Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 8, Issue 29, pages 33-42, 2022

Game Theory, Electrical Power Market and Dilemmas

Md. Ahsan Habib
[1]Interdisciplinary Graduate School of Engineering Sciences, [2]Department of Electrical and Electronic Engineering
[1]Kyushu University, [2]Begum Rokeya University
[1]Fukuoka, Japan, [2]Rangpur, Bangladesh
emonape@gmail.com

Abstract – **Several issues that are evolving in the highly competitive electric power market are going to be crucial, day by day, in terms of the motivation for the electricity generation with profit. The key point to optimize for the electrical power generators is to understand the real fact of power generation system behind existing dilemma situations that will carry the better prospect with more profit in the long run. Game theory can approach the solution of the problems as well. This paper shows the profit with production in terms of with (out) contract for difference (CfD) for two electrical power generators that face the various dilemma strength situations in four different game classes: Prisoner's dilemma, Trivial, Chicken, and Stag-Hunt relying on the different payoff matrix of 2 × 2 games. Prisoner's dilemma matrix game indicates the higher profit which is achieved through the lower production rate for both generators by negotiation as Nash equilibrium and the profit is also increased with reducing dilemma situation, that is more realistic than Trivial game which provides higher profit with the agreement. According to the risk-aversion severity, the Chicken game has a strong impact based on real-life regarding the electrical power generators against dilemma situations. Stag-hunt shows neutrality to choose better option due to the demand of the situation.**

Keywords-component; Game theory; Electrical power generators; Contract for difference; Dilemma situations; Payoff; Profit.

I. Introduction

The market power in the world is increasingly emphasized on power demand and supply related to ongoing liberalization development. The key point is that presuming the perfect model of a competitive market in which a better market efficiency has been provided for the whole society. Based on the characteristics of our real society, the power markets are oligopolistic in the real sense that monitors continuously different types of dilemma situations which are needed to mitigate the problems for the sustainable market power society. As for instance, the power market in California was acknowledged by a lot of dilemmas once [1-2]. Compare the market power with the other markets show the profit which can be aroused based on different strategic interactions [3]. Besides, electric power markets are more vulnerable in the market power than other markets due to face difficulty in generation capacity constraints, storing power, and transmission capacity constraints [4-5] of electricity. Market equilibrium of market power, one of the game-theoretical approach, which is defined as the set of prices, generators output, profits that meet participant's conditions for maximization of its profit while clearing the market; Hobbs [6] shed light on the two Cournot models of the imperfect competition in bilateral and POOLCO power markets among the electricity producers presuming the mixed linear complementarity problems (LCPs), Xiaohong et al. [7] studied on gaming and price spikes that have been observed based on prisoner's dilemma game matrix which show the strategic bidding behaviour to see how the power suppliers and the demand services were actually worked on the energy market, Bajpai et al. [8] focused on the theoretical aspects of the game theory adopted bidding strategic behaviour by the participants as the power generation companies in the competitive electrical power market have the significant impact to get the maximum profit, Bompard et al. [9] introduced the application of the game theory to the physical constrained of electricity markets with the aim of providing tools for assessing performance of electrical power market, Saguan et al. [10] stated that the two approaches; game theory and agent-based economics, converged to the same outcome when the unique Nash equilibrium existed that complied with the game theoretical approach, Berry et al. [11] considered the competition in the electric network which was to examine the non-cooperative behavior among the producers and calculated the Nash equilibrium under the different market specifications, Baldick et al. [12] represented to compare the Cournot model and the supply function equilibrium model of bid-based electricity power markets with(out) transmission constraint.

