ISSN 1749-3889 (print), 1749-3897 (online)
International Journal of Nonlinear Science
Vol.17(2014) No.2,pp.166-171

Coordinated Development Analysis of Energy-saving and Emission-reduction(ESER) Systems between Two Regions

Aiqin Hua[1], * Lixin Tian[1,2], Guochang Fang[1], Ruijin Du[1]
[1] Nonlinear Scientific for Research Center, Faculty of Science, Jiangsu University, Zhenjiang, Jiangsu 212013, China
[2] School of Mathematical Sciences, Nanjing Normal University, Nanjing 210046, China
(Received 11 November 2013, accepted 10 April 2014)

Abstract: Balanced regional economic, environmental and energy development is the major issues we are facing. This paper investigates the coordinated development theory between two regions based on a nonlinear evolution system. Using the synchronization control theory as the regulating and controlling theory,the coordinated development between two regions is explored. With the method of the parametric adaptive synchronization control,the demanding conditions of the systems' synchronization are obtained. Then we analysis the requirements in two parts. According to the real data of Jiangsu and Zhejiang Province, combining with the fitting performance and analysis, it's estimated that they can achieve coordinated development after the year of 2019.At last,we do conclusions and propose some inspirations for the coordinated development between regions.

Keywords: energy-saving and emission-reduction; adaptive synchronization;carbon emission;fitting analysis

1 Introduction

Currently,our country is in the development stage of industrialization with the acceleration of economic development, social progress, population growth, urbanization and living standards. The energy consumption and carbon dioxide emissions will continue to grow in the coming decades. However, the energy and environmental problems is increasingly serious.So while we are developing the economy, we should ensure the coordinated development of economy, environment and energy.

Taking mutual influence and mutual restrict relations of energy systems and economic systems, environmental systems (3E system)into Consideration, Zhao Tao and Li Xuanyu [1]established a system of coordination 3E evaluation model. Liao Mingqiu[2]incorporated both the energy conservation and emission reduction into input-output analysis framework, developed the input-output model based on the two sides, and studied the energy conservation issues from the adjustment point of industrial structure. Chen Zhongquan and Zhao Xinliang[3]worked on game analysis in ESER among the superior-subordinate governments, local government and enterprises as well as that between enterprises through the establishment of models, seek the law in the work of different sides, and explore diversification policies tool to promote ESER work.Fang GC et al[4]created a nonlinear evolution model about ESER based on the relationship of energy conservation, carbon emission economic growth. Energy intensity formulas is derived varying with time. On the empirical research data to China,it was found that significant variables affecting energy intensity in the evolution model.

However, the policies and regulations of ESER, the level of technological development, the concept of civic awareness levels are not the same in different regions. It means that the ESER systems have differences in every region. So the discussion of coordinated development between different regions is necessary. If the differences in regional ESER systems are narrowed, or even synchronized with each other, then the research results of some policies and laws, the evaluation index system, and the new management mechanism will have unity,and its applicability will be more wide.

This paper attempts to discuss the issues of regional ESER synchronization control between the two systems, and to identify the conditions for coordinated development of economy environment and energy. We use the ESER systems with some unknown parameters to reflects the situation of the two regions. After we synchronize the two regions, more areas can be synchronized and coordinated.At the same time, we obtain the corresponding controller and synchronization

*Corresponding author. *E-mail address*: hua99dushu@163.com

IJNS.2014.04.15/799

conditions needs to be met. Then using the real data of Jiangsu and Zhejiang Province to reflect their situation,with the method of curve fitting,we analyze the fitting performance to predict the approximate time when the two provinces can achieve ESER synchronization and coordinated development. Finally, we do summary, and put forward some relevant proposals about the coordinated development of ESER work in China.

2 Model, Method and Results

2.1 Research Content

Fang GC et al[4]created a nonlinear evolution model about ESER in 2012.We did some study in it,and found that $x(t)$ says the quantity of ESER which is affect by the investment, the usage of renewable energy, nuclear energy and so on. So it can be used as indicators of energy development.As the development of energy,more investment will be use in the carrying out of ESER and the development of new kinds of energy will be more fast.$y(t)$ shows the carbon emission, and it can be treat as the indicators of environmental protection development.That's because more emissions means more pollution to the environment in the current situation of China.$z(t)$ expresses the economic growth,and it can describe the economic development.From the above analysis,it can be seen that the nonlinear evolution model can reflect the energy,environment and economic development of a region.

