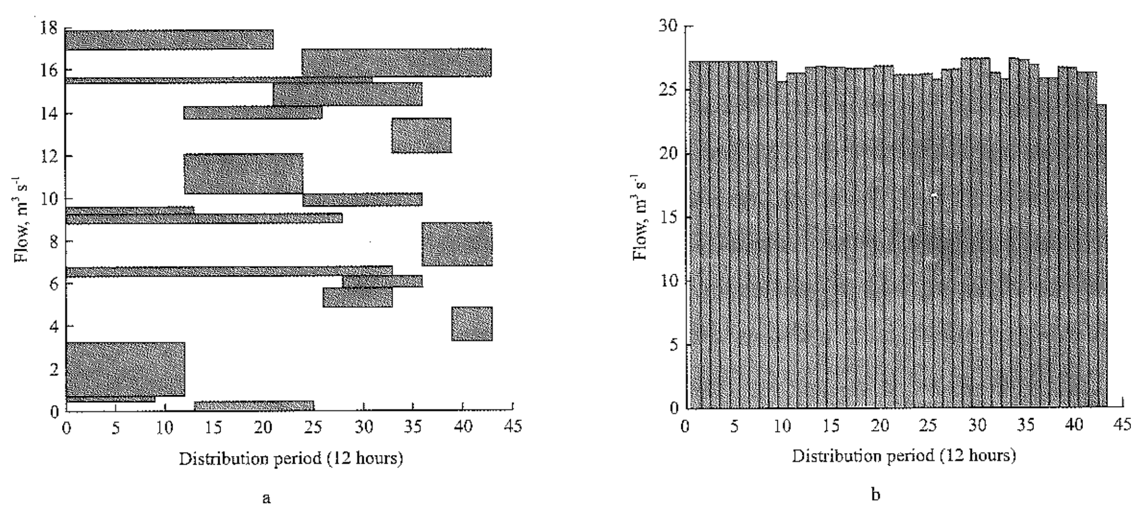

Figure 3 Distribution flow of the main canal and its branch canal

3.3.2 Results of operation of the system when considering precipitation

When an irrigation task is being finished in accordance with the original optimal water distribution scheme, any changes of feedback information will result in a deviation between the original water distribution scheme and the actual irrigation demand in a certain extent. Therefore, when irrigation feedback information changes, AGA must be used again to ensure the real-time water distribution scheme is optimal. The concrete steps are as follows: 1) Update the parameters of the new irrigation status according to the changed feedback information of the irrigation area; 2) Using AGA to reconstruct a new the water distribution scheme, which is optimal to now.

Meteorological factors have great effect to the water distribution scheme, which is mainly reflected in the rainfall. For example, it is d that there is raining in the north main canal irrigation area, which is cited from the second chapter.

Before rainfall, the water distribution scheme of the North main canal is shown in Figure 4, and the water distribution period is 43 (each period is 12 hours).

Suppose that rainfall occurs during the number 26 and 27 water distribution period. The total rainfall is 20 millimeters and is evenly distributed over time. At this time, using AGA again to calculate the water distribution scheme of the branch canals which do not finished their water distribution plan. Similarly, the minimum water loss is the objective function, and the parameters such as crossover rate, mutation rate, algorithm iteration number are the same. The fitness function is:

$$F_{fit} = 1 \Big/ \left\{ \left(S_u + S_d\right) \cdot \left[\sum_{i=1}^{T} \left(\left| Q_u - q_{ui} \right| \right) \right] \right\} \tag{3}$$

where, S_u and S_d respectively means the water leakage loss of main canal and its branch canal, (m^3); T is mean the total water distribution time, 12 hours; $|Q_u - q_{ui}|$ means the deviation between the actual water flow of the main canal and its designed flow during the water distribution period of number i, m^3/s; $\sum_{i=1}^{T}\left(\left|Q_u - q_{ui}\right|\right)$ means the penalty term of fitness function, which is the sum of all the deviation between the actual water flow of the main canal and its designed flow during the water distribution process. An individual with smaller water leakage loss has a greater fitness value. That means this individual has a greater probability of being retained, and to be participated in the operation of crossover and mutation.

The optimized calculation results are shown in Figure 5.