Based on the different strategic interactions, game theory has a strong impact on power markets as well as power generators, which show different attributes rely on the decisions of other competitors; Hobbs et al. [13] indicated the strategy of the gaming model for analyzing oligopolistic market economy consisting of the several dominant firms in the network of electric power in which each firm submitted bids to choose maximize benefits as from multi-firm Nash equilibria to anticipate reactions by the rival firms, Cardell et al. [14] demonstrated that the model of Cournot firms with the collection of the competitive fringe participants illustrated possible strategic interactions of the electrical network, Li et al. [15] focused on the competitive bi-level problem; the upper sub- problem expressed as individual GENCOs (i.e. maximize the payoff of the individual regarding GENCOs') and lower sub-problem presented Independent System Operator (ISO)(i.e minimize the payments of the consumers' for clearing the problems), Xian et al. [16] showed that the generating firms could exercise their market power by the over-production under congestion system, or by the capacity withholding in case of the shortage of power, Cunningham et al. [17] shed light on pure strategy equilibrium which could break down even if the transmission constraint exceeded the value of line flow of the unconstrained Cournot equilibrium, Contreras et al. [18] represented the relaxation algorithm to compute the players' payoffs under the cooperative game theoretical concepts; the bilateral Shapley value and the kernel, Neuhoff et al. [19] revealed the Cournot equilibria which were the highly sensitive to the presumptions of the power market design regarding the northwest Europe (whether the timing of generation and the transmission decisions were integrated or sequential), Simaan et al. [20] stated the Stackelberg model solution by using Nash strategy with many leaders and many followers. Yu. et al. [21] displayed the model of Stackelberg leadership model for simulating the deregulated electricity markets which consisted of large producers those could adopt the oligopoly strategy with small producers using the Bertrand-like strategy to get the maximum profit, Tasnadi et al. [22] stated the game-theoretical approach of the Forchheimer's model of the dominant-firm with respect to the game setting quantity with large firm as well as a lot of small firms. Stephen DeCanio et al. [23] revealed from the view of scientific point to severity of risks of the climate change suggested the characterization of negotiations as the Coordination game rather than the Prisoner's Dilemma game, Yanni et al. [24] stated that the peer-to-peer (P2P) electricity trading provided the profits to the prosumers and promoted the development of the electricity market in the energy blockchain environment, Hakimi et al. [25] depicted that a Cournot equilibrium with game theory (GT) were applied to the model of the real-time electricity market & their interactions with the multi-microgrid (MMG), and the achieved results authenticate the prominent of the modeling of the interaction between the MMG and the electricity market, Oh et al. [26] shed light on the electricity consumption responsiveness to the change of electricity price was greater if the wholesale prices, the consumer income, the prior consumption, and the supply elasticity were higher, and the retail prices were lower, Kwonga et al. [27] focused on the stackelberg game theoretical approach which was adopted to formulate the joint optimization model that involved with manufacturer and retailer, Yucekaya et al. [28] examined the electricity trading and market design in the Turkish power market to maximize the expected profit based on spot, derivative , and bilateral contract market. Game-theoretic models, one of the most elegant formalizations of the strategic interactions, from Morgenstern and Von-Neumann [29] which presented the application of game theory to the problems of power markets. Let's focus on the symmetric 2-player & 2-strategy game, named 2 × 2 games, [30-32] where two players are from infinite and well-mixed population and the payoff structure of two players are presumed as the "column" and "row", are imposed of two strategies; higher production as well as lower production given in Table I. Thus, the upper left cell of the matrix "e" shows the payoff for the row if the row adopts the higher production, and the column adopts higher production. The payoffs to each player are measured in {e, f, g, h} respectively in which e (h) shows the mutual cooperation (defection) payoff, f (g) indicates the focal player cooperating (defecting) when his opponent defecting (cooperating). A very new innovative concept called dilemma strengths for 2 × 2 games was initiated in [31-32], according to the game theory and evolutionary game-theoretical approach, that is to say;

Dg=g-e (1), Dr = h – f (2),
Dg/=Dg / (e-h) (3), Dr/= Dr / (e-h) (4).

TABLE I: 2× 2 PLAYER GAME

		Column's strategy	
		High production	***Low production***
Row's strategy	***High production***	e, e	f, g
	Low production	g, f	h, h

where D_g provides the gamble-intending dilemma (GID) in which two equal players can exploit each other, and D_r presents the risk-aversion dilemma (RAD) that shows the equal players are never trying never to be exploited. Again, $D_g^/$ and $D_r^/$ which reveals the normalized D_g and D_r,due to the dilemma strength with social viscosity, a certain mechanism ,is quantitatively evaluated by e – h [33-34].So, the results can be reported regarding dilemmas on real-life situations with respect to different game classes[31-32,35] ; Prisoner's Dilemma (PD) game (Dg > 0 & Dr > 0), Trivial game (Dg < 0 & Dr < 0), Chicken (CH) game (Dg > 0 & Dr < 0), and Stag Hunt(SH) game (Dg < 0 & Dr > 0).

Research on the application of game theory involves the power's cost-profit to the market power issue. H. Singh [36] established a new innovative game-theoretical approach in which the Trivial game [31-32] is used as the application of game theory in terms of electric power markets. But, choosing the different best strategies for the Trivial game was imperfect and the dilemma situation of different games regarding market power is another central determinant for power generation system which is not discussed there. So, this research's focus on the choosing the various best strategy based on game theoretical analysis in the power market which can resolve those problems.

