ISSN: 2664-9640

Collaborative strategy analysis of clean energy generators and energy storage providers in the blockchain environment

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Abstract

With the development of clean energy, the application of blockchain technology in the field of clean energy is getting more and more attention. In this paper, the block chain environment clean energy and energy storage power providers business collaboration strategy research, is an object with the generators and energy storage, build a evolutionary game model, discusses the local equilibrium of the game and the dynamic evolution process, and connecting with the simulation results were analyzed, and a reasonable conclusions and Suggestions, provide reference for the development of clean energy.

Keywords

Clean energy, blockchain, Collaborative strategy, evolutionary game.

1. Introduction

The cooperation between clean energy generators and energy storage providers is one direction of clean energy development. However, the widespread information asymmetry will affect the trust level of both parties and reduce the efficiency of cooperation [1]. The application of blockchain technology provides a way to eliminate information asymmetry. Clean energy and energy storage companies can greatly increase the mutual trust level of the two engines, improve the efficiency of cooperation and obtain more cooperation benefits through the joint construction of the blockchain platform. The research on the cooperation strategies of clean energy power generators and energy storage providers in the blockchain environment can provide a reference for the cooperation between the two parties, which is conducive to the development of clean energy.

As one of the representatives of the new generation of information technology, blockchain has the characteristics of decentralization, tamper-resistant, traceability and so on, which can effectively solve the information asymmetry between nodes [2]. The application of blockchain in the energy field is mainly in energy dispatching, energy trading, etc., which can effectively solve the trust problem between the trading parties [3-5]. For the cooperation between clean energy power generators and energy storage providers, the cooperation strategies of both sides in the blockchain environment influence each other and constantly evolve, which is in line with the idea of evolutionary game. Currently using evolutionary game theory research in the field of energy has a lot of, such as Chai Ruirui [6] built evolutionary game model between government departments and power generation enterprises, analysis of government power subsidy policy and stable equilibrium of power generation enterprises to select the energy structure evolution, discussed the traditional clean energy utilization and renewable clean energy inclusive development boundary conditions. From the perspective of stakeholders, Wang Wei et al. [7] explored the sustainable development path of rural clean energy transformation by constructing a three-party evolutionary game model among local government, enterprises and rural residents. Xie Jingdong et al. [8] constructed a three-party

ISSN: 2664-9640

game model of regulatory agencies, power grid companies and micro grid based on the actual regulatory scenario by using evolutionary game theory, and studied the correlation of game strategies of each game subject as well as the asymptotic stability conclusion. In addition, the application of evolutionary game in the bidding behavior among energy subjects, energy use behavior, development of new energy vehicles and other aspects [9-11] has also attracted scholars' attention.

Through the analysis of the above literature, we can find that although there have been many researches in the energy field using evolutionary game theory, there are few researches on the cooperation strategies of clean energy power generators and energy storage providers using evolutionary game model in the blockchain environment. Therefore, this paper, by using evolutionary game model of block chain environment clean energy and energy storage power generators business collaboration strategy were analyzed, and the first according to the basic assumption to construct electricity generators and energy storage business collaboration evolution game model, and analysis of parameter changes, from synergies, block chain construction fee, the percentage of government subsidies, simulation analysis was made on three aspects, According to the simulation results, the game equilibrium is expounded and reasonable suggestions are given.

2. Basic Assumptions and Model Construction

2.1. Basic Assumptions

Blockchain platform serves the energy transaction between clean energy power generators and energy storage providers, provides a reliable trading platform for both parties, and ensures the security and tamper-resistant of transaction information. The construction of the blockchain platform is jointly completed by both parties. Due to the distributed characteristics of the blockchain technology, power generators and energy storage providers can start from the unilateral construction of the blockchain platform and use it together after the completion of the construction respectively. In addition, for the sake of information security, both parties independently completed the construction of unilateral blockchain platform, so there is no free-riding behavior. Based on the above analysis, we have the following assumptions:

Hypothesis 1: According to whether the power generator and energy storage provider participate in the construction of the blockchain platform, it can be concluded that the strategy sets of both sides are {participate, do not participate}, as {P, DP}. Set x as the probability when the power generator participates in the construction of the blockchain platform, the probability when the energy storage provider participates in the construction of the blockchain platform, and $x, y \in [0,1]$.