In the case of actual ESER situation, two regions (under China's national conditions, here is A, B) is certainly different. To facilitate the discussion below, and considering the fact, we assume that the economic strength are nearly the same, development of other aspects are similar to each other.According to the assumption,then we have $C1 = C2, E1 = E2$. The significance of each coefficient indicates see Reference[4]. a_1 is the development coefficient of $x(t)$. Due to discrepancy in ESER technology investment and some relevant policies in Place A and B, it is different and respectively is a, $\acute{a}$; b_2 is the elastic coefficient of $y(t)$ development, because of the differences in industrial gathering and lifestyle(high carbon or low carbon lifestyle)in Place A and B.Seperately It is b,$\acute{b}$; c_3 is the suppression coefficient of $z(t)$ development. Although it's considered that the economic strength are nearly the same, the pace of development is different.It is c,$\acute{c}$ respectively. The actual significance of other parameters reflected the pairwise interaction between the two regions. Since the regions we discuss is under the same policy radiation, these parameters can be considered almost the same in different regions.Consequently,what we discuss is the coordinated energy,environment and economic development of place A and B.Formula(1) represents the ESER system of place A; Formula(2) represents the ESER system of place B,as show in below.

$$\begin{cases} \frac{dx_1}{dt} = ax_1(\frac{y_1}{M} - 1) - a_2y_1 + a_3z_1 \\ \frac{dy_1}{dt} = -b_1x_1 + by_1(1 - \frac{y_1}{C}) + b_3z_1(1 - \frac{z_1}{E}) \\ \frac{dz_1}{dt} = c_1x_1(\frac{x_1}{N} - 1) - c_2y_1 + cz_1 \end{cases} \tag{1}$$

$$\begin{cases} \frac{dx_2}{dt} = \acute{a}x_2(\frac{y_2}{M}) - 1 - a_2y_2 + a_3z_2 \\ \frac{dy_2}{dt} = -b_1x_+\acute{b}y_2(1 - \frac{y_2}{C}) + (1 - \frac{z_2}{E})b_3z_2 \\ \frac{dz_2}{dt} = c_1x_2(\frac{x_2}{N} - 1) - c_2y_2 + \acute{c}z_2 \end{cases} \tag{2}$$

In system(1) and (2),a,$\acute{a}$,b,$\acute{b}$,c,$\acute{c}$ is unknown.We assume other parameters are foregone.

2.2 Method

In this part,we will use the synchronization control theory to explore the coordinated development between two regions. Chaotic synchronization[5]is to reconstruct the state of two chaotic systems completely, namely designing the appropriate controller to make the motion trajectory of one chaotic system track another chaotic system. Synchronization of chaos theory has been applied to some energy system. Sun Mei et al[6] studied the adaptive-pulse synchronization of the four dimensional energy supply and demand system based on comparison theory of pulse control stability. Tian Lixin et al[7] used an improved adaptive synchronization method to realize the synchronization of two energy system with different unknown parameters. FARIVAR[8] studied generalized projective synchronization of uncertain chaotic systems with external disturbance, and applied it into different systems. GAMBINO[9]studied the post-double Hopf bifurcation dynamics and adaptive synchronization of a class of hyperchaotic system.CHENG[10]studied the fast synchronization of a class of directionally coupled chaotic system,and uses the numerical simulation to verify the correctness of the theory.As for our problem,that is the synchronization of two systems with some different unknown parameters,the adaptive synchronization control is a suitable method. The chaos characteristic was proved in [4].

Here we can set systems (1)that represents A as the drive system, systems(2) as the response system.So we add proper controller,respectively $u_1(t), u_2(t), u_3(t)$. $u_1(t)$ is a control on the ESER rate, which is related to x,y and z.it is likely to

increase the ESER technology investment when z grows fast. $u_2(t)$ is the control of carbon emission growth, which is not only related to carbon emissions itself, but also has a close relationship to economic growth ;$u_3(t)$ is a control to economic growth, it is also influenced by various factors. So $u_1(t), u_2(t), u_3(t)$ are all complex function of several variables. We should note that the control is not inhibited all the time, because controlling for the economic growth rate and ESER speed sometimes may be positive.