This paper implements the symmetric 2 × 2 game models to analyze the power generation having different dilemma situations; PD, Trivial, CH, and SH in the power market. The more realistic presumption is that power generators can accurately predict the effect of their decisions regarding profits during dilemma situations by game theory. To embed the game-theoretical approach for power generator's optimization, profit and dilemma strength situation shows the most important impact in market power. Besides, the most serious matter is that the game theory is more consistent with the realism, this is because, players are presumed to have unitary will, that is to say, how the premise of the self-interested behavior can concern on the welfare-improving outcomes with respect to the power market economy.

The remaining of the paper proceeds on as follows: Section II introduces electrical market power mitigation regarding contract for difference; Section III establishes the explanation of the working procedure of the different games; Section IV shows different games on different situations, and the last one is the research conclusion.

II. The Theoretical Concept of Electrical Market Power Mitigation Regarding Contract for Difference (CfD)

The market power is the measuring tool to know the cost-profit efficiency based on power resources. The electrical market power problematic situation can be resolved by the generation divestiture, which is not a viable solution, actually. Consequently, contracts for differences (CfD) [36-37] is the feasible solution to optimize for the electrical market power. CfD is such type of contract that can be used for the most accurate prediction to mitigate the market power problem. The aim of CfD is used to isolate suppliers from temporary price fluctuations in the power market. In CfD, one party (retailer/consumer) agrees to pay the other (consumer/retailer) regarding the difference between the contract price and prevailing marginal cost from the power pool, as depicted in Figure 1. Two-way contract of CfD, presuming both value X; retailer pays consumer & Y; consumer pays retailer, show the futures contract of the financial system that is related to the exercise price ($/MWh) and loads in hours (MWh), which is shown in Figure. 2. If the marginal cost rises higher than the exercise price then the retailer pays the consumer, and if it is in inverse case then the consumer pays to the retailer. In a one-way contract of CfD is considered only X, if the marginal cost rises higher than the exercise price, as a result, payments difference is aroused only, which is shown in Figure 2. Consequently, game theory is applied to determine the impacts of CfD.

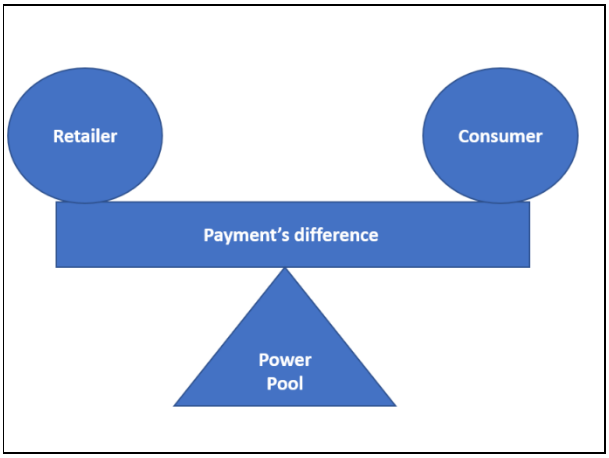


Figure 1. Different features of CfD regarding payment

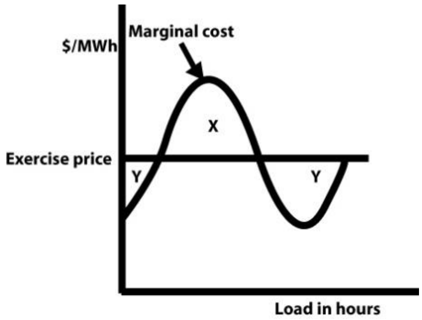


Figure 2. Two-way contract of CfD presuming both value X;retailer pays consumer & Y;consumer pays retailer, and one-way contract of CfD is considered only X.

The profit for each power generators is offered as [37]-

$$U_i = (MP_i - MC_i) \times E_i \qquad (5)$$

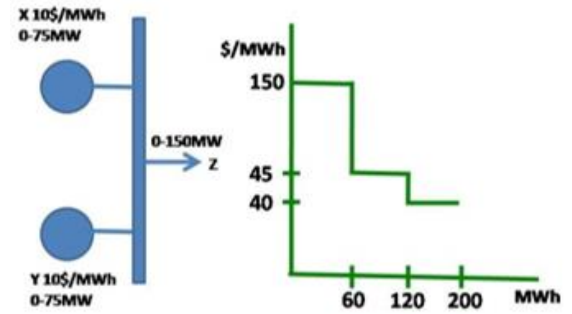
MP = Market exercise price, MC= Marginal cost, and E = Power generators offer an amount of energy.