Hypothesis 2: The basic income of the power generator without participating in the blockchain platform is the difference between the generation income and the generation cost. The generation income is R1 and the generation cost is C1.

Hypothesis 3: The basic benefit of the energy storage provider without participating in the blockchain platform is the difference between the revenue of the integrated energy service and the equipment cost. The revenue of the integrated energy service is R2 and the equipment cost is C2.

Hypothesis 4: Power generators and energy storage providers can produce synergies only when they join the blockchain platform at the same time, and the synergies generated are B1 and B2 respectively.

Hypothesis 5: When power generators and energy storage providers participate in the construction of the blockchain platform, they should pay the construction fee of the blockchain platform, Q, including the construction cost and operation and maintenance fee.

ISSN: 2664-9640

Hypothesis 6: In order to encourage power generators and energy storage providers to carry out information construction, the government will provide appropriate subsidies to them when they construct blockchain platform, and the subsidy ratio is θ, $\theta \in [0,1]$. When the θ is 1, it means that the government fully funded the construction of the blockchain platform; When the θ is 0, the government does not subsidize this.

Based on the above assumptions, we define the meanings of the parameters, as shown in Table 1.

Table 1 Parameter meanings

Parameter	meaning
x	Probability that power generators will participate in building a blockchain platform
y	The probability that energy storage providers will participate in building blockchain platforms
R1	Generator revenue
C1	Generation cost
R2	Energy storage providers integrated energy services revenue
C2	Energy storage equipment cost
B1	The synergies enjoyed by power generators
B2	The synergies enjoyed by energy storage providers
Q	Blockchain construction fee
θ	Government subsidy ratio

2.2. Evolutionary Game Model

Based on the basic assumptions, we can get the payment matrix of power generator and energy storage provider, and analyze their evolutionary game model.

(1) Construction of payment matrix

Based on the above assumptions, the payment matrix of the game between power generator and energy storage provider can be constructed as follows:

Table 2 Game payment matrix of power generator and energy storage provider

		energy storage provider	
		P (y)	DP (1-y)
Power generators	P (x)	$(R1-C1+B1-(1-\theta)Q,$ $R2-C2+B2-(1-\theta)Q)$	$(R1-C1-(1-\theta)Q,$ $R2-C2)$
	DP (1-x)	$(R1-C1,$ $R2-C2-(1-\theta)Q)$	$(R1-C1, R2-C2)$

(2) Analysis of evolutionary game model

In order to obtain the dynamic replication process in evolutionary game between power generators and energy storage providers, based on the relevant theories of evolutionary game and the calculation method of expected revenue [1], E1 and E2 respectively represent the

ISSN: 2664-9640

average expected revenue of power generators and energy storage providers, and the following can be obtained according to Table 2:

The expected revenue of the power generator choosing the P strategy is:

$$E_{11} = y(R_1 - C_1 + B_1 - (1-\theta)Q) + (1-y)(R_1 - C_1 - (1-\theta)Q) \tag{1}$$

The expected revenue when the power generator chooses DP strategy is:

$$E_{12} = y(R_1 - C_1) + (1-y)(R_1 - C_1) = R_1 - C_1 \tag{2}$$

Therefore, the average expected revenue when the power generator chooses the P strategy is:

$$\begin{aligned} E_1 &= xE_{11} + (1-x)E_{12} \\ &= x[y(R_1 - C_1 + B_1 - (1-\theta)Q) + (1-y)(R_1 - C_1 - (1-\theta)Q)] + (1-x)(R_1 - C_1) \end{aligned} \tag{3}$$