So the response systems with controllers are as below,we number it (3).

$$\begin{cases} \frac{dx_2}{dt} = \acute{a}x_2(\frac{y_2}{M} - 1) - a_2y_2 + a_3z_2 + u_1(t) \\ \frac{dy_2}{dt} = -b_1x_2 + \acute{b}y_2(1 - \frac{y_2}{C}) + b_3z_2(1 - \frac{z_2}{E}) + u_2(t) \\ \frac{dz_2}{dt} = c_1x_2(\frac{x_2}{N} - 1) - c_2y_2 + \acute{c}z_2 + u_3(t) \end{cases} \tag{3}$$

In addition,we assume $\acute{a} = a + \gamma_1 a, \acute{b} = b + \gamma_2 b, \acute{c} = c + \gamma_3 c$,and $\gamma_i (i = 1, 2, 3)$ express the relationship of corresponding unknown parameters between the A, B places. Then we can obtain the error system of system(3) and (1).We number it (4).

$$\begin{cases} \frac{de_1}{dt} = -ae_1 - a_2e_2 + a_3e_3 + \frac{a}{M}x_2y_2 - \frac{a}{M}x_1y_1 + \gamma_1 a(\frac{x_2y_2}{M} - x_2) + u_1(t) \\ \frac{de_2}{dt} = -b_1e_1 + be_2(1 - \frac{y_1+y_2}{C}) - b_3e_3(\frac{z_1+z_2}{E} - 1) + \gamma_2 b(y_2 - \frac{y_2^2}{C}) + u_2(t) \\ \frac{de_3}{dt} = (\frac{x_1+x_2}{N} - 1)c_1e_1 - c_2e_2 - c_3e_3 + \gamma_3 cz_2 + u_3(t) \end{cases} \tag{4}$$

Synchronization of two systems is transformed into the asymptotic stability of the origin of system (4).

Theorem 1 *When the control function is described as (5), the parameter estimation rate is showed as (6),and* $y1 + y2 > C$*, the error system(4)will be asymptotic stable at the origin.That means,for any initial value* $[x_1(0), y_1(0), z_1(0)]^T$, $[x_2(0), y_2(0), z_2(0)]^T$*,there is* $\lim_{t\to+\infty} \|e\| = 0, e = [e_1, e_2, e_3]^T$.

$$\begin{cases} u_1(t) = a_2e_2 - a_3e_3 - \frac{a}{M}x_2y_2 - x_1y_1 - \hat{\gamma}_1 a(\frac{x_2y_2}{M} - x_2) \\ u_2(t) = b_1e_1 + b_3e_3(\frac{z_1+z_2}{E} - 1) - \hat{\gamma}_2 b(y_2 - \frac{y_2^2}{C}) \\ u_3(t) = (1 - \frac{x_1+x_2}{N})c_1e_1 + c_2e_2 - \hat{\gamma}_3 cz_2 \end{cases} \tag{5}$$

$$\begin{cases} \dot{\tilde{\gamma}}_1 a = (\frac{y_2}{M} - 1)x_2e_1 \\ \dot{\tilde{\gamma}}_2 b = (1 - \frac{y_2}{C})y_2e_2 \\ \dot{\tilde{\gamma}}_3 c = z_2e_3 \end{cases} \tag{6}$$

We assume $\tilde{\gamma}_i = \gamma_i - \hat{\gamma}_i, i = 1, 2, 3$.$\hat{\gamma}_1, \hat{\gamma}_2, \hat{\gamma}_3$ *is the estimates of* $\gamma_1, \gamma_2, \gamma_3$ *respectively.*

Proof. Constructing lyapunov function V as in below:

$$V = \frac{1}{2}(e_1^2 + e_2^2 + e_3^2) + \frac{1}{2}(\tilde{\gamma_1}^2a^2 + \tilde{\gamma_2}^2b^2 + \tilde{\gamma_2}^2c^2) \tag{7}$$

Applying eq(5)and eq(6) in eq(4),and do calculating,we wii obtain: $V' = -ae_1^2 + (1 - \frac{y_1+y_2}{C})be_2^2 - ce_3^2$.

When V is positive, $\dot{V}$ is negative, we can judge the asymptotic stability of the system by the Lyapunov stability theorem. As a,b,c has factual meaning, they are positive.So $1 - \frac{y_1+y_2}{C} < 0$,i.e. $y_1 + y_2 > C$, the error system(4) is asymptotic stable at the origin.In the other side, C is the peak value of carbon emissions of one region, essentially reflects the maximum consumption of energy in the future. It is unable to achieve in the current period,so we have $y_1 + y_2 < 2C$.In a word, under appropriate control and meeting the conditions of $C < y_1 + y_2 < 2C$,system(3) and (1) can achieve synchronization.That means,the coordinate development of energy, environment and economy between two regions can realized in some time (year).