III. Explanation of the Working Procedure of the Different Games

Presuming, a simple model having two generators; X (0-75 MW) and Y;(0-75 MW) with the incremental cost is $l0/MWh and one load Z (0-150 MW) is set up to demonstrate how CfDs will try to get the incentives after raise prices, as depicted in Figure 3. (a) and 3(b) [36]. The market price is set by the market operator [36-37]; i) if total power demand < 60MW, the price will be set as 150$/MWh, ii) if 60MW < total power demand < 120MW, the price will be set as 45$/MWh, iii) if 120MW < total power demand < 200MW, the price will be set as 40$/MWh. The strategic decisions for the generators are to choose the power production level (either High or Low production) that maximizes

Price($/MWh)		PG Y	
		High	***Low***
PG X	***High***	40	45
	Low	45	150

(a)



(b)

Figure 3. Two power generation game for (a) price set up by market operator and (b) equivalent of (a) with production [36]

their profits. Prices are set up by the power market operator according to the demand and supply, which is also shown in Figure.3. As an instance, let's assume that a generation company signs for100 MWh one-way CfD for the consumers, in which the exercise price is $45/MWh and the marginal cost is set as 40$/MWh. In this case, the generator would earn $45×100 = $4,500 in revenue from the CfD but would ready to pay the consumer ($45-$40) ×100 = $500 under the terms of the CfD. So, the generator's net CfD revenue would be $500.In CfD, if the exercise price is equal to the competitive price of $45/MWh then the profits are maximized for each of the generators which is $4,500.

IV. Different games on different situations

Presume, an infinite and well-mixed situation for the symmetric 2 × 2 games in which profits of the power industries are related with(out) contract for difference (CfD) for four game classes in addition to dilemma strength situations regarding the power market.

A. *The prisoner's dilemma games*

A.1 Electrical market power scenarios with(out) contract for difference (CfD) regarding Game theoretical approach

In order to simplify a real context situation in the perspective of the electrical power market, a simple 2 × 2 game template model is presumed based on the game theoretical approach in which each power generator (i.e .electricity production power generators (PG); X & Y) chooses power output production in Case 1, for (a);high output 70MW and a low output 15MW, and for (b)maximum output 80MW and minimum output 18MW as shown in Table 2. The prices of the power production are set by the market operator [36] [Figure 3(a) & (b)]. In Table II, Case 3 (i.e. (d) and(e)) represents both power generators achieve their maximum profits, if the output production is low that is denoted as Nash equilibrium. However, if the contract for difference (CFD) is implemented for 10MW for the generator's output, the Nash equilibrium is obtained, as shown in Case 4 (i, e. (f) and(g)). If it is the case, then negotiation of the two power generators can get their better off situation as profit from the market power in the real sense of view.

A.2 Electrical market power against dilemma situation for PD game

Table III illustrates different dilemma strength parameters that satisfy Dg = Dr, and Dg$^{/}$ = Dr$^{/}$ for two power generators in Case1 of Table II regarding market power. Here the combination of normalized dilemma strength and original dilemma strength; (Dg$^{/}$, Dg), are varied as (0.29,10), (0.23,10) in terms of case 1; (a) and (b), respectively. It is noted that normalized dilemma strength has different values whereas original dilemma strength has the same value, this is because normalized dilemma strength can precisely measure the real scenarios [34]. The dilemma situation, shown in Table 3has a strong relationship with the maximum profits of with(out) CfD based on Case 1; ((a) – (b)) in Table II. Table III against Table II (regarding Case 3 and Case 4) reveals, when dilemma situation is decreased (5.5 to 2.2) then the maximum profit rate is achieved that is called as Nash equilibrium for the power generators. This is consistent with the real fact that if the cost of electric equipment as well as different production costs and so forth are usually decreased, as a result, the profits are increased.

B. *The Trivial games*

B.1Electrical market power scenarios with(out) contract for difference (CfD) regarding Game theoretical approach

Presuming, 2 by 2 games in which two electrical power generators named X and Y, have been implemented to generate the electricity for the market to the consumers. Regarding Table IV, Case 1 represents (a) and (b) with their maximum and minimum output power level as (50,18), and (75,8), respectively. So, the different prices are chosen based on market power which is shown in Case 2 [36]. The low-level output production can be defined as withholding capacity with an inspiration to raise the prices. If the prices are enhanced a huge, then the power generator can earn higher profit at the low and high output production which is visualized at Case 3 (i.e. (d) and (e)) for without CfD in Table II. To the demand for 10MW power in CFD for both power generators, the output profit what is called as Nash equilibrium is varied, displayed in Case 4 (i, e. (f) and (g)) in Table IV. This is because the agreement of two power generators can make higher profit in real-sense, but, actually, it is not shown always.