According to the Malthusian dynamic equation, the replication dynamic equation of the power generator choosing the P strategy can be obtained as follows:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x(E_{11} - E_1) \\ &= x(1-x)[y(R_1 - C_1 + B_1 - (1-\theta)Q) + (1-y)(R_1 - C_1 - (1-\theta)Q) - (R_1 - C_1)] \\ &= x(1-x)(yB_1 - (1-\theta)Q) \end{aligned} \tag{4}$$

The expected revenue of energy storage providers choosing P strategy is:

$$E_{21} = x(R_2 - C_2 + B_2 - (1-\theta)Q) + (1-x)(R_2 - C_2 - (1-\theta)Q) \tag{5}$$

The expected revenue of energy storage companies when they choose DP strategy is:

$$E_{22} = x(R_2 - C_2) + (1-x)(R_2 - C_2) = R_2 - C_2 \tag{6}$$

Therefore, the average expected revenue of energy storage providers when they choose the P strategy is:

$$\begin{aligned} E_2 &= yE_{21} + (1-y)E_{22} \\ &= y[x(R_2 - C_2 + B_2 - (1-\theta)Q) + (1-x)(R_2 - C_2 - (1-\theta)Q)] + (1-y)(R_2 - C_2) \end{aligned} \tag{7}$$

Similarly, the replication dynamic equation of the energy storage providers choosing the P strategy can be obtained as follows:

$$\begin{aligned} F(y) &= \frac{dy}{dt} = y(E_{21} - E_1) \\ &= y(1-y)[x(R_2 - C_2 + B_2 - (1-\theta)Q) + (1-x)(R_2 - C_2 - (1-\theta)Q) - (R_2 - C_2)] \\ &= y(1-y)(xB_2 - (1-\theta)Q) \end{aligned} \tag{8}$$

Let $F(x) = 0$ and $F(y) = 0$, the local equilibrium points of five evolutionary game matrices can be obtained by solving the differential equations, namely:

$O(0,0), A(0,1), B(1,1), C(1,0),$

$$D = (x^*, y^*) = \left(\frac{(1-\theta)Q}{B_2}, \frac{(1-\theta)Q}{B_1}\right) \tag{9}$$

(3) Equilibrium point analysis and stability discussion

According to the method proposed by Friedman, the system of differential equations describes the population dynamics, and the stability of its equilibrium points can be obtained by analyzing the local stability of the Jacobi matrix of the system. The Jacobi matrix of the system and its corresponding determinant and trace can be obtained as follows:

$$J=\begin{bmatrix}\dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y}\\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y}\end{bmatrix}=\begin{bmatrix}(1-2x)(yB_1-(1-\theta)Q) & x(1-x)B_1\\ y(1-y)B_2 & (1-2y)(xB_2-(1-\theta)Q)\end{bmatrix} \tag{10}$$

$$\begin{aligned}\det(J)&=(1-2x)(1-2y)(yB_1-(1-\theta)Q)(xB_2-(1-\theta)Q)\\&-xy(1-x)(1-y)B_1B_2\end{aligned} \tag{11}$$

$$tr(J)=(1-2x)(yB_1-(1-\theta)Q)+(1-2y)(xB_2-(1-\theta)Q) \tag{12}$$

The purpose of power generator and energy storage providers to cooperate in building a blockchain platform is to obtain more benefits. Therefore, the necessary condition for both parties to choose to participate in building a blockchain platform is that the synergistic benefits obtained by power generator and energy storage providers when they adopt P strategy in the game process should be greater than the benefits obtained by both parties when they adopt DP strategy, as follows:

$$B_1>Q\ ;\ B_2>Q$$

On this basis, the stability of the equilibrium of differential equations is analyzed, which can be judged by sign of the determinant $\det(J)$ and trace $tr(J)$ of Jacobi matrix. When $\det(J)>0$ and $tr(J)<0$, the equilibrium point of the replicated dynamic equation is the evolutionary stable strategy (ESS). Therefore, the stability of evolutionary game can be obtained as shown in Table 3.