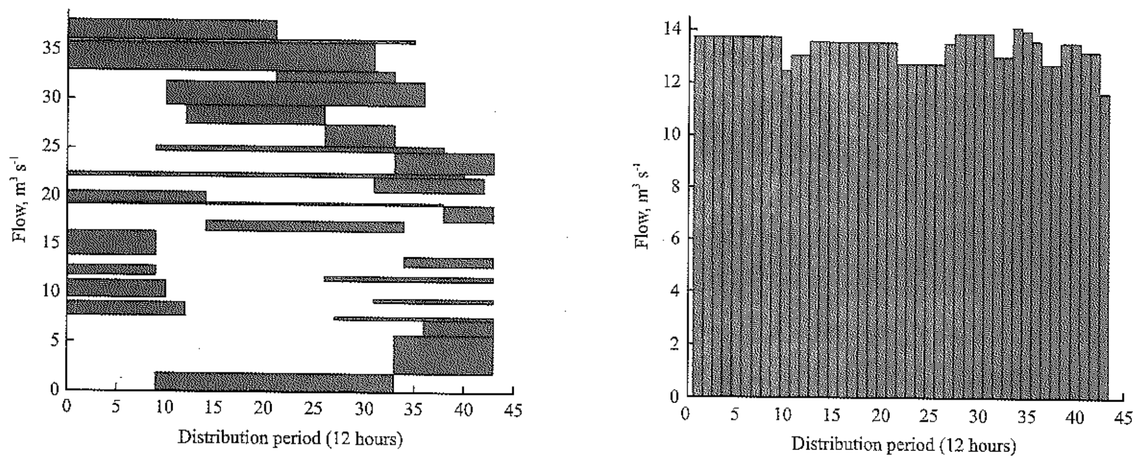

Figure 4 Distribution flow of the north main canal and its branch canal

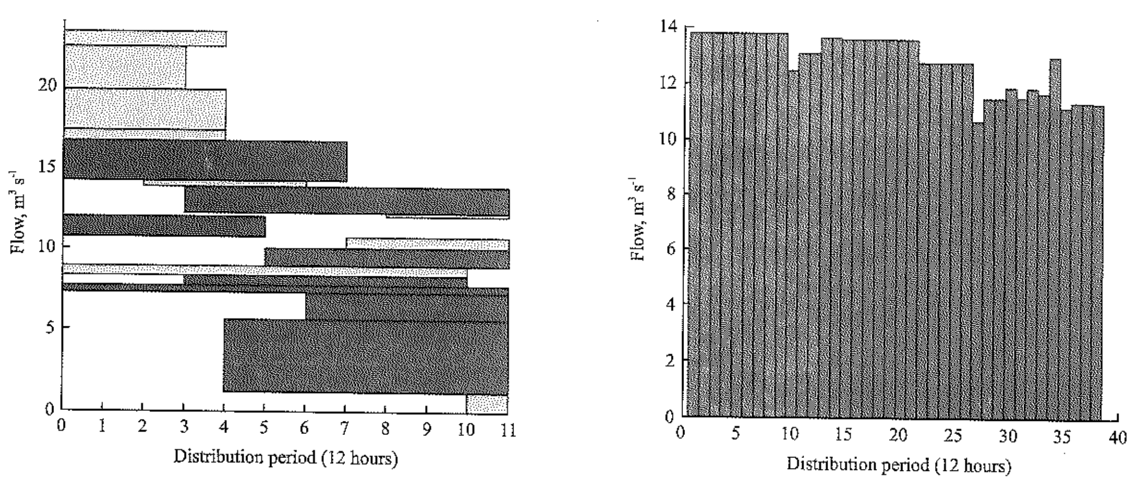

Figure 5 Distribution flow of the north main canal and its branch canal

Compared with Figure 4, after using AGA to calculate the water distribution scheme of the branch canals which do not finished their water distribution plan, It is easy to find that there exist differences of water flow and water distribution time of the North main canal between the new scheme and the original one. Obviously, the total water distribution time is shortened from 43 water distribution periods to 38, and the total water delivery volume is reduced as well.

Therefore, when the precipitation occurs, intelligent irrigation system can restrict a new optimal water distribution scheme, which can improve the efficiency of water distribution. And the frequency conversion technology which is used in intelligent irrigation system enables pump motor to output variable flow, which is fitted to the actual need of farmland.

4 Conclusion

In the intelligent irrigation system, adaptive genetic algorithm can be used to achieve the scientific irrigation strategy according to the farmland parameters as well as the canal topology. And the application of frequency conversation technology allows pump motor to output flow which can be changed according to the optimal water distribution scheme. Meanwhile, the intelligent irrigation system can collect the feedback parameters reflecting water demand of farmland in real time, and adjust the irrigation strategy according to the feedback parameters, so that the irrigation system can work under the most optimal irrigation strategy.

In addition, the irrigation system mentioned above has perfect feedback system and gate system, if the feedback system and the gate system are not complete, the effect of water saving and energy saving will be more obvious.

In summary, intelligent irrigation system will be one of the effective ways to improve the efficiency of irrigation in China.

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