TABLE II: CASE 1; OUTPUT DECISIONS OF X AND Y FOR PRISONER'S DILEMMA GAME IN TERMS OF (A) AND (B) [36], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C)[36] , CASE 3; PROFITS WITHOUT CFD, FOR (D) AND (E) [36], CASE 4; PROFITS WITH CFD FOR THE 10MW FOR PD GAME[36].* =NASH EQUILIBRIUM

Case 1

(a)

Output (MW)		PG Y	
		High	*Low*
PG X	*High*	60, 60	15, 70
	Low	70, 15	25, 25

(b)

Output (MW)		PG Y	
		High	*Low*
PG X	*High*	75, 75	40, 43
	Low	43, 40	8, 8

Case 2

(c)

Price($/MWh)		PG Y	
		High	*Low*
PG X	*High*	40	45
	Low	45	150

Case 3

(d)

Profit($)		PG Y	
		High	*Low*
PG X	*High*	1500, 1500	1750, 630
	Low	630, 1750	2520, 2520*

(e)

Profit($)		PG Y	
		High	*Low*
PG X	*High*	2100, 2100	630, 2800
	Low	2800, 630	3920, 3920*

Case 4

(f)

Profit($)		PG Y	
		High	*Low*
PG X	*High*	1800,1800	475, 2400
	Low	2400, 475	2400, 2400*

(g)

Profit($)		PG Y	
		High	*Low*
PG X	*High*	2100, 2100	580, 2750
	Low	2750,580	2820, 2820*

TABLE III: SUMMARY OF THE DILEMMA STRENGTH OF PD REGARDING CASE 1; ((A) – (B)) IN WHICH PRESUMING DG (=DR) AND DG/(=DR/).

PD setting		*(a)*	*(b)*
Case(I)	$D_g (= D_r)$	10	10
	$D_g^{/} (= D_r^{/}$	0.29	0.23

B.2Electrical market power against dilemma situation regarding Trivial game

Table V presents the different dilemma strength parameters that satisfy Dg = Dr, and Dg/ = Dr/ for power generators in the market power, in which the magnitude of normalized dilemma strength as well as original dilemma strength, (Dg/, Dg), are changed as (-1,-32),(-0.48,-32) , with respect to Case 1; (a) to (b), in Table IV, respectively. It is needed to mention that the value of normalized dilemma strength which has different value in contrast to original dilemma strength has the same, this is because normalized dilemma strength can precisely measure the actual scenarios regarding the real-life situations. Case 3 (without CfD) as well as Case 4 (with CfD) show the maximum profit as Nash equilibrium coming from Case 1 in Table IV which has strong relationship with the dilemma situation that is shown in Table V. It is revealed from the Table between V and IV (regarding Case 3 and Case 4), which represents the maximum profit is enhancing over dilemma situation decreasing (-1 to -0.46) for both power generators system. This is due when the cost related to the electric systems and so forth are usually going to a lower level, after that, the tendency of the profits will go for the higher level.

C. The Chicken (CH) game

C.1 Electrical market power scenarios with(out) CfD regarding Game theoretical approach in CH game

Presuming CH game using 2×2 game for two electrical power generators (i.e. power generators (PG); X & Y) adopt two levels of output regarding Case 1, for (a); maximum output 75MW and minimum output 29MW, and for (b) high output 70MW and low output 15MW as shown in Table VI. The different prices with respect to market operator through production are illustrated in Case 2 [36]. Case 3 (i.e. (d) and(e)) without CfD in Table VI, the profit arises from choosing the combination of lower and higher production as named Nash equilibrium for two power generator industries. This is why, when two power generators are not interested to share with each other due to risk-aversion situation but need to mitigate the problem in the real situation. Consequently, it is seen that one cooperates, and another does not. After that, Case 4 (i.e.(f) and (g)) in Table 6 is found from the CfD for 10MW power in which Nash equilibrium is achieved due to the risk aversion characteristics.