Table 3 Stability analysis of evolutionary game system in which power generators and energy storage providers participate in the construction of blockchain

Balance	$\det(J)$	$tr(J)$	Stability
$O(0,0)$	+	–	ESS
$A(0,1)$	+	+	unstable
$B(1,1)$	+	–	ESS
$C(1,0)$	+	+	unstable
$D(x^*,y^*)$	–	0	Saddle point

The equilibrium points O and B represent two equilibrium points with local stability, corresponding to the strategies when both the power generators and the energy storage providers choose to participate or not to participate, respectively. The phase diagram of the game system evolution of both sides is shown in FIG. 1. Five equilibrium points divide the entire game system into two evolution regions with completely different evolution trends. Part of the evolutionary game of AOCD converges to O(0,0), that is, both the power generator and the energy storage provider adopt the non-participation strategy. Electricity generators in the generated output curve and the user's load curve does not necessarily fit, and at the time of the load low energy storage, can store electricity and energy released when the peak load to adjust, to realize the improvement of energy utilization, and block chain platform can strengthen the trust between parties, improve the efficiency of cooperation, to create more benefits of cooperation, Therefore, in the final game, both sides choose the participation strategy in order to obtain the best payoff, that is, the two-side evolutionary game converges to a stable state of B(1,1). And only one choice to participate in the chain platform to work not the block effect of chain platform, namely cannot achieve cooperation of mutual trust and participate in building block chain platform will increase costs, as a result, the aggrieved party will eventually choose

ISSN: 2664-9640

to no longer participate in the building, which is O (0, 0) in the long term evolutionary game of both sides to another steady state.

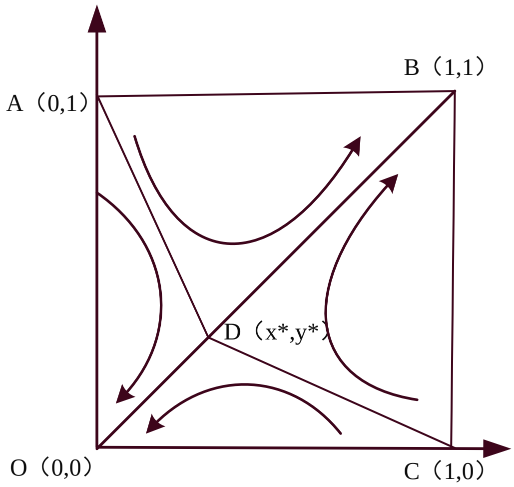

FIG. 1 Phase diagram of game system evolution between power generator and energy storage provider

3. Parameter Change Analysis and Simulation

3.1. Effect of parameter variation on convergence of evolutionary system

S2 represents the area of region ABCD, and represents the probability that the game system converges to B (1,1). The larger THE S2 is, the higher the probability of the power generator and energy storage provider cooperating to build the blockchain is. The calculation formula is as follows:

$$S_2=1-\frac{1}{2}\left(\frac{(1-\theta)Q}{B_2}+\frac{(1-\theta)Q}{B_1}\right)$$

Based on this, the parameters affecting the convergence of the evolutionary game system of power generator and energy storage provider are analyzed:

(1) Power generators enjoy synergistic benefits (B1) and energy storage operators enjoy synergistic benefits (B2). Because of $\frac{\partial S_2}{\partial B_1}>0$ and $\frac{\partial S_2}{\partial B_2}>0$, through to the saddle point D (x * y *) analysis, can be found, as B1, B2 increase saddle point D to move left, S2, namely when electricity generators to enjoy synergies or, energy storage, to enjoy the synergies of larger probability of cooperation between the two sides will increase, convergence in the final game both sides option to increase the probability of P strategy.

(2) The impact of blockchain construction cost and operation and maintenance cost (Q). Because $\frac{\partial S_2}{\partial Q}<0$, so, through the analysis of the saddle point D can be found, it is time when Q increases, saddle point move D to the upper right, S2 decrescent, i.e., when the power generators and building blocks of chain store business would have to pay the costs and operations to increase, the probability of cooperation between the two sides will be reduced, the probability of convergence in the final game both sides DP strategy.