2.3 Result Analysis

For the part results of $y_1 + y_2 > C$, to achieve complete synchronization of ESER system of two regions, namely their coordinated development of energy economy, environment, we should not reduce the carbon emissions largely, and we need to control carbon emissions within a proper range. This is in line with the actual situation. Carbon emissions has positive relationship with economic growth[11]. If we reduce the carbon emissions excessively, the economic growth will be inhibited to some degree.This is not the best choice. So to keep the economy development, carbon emissions should be controlled beyond a certain range.

For the part result of $y_1 + y_2 < 2C$, the peak value of carbon emissions of A, B region will achieve in some timeyear.Before that time,they should be in coordinated development,and the governments of regions ought to work together to control carbon emissions. So that the arrival of the peak will come later.

Table 1: Energy consumption of regional gross product(equal value,ton/10 thousand yuan)

Region/year	2009	2010	2011
Jiangsu	0.76	0.92	0.6
Zhejiang	0.74	0.90	0.59

Table 2: Carbon emissions of energy consumption of Jiangsu and Zhejiang from year 2000-2010(10^4 ton carbon)

year/Region	Jiangsu	Zhejiang
2000	7217	4244
2001	7344	4619
2002	7800	5043
2003	8796	5591
2004	10607	7103
2005	13266	8270
2006	14893	9778
2007	16219	11268
2008	17303	11223
2009	17677	11561
2010	19786	12509

3 When Coordinated Development Come?Based on Real Data.

In section 2.3,it is said that the coordinate development of enrgy, environment and economy between two regions can realized in some time (year).So when it can be achieved is question.In the next,we will talk about this based on the real data of Zhejiang and Jiangsu Province of China.

According to the research hypothesis: economic strength and other situations about our system are similar, We select Zhejiang and Jiangsu provinces empirical analysis. This selection, mainly based on the statistical data of "energy consumption of regional gross product " , which shows Jiangsu and Zhejiang is in line with the assumption(see Tab 1[12]).

In section 2.2,in the demanding conditions, C is unknown. So it is essential to estimate the value of C. Experts of the NDRC Energy Research Institute think that Chinas Carbon emissions peak will come in 2030 to 2040, and some other experts believe that it will come 10 years ahead. In such national conditions, it will also appear in 2020 to 2030 in Jiangsu and Zhejiang. We assume that is in 2025.First, with the method of Physical volume calculation[13],we calculate the carbon emissions of the two provinces from 2000 to 2010 by the way in below(see Tab2[14]).Second, on the bases of table 2 and table 3, and with the Matlabs curve fitting tool, we do fitting analysis and adjusting. Finally we will obtain the estimates of carbon emissions in 2025 of them(see fig 1,fig 2).

According to the fitting analysis results, the estimates of energy consumption and carbon emission of Jiangsu is 9735120 thousand ton carbon. It is 6967650 thousand ton carbon of Zhejiang. To the demanding conditions: $C < y_1 + y_2 < 2C$ (When we take about the factual situation,we can use $\frac{C_1+C_2}{2} < y_1 + y_2 < C_1 + C_2$). So the starting time satisfied with the conditions is expected to be 2019,when the sum emission is 8904940 thousand ton carbon.After this period of time, it is likely to achieve coordinated development. We say "probably" because it is also due to the different controller.

4 Conclusions

This paper discusses the synchronization control problem of regional ESER system, i.e. the energy ,environment and economic coordinated development of two regions. With the method of adaptive synchronization, the conditions of coordinated development are obtained. Then we analyze the results in two parts.Based on the results,we have some inspirations.

There are some inspirations from the results of the discussion in this paper. First of all, the premise of coordinated development between two regions is to keep carbon emissions over an appropriate range, which also describes the coordination development between different areas is inseparable from economic development. So the government still has to focus on economic development as the center, to maintain sustainable economic development.

Secondly, the government is the operator and controller for the implementation of energy conservation. Combining