TABLE IV: CASE 1; OUTPUT DECISIONS OF X AND Y FOR TRIVIAL GAME IN TERMS OF (A) AND (B) [36], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [36] , CASE 3; PROFITS WITHOUT CFD, FOR (D) AND (E) [36], CASE 4; PROFITS WITH CFD FOR THE 10MW FOR TRIVIAL GAME[36].* =NASH EQUILIBRIUM

Case 1

(a)

Output (MW)		**PG Y**	
		High	***Low***
PG X	***High***	50, 50	50, 18
	Low	18, 50	18, 18

(b)

Output (MW)		**PG Y**	
		High	***Low***
PG X	***High***	75, 75	40, 43
	Low	43, 40	8, 8

Case 2

(c)

Price($/MWh)		**PG Y**	
		High	***Low***
PG X	***High***	40	45
	Low	45	150

Case 3

(d)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1500, 1500	1750, 630
	Low	630, 1750	2520, 2520*

(e)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	2250, 2250*	1400, 1505
	Low	1505,1400	1120, 1120

Case 4

(f)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1500, 1500*	1700, 580
	Low	580,1700	1420, 1420

(g)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	2250, 2250*	1350, 1455
	Low	1455, 1350	20, 20

TABLE V:SUMMARY OF THE DILEMMA STRENGTH OF TRIVIAL GAME FOR THE CASE 1; ((A) – (B)) REGARDING, IN WHICH PRESUMING, DG (=DR) AND DG/(=DR/).

Trivial setting		***(a)***	***(b)***
Case (I)	$D_g (= D_r)$	- 32	- 32
	$D_g^{/} (= D_r^{/})$	- 1	- 0.48

C.2 Electrical market power against dilemma situation regarding CH game

Table VII, represents various dilemma strength situations; Dg (Dr), and Dg/ (Dr/) for two power generators, with respect to Case 1;(a) and (b) of Table VI. It is seen that the magnitude of dilemma situation of Dg (Dr), are 10 (-10) and 10 (-10) for (a) and (b) which are same, by contrast, normalized dilemma situation Dg/ (Dr/) shows (a); +0.28 (-0.28) and (b); 0.22 (-0.22), differ in value, respectively. It is revealed that decreasing normalized dilemma situation (for Dg/, 0.28 to 0.22) which allows the tendency to get the better profit with lower and higher output production as well, which represents Nash equilibrium that comes from the Case 3 (i.e. d to e) without CfD and Case 4 (i.e. f to g) with CfD according to the power market consists with the severe risk-aversion situation.

D. The Stag-hunt (SH) game

D.1Electrical marketpower scenarios with(out) CfD regarding Game theoretical approach for SH game

Two power generators (X & Y) are presumed, in which VIII (a) shows higher output 70 MW and lower output 5 MW, and VIII (b) belongs to maximum and minimum output as (75 MW,28MW) which are illustrated. With the production of electricity for the consumer, the power market operator sets up the price rate that is revealed at Case 2 in Table VIII [36]. Without CfD for Case 3 (d & e) and with CfD for Case 4 (f & g) regarding 10MWshow profit of the two power generators regarding higher and lower power production that satisfies the Nash equilibrium of Stag-hunt game. This is due to the fact that both power generators are very interested to go with either higher or lower production with the demand of power of consumers according to the situation demands which is actually called neutral situation.

D.2 Electrical market power against dilemma situation regarding SH game

The outcome magnitude of the dilemma strength Dg (Dr), and Dg/ (Dr/) for two power generators in electrical market power is displayed in Table 9 that are coming from VIII(a) and VIII(b), in which the value of

TABLE VI: CASE 1; OUTPUT DECISIONS OF X AND Y FOR CHICKEN GAME IN TERMS OF (A) AND (B) [36], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [36] , CASE 3; PROFITS WITHOUT CFD, FOR (D) AND (E) [36], CASE 4; PROFITS WITH CFD FOR THE 10MW FOR GAME[36].* =NASH EQUILIBRIUM

Case 1

(a)

Output (MW)		**PG Y**	
		High	***Low***
PG X	***High***	65, 65	39, 75
	Low	75, 39	29, 29

(b)

Output (MW)		**PG Y**	
		High	***Low***
PG X	***High***	75, 75	40, 43
	Low	43, 40	8, 8

Case 2

(c)

Price($/MWh)		**PG Y**	
		High	***Low***
PG X	***High***	40	45
	Low	45	150

Case 3

(d)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1950,1950	1365, 2625*
	Low	2625,1365*	4060, 4060*

(e)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1800, 1800	875, 2450*
	Low	2450,875*	2100, 2100*