(3) The influence of government subsidy ratio (θ).Because of $\frac{\partial S_2}{\partial \theta}>0$, through the analysis of saddle point D, it is found that when θ becomes larger, saddle point D moves to the lower left and S2 becomes larger. In other words, when the government's subsidy for the construction of

ISSN: 2664-9640

blockchain increases, the probability of both sides of the game choosing to jointly build A blockchain platform will increase, and the probability of the final convergence of the game will increase as both sides choose the P strategy.

3.2. The Example Simulation

We take the power generators and energy storage provider in a power supply area as an example to conduct simulation, change the value of different parameters, simulate the game strategy change of power generator and energy storage provider, and quantitatively analyze the influence of various factors on the cooperation of power generator and energy storage provider to build the blockchain platform. It can be seen from Eq. (4) and (8) that the equilibrium result of the evolutionary game is only related to the synergistic benefits (B1, B2), blockchain construction fee (Q) and government subsidy ratio (θ) of power generators and energy storage providers. Therefore, we respectively assume that the initial probability of power generators and energy storage providers to participate in the construction of blockchain platform is 0.5. The synergistic benefits obtained by power generators and energy storage providers are 100,000 yuan and 80,000 yuan respectively, the construction fee of blockchain is 50,000 yuan, and the ratio of government subsidy is 20%, namely B1=10, B2=8, θ =0.2, Q=5. According to the above initial values, the simulation analysis is carried out, and the results are shown in Figure 2. It can be seen that with the progress of the game, the final X and Y converge to 1, that is, the equilibrium result of the game is that both sides participate in the construction of the blockchain platform.

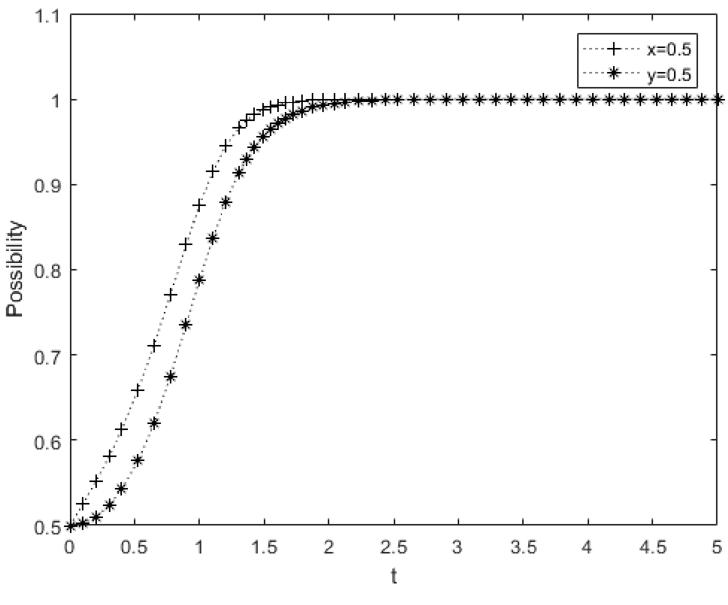

FIG. 2 Simulation results

By changing the size of parameter values, we analyze the effects of synergistic benefits, construction cost and maintenance cost of blockchain, and government subsidy ratio on the game equilibrium result respectively. The simulation results are shown in FIG. 3, FIG. 4 and FIG. 5. It can be seen from FIG. 3 that with the increase of synergistic benefits, the game will reach the equilibrium state of cooperative block platform construction at a faster rate. As can be seen from Figure 4, the increase of the construction fee of blockchain will lead to the game evolution to the equilibrium result that neither party participates in the construction of blockchain platform; As can be seen from Figure 5, as the government subsidy rate increases, the game will also reach the equilibrium state of cooperative block platform at a faster rate.