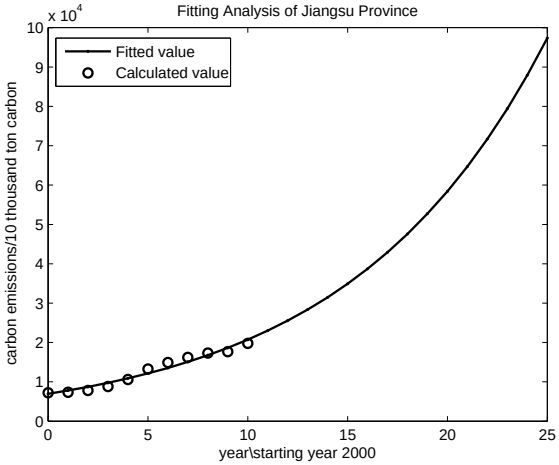

Figure 1: Fitting results of carbon emissions of Jiangsu

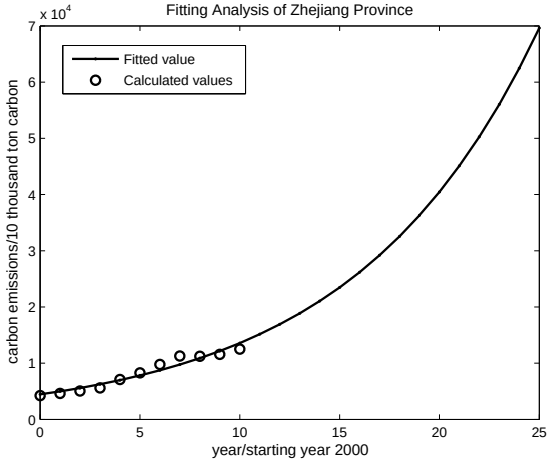

Figure 2: Fitting results of carbon emissions of Zhejiang

with present situation and goals, the government can develop and improve some policies related to ESER and fully play a role in macro-control functions, so as to gradually change the mode of production and consumption structure, and to do better work in policy support for the coordinated development. Enterprises, especially the second industry related businesses, is the main energy consumption body. They should focus on strategic transformation, take a low carbon economy as the core, and treat the technology investment as means to practice the ESER work.

In a word, it requires the government to implement highly effective energy conservation management mechanism, enterprises, communities, families and individuals to work together for the coordinated development between two regions. It will take a long time, which indicates that we will experience a big ordeal before China's energy conservation work entering into a new stage. But ultimately the coordinated development can be achieved.

References

[1] T.Zhao and X.Y. Li. On the Coordinating evaluation model for energy- economy- environment system. *Journal of Beijing Institute of Technology: Social Sciences Edition.*, 10(2)(2008): 11-16.

[2] M.Q. Liao. Research on the input-output model based on energy saving. *China Industrial Economics.*, 7(2011): 26-34.

[3] Z.Q. Chen and X.L. Zhao. Game analysis in the process of the energy saving and emission reduction. *Journal of China University of Geo Sciences: Social Sciences Edition.*, 9(1)(2009): 54-58.

[4] G.C. Fang,L.X. Tian,M. Sun,et al. Analysis and application of a novel three-dimensional energy-saving and emission-reduction dynamic evolution system. *Energy.*, 40(2012): 291-299.

[5] G.R. Wang,X.L. Yu and S.G. Chen. Chaos control, synchronization and its application. National Defence Industry Press,China. 2001

[6] M. Sun,Y.W Tao and C.Y. Zeng. Adaptive-impulsive synchronization of a four-dimensional energy supply-demand system. *China mining Magazine.*, 18(8)(2009): 88-90.

[7] L.X. Tian,J.Xu and M.Sun. Adaptive synchronization of energy resource system with uncertain parameters. *ournal of Jiangsu University: Natural Science Edition.*, 28(4)(2007): 358-361.

[8] F. Faivar,M.A. Shoorehdeli,M.A. Nekoui,et al. Generalized projective synchronization of uncertain chaotic systems with external disturbance. *Expert Systems with Applications.*,38(2011): 4714-4726.

[9] G. Gambino and S.R. Choudhury. Post-double hopf bifurcation dynamics and adaptive synchronization of a hyper-chaotic system. *Acta Appl. Math.*, 122(2012): 269-282.

[10] S. Cheng,J.C Ji and J.Zhou. Fast synchronization of directionally coupled chaotic systems. *Applied Mathematical Modelling.*,37(2013): 127-136.

[11] S.H. Xie,X.Y. Xu and Z.H. Wei. Empirical research on relationship between carbon emission and economic growth in China. *Resource Development and Market.*, 29(1)(2013): 28-31,40.

[12] National Bureau of Statistics of China. CHINA STATISTICAL YEARBOOK. Beijing: China Statistics Press. 2009-2011.

[13] R.L. Jin. Carbon emissions evolutionary dynamic system and evolutionary scenario analysis. Jiangsu: Jiangsu University. 2011.

[14] Department of Energy Statistics,National Bureau of Statistics P R China. CHINA ENERGY STATISTICAL YEARBOOK. Beijing: China Statistics Press. 2000-2010.