Case 4

(f)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1950,1950	1315,2575*
	Low	2575, 1315*	2960, 2960

(g)

Profit($)		**PG Y**	
		High	***Low***
PG X	***High***	1800, 1800	825, 2400*
	Low	2400,825*	1000, 1000

original dilemma strength; Dg (Dr), is 10 (-10) for (a) and (b) has same and the normalized dilemma strength (Dg/, Dg) has differ in value; (a) (- 0.18, -10) and (b) (- 0.21, -10). To predict the accurate dilemma situation, normalized dilemma situation is the best due to the variation of the outcome. The observation of without CfD in Case 3 regarding Table VIII, shows the Nash equilibrium supported by either PD or Trivial game. So, go along with CfD, after increasing dilemmas, the situation goes to PD game at Case 4 (i.e.(f) to (g)) which is quite natural in the real sense according to the power market perspective.

TABLE VII:SUMMARY OF THE DILEMMA STRENGTH OF THE CH FOR CASE 1; ((A) – (B)) IN TABLE 6, IN WHICH CONSIDERING DG (DR), AND DG/ (DR/)

CH setting		***(a)***	***(b)***
Case (I)	$D_g (= D_r)$	10 (-10)	10 (-10)
	$D_g^/ (= D_r^/)$	+0.28 (-0.28)	0.22 (-0.22)

CONCLUSION

Based on 2×2 game, inspired by observing the most prominent and basic archeological real-world issues of evolutionary game theory, electrical power market with different power generators profit against dilemma situations is addressed here. It is designed for the two electrical power generators (i.e. X and Y) with four game classes (PD, Trivial, CH, and SH game) in line with(out) contract for difference (CfD) regarding dilemma situations which might cover every possibility of different strategic interactions that would characterize the power generator industries.

The power production based on 2×2 game template recommends several suggestions as conclusion. The first one, perhaps most important one, Prisoners dilemma represents the maximum profit with lower production for the power generator industries negotiation which meets the Nash equilibrium condition. The most attractive situation could be the Trivial situation, this is because agreement for higher power production in both industries would be the better profit for them but most of the real-life incidents do not always show the characteristics. However, Chicken game, the prominent one, is the real fact of the real world which provides the agreement to get the profit for the power generators in combined with between lower and higher production of electrical power system that is consistent with Nash equilibrium. The Stag-hunt game shows equilibrium situation as fairness for the

TABLE VIII: CASE 1; OUTPUT DECISIONS OF X AND Y FOR STAG-HUNT IN TERMS OF (A) AND (B) [36], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [36] , CASE 3; PROFITS WITHOUT CFD, FOR (D) AND (E) [36], CASE 4; PROFITS WITH CFD FOR THE 10MW FOR SH GAME[36].* =NASH EQUILIBRIUM

Case 1

(a)

Output (MW)		PG Y	
		High	***Low***
PG X	***High***	70, 70	5, 60
	Low	60, 5	15, 15

(b)

Output (MW)		PG Y	
		High	***Low***
PG X	***High***	75, 75	38, 65
	Low	65, 40	28, 28

Case 2

(c)

Price($/MWh)		PG Y	
		High	***Low***
PG X	***High***	40	45
	Low	45	150

Case 3

(d)

Profit($)		PG Y	
		High	***Low***
PG X	***High***	2100, 2100*	325, 2100
	Low	2100,325	2100, 2100*

(e)

Profit($)		PG Y	
		High	***Low***
PG X	***High***	2250, 2250*	2470, 2275
	Low	2470,1400	3920, 3920*

Case 4

(f)

Profit($)		PG Y	
		High	***Low***
PG X	***High***	2100, 2100*	275, 2050
	Low	2050,275	1000, 1000*

(g)

Profit($)		PG Y	
		High	***Low***
PG X	***High***	2250, 2250*	2420, 2225
	Low	2225, 2420	2820, 2820*

TABLE IX:SUMMARY OF THE DILEMMA STRENGTH OF SH REGARDING THE CASE 1; ((A) – (B)), IN WHICH CONSIDERING DG (DR), AND DG/ (DR/)

SH setting		*(a)*	*(b)*
Case (I)	$D_g (= D_r)$	-10 (10)	-10 (10)
	$D_g^{/} (= D_r^{/})$	- 0.18 (0.18)	- 0.21 (0.21)

electrical power generators to achieve their desired profit.