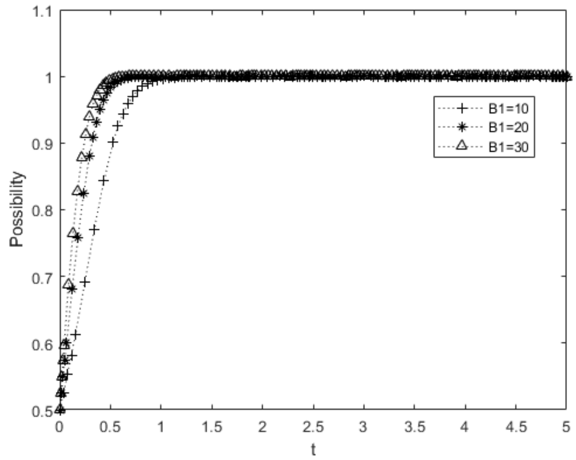

FIG. 3 Effect of synergistic benefits on game equilibrium

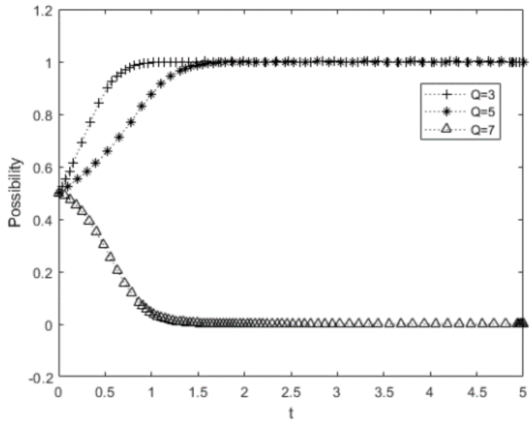

FIG. 4 Impact of construction cost and maintenance cost of blockchain on game equilibrium

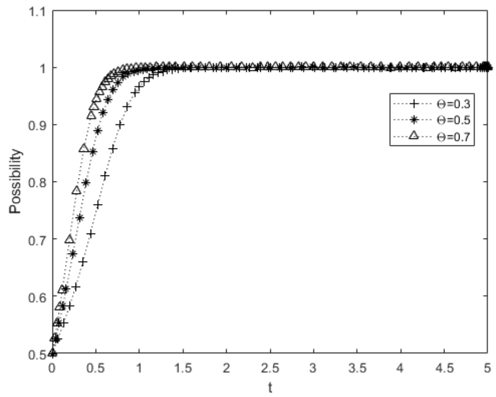

FIG. 5 Influence of government subsidy ratio on game equilibrium

4. Conclusions and Suggestions

The use of blockchain technology can improve the benefits of cooperation between clean energy power generators and energy storage providers. The strategy of cooperation between clean energy power generators and energy storage providers to build a blockchain platform is conducive to maximizing the benefits of both sides. In addition, with the development of clean energy technology, the cooperative benefits obtained by the cooperation between power generators and energy storage providers will be greater, and the game equilibrium result will also move towards the direction of cooperative construction of blockchain platform. In addition, with the development of blockchain technology, the cost and maintenance cost of building a

ISSN: 2664-9640

blockchain platform will be constantly reduced, and the probability of clean energy power generators and energy storage providers to cooperate to build a blockchain platform will be greater. In addition, the government's subsidies for building blockchain platforms will affect the strategic choices of power generators and energy storage providers. The greater the government's subsidies, the greater the probability that both sides will cooperate to build blockchain platforms.

To this end, we propose the following suggestions:

(1) Vigorously develop clean energy technology and energy storage technology, and strengthen the synergistic benefits of cooperation between the two parties;

(2) Promote the application of blockchain technology, reduce the construction cost of blockchain platform, can effectively strengthen the possibility of cooperation between clean energy power generators and energy storage providers, so as to obtain greater benefits;

(3) The government makes reasonable use of policy means and takes appropriate subsidies for the construction of blockchain platform, which can promote the rapid development of the market and facilitate the cooperation between clean energy power generators and energy storage providers.

Acknowledgments

This study is supported by the National Science Foundation of China (NSFC) (71771085). The authors appreciate the editors and the anonymous reviewers for their valuable comments, which are helpful to improve the work.

Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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