Dilemma situation is another possible indicator to solve the power production in real sense. In prisoner's dilemma, with decreasing dilemma strength situation, the power generator industries would get more profit. Trivial game with minimum dilemma situation shows the higher profit, ideally Trivial game with no dilemma situation exists in real-world life. Besides, CH game having dilemma situations support lower and higher production together due to the risk-aversion situations. In SH game supports profit with dilemmas, this is because of the neutrality in terms of economic perspective.

The justification why the results are considered as the imperative intelligent rational decisions, this is because the procedure to instruct the game settings was so persuasive and the comprehensive when compared to the story of social realistic present day situation [28,38], was implemented. Generally, it is revealed, game theoretical approach can offer the guidance for successful navigation rely on those diplomatic shoals.

ACKNOWLEDGMENT

This research was inspired by Professor Jun Tanimoto, Dr., kyushu University, Japan. I am really grateful to him.

REFERENCES

[1] V.S. Budhraja, "California's electricity crisis. Power Engineering Society Summer Meeting ", IEEE, vol.1, pp.397 – 399, July 2001.

[2] C. Mensah-Bonsu, and S. Oren,"California electricity market crisis: Causes, remedies, and prevention", IEEE Power Engineering Review, vol.22 (8),pp. 4-5, 2002.

[3] E. Bompard, W. Lu, R. Napoli, "Network Constraint Impacts on the Competitive Electricity Markets Under Supply Side Strategic Bidding," IEEE Trans. on Power Syst., vol.21(1), Feb 2006.

[4] S. Borenstein, and J. Bushnell, "Electricity Restructuring: Deregulation or Reregulation?" PWP-074, University of California Energy Institute. [Online]. Available: www.ucei.berkeley.edu/ucei.

[5] J. Bushnell, and F. Wolak, "Regulation and the Leverage of Local Market Power in the California Energy Market." University of California Energy Institute. [Online]. Available: www.ucei.berkeley.edu/ucei.

[6] B. Hobbs, "Linear Complementarity Models of Nash–Cournot Competition in Bilateral and POOLCO Power Markets", IEEE Transactions on Power Systems, vol. 16(2), pp.194- 202, May 2001.

[7] X. Guan, Y. C. Ho, and D. L. Pepyne, “Gaming and price spikes in electric power markets”, IEEE Trans. Power Syst., vol.16(3), pp.402-408 , 2001.

[8] P. Bajpai, and S. Singh, “Bidding and gaming in electricity market: an overview and key issues”,Proceedings of national power system conference (NPSC),338–346, 2004.

[9] E. Bompard, Y. C. Ma, and E. Ragazzi, “ Micro-economic analysis of the physical constrained markets: Game theory application to competitive electricity markets”, Eur. Phys. J. B,vol. 50, pp.153–160 , 2006.

[10] M. Saguan, N. Keseric, P. Dessante, and J. M. Glachant,; “Market power in power markets: Game theory vs. agent-based approach”, 2006 IEEE PES Transm. Distrib. Conf. Expo. Lat. Am. TDC’06, 2006. doi:10.1109/TDCLA.2006.311439.

[11] C. A. Berry, B.F.Hobbs, W.A. Meroney, R.P. O'Neill, and , Jr. W.R. Stewart, “Understanding how market power can arise in network competition: a game theoretic approach”. Utilities Policy, vol.8 (3),pp.139-158, 1999.

[12] R. Baldick, “Electricity Market Equilibrium Models: The Effect of Parameterization” IEEE Trans. on Power Syst, vol.17(4),pp.1170–1176 , 2002.

[13] B. F. Hobbs, C.B. Metzler, J.S. Pang, “Strategic Gaming Analysis for Electric Power Systems: an MPEC Approach” IEEE Trans. Power Syst., vol.15 (2),pp. 638 – 645, 2000.

[14] J. Cardell, C. C. Hitt, W. W. Hogan, “Market Power and Strategic Interaction in Electricity Networks,” Res. and Energy Econ., vol.19(3),pp.109-137,1997.

[15] T. Li, M. Shahidehpour, “Strategic Bidding of Transmission constrained Gencos with Incomplete Information,” IEEE Trans. on Power Syst, vol. 1(1),pp. 437-447, 2005.

[16] W. Xian, L.Yuzeng, Z. Shaohua, “Oligopolistic Equilibrium Analysis for Electricity Markets: A Nonlinear Complementarity Approach,” IEEE Trans. on Power Syst, vol.19(3),pp.1348-1355, 2004.

[17] L. B. Cunningham, R. Baldick, M. L. Baughman, “An empirical study of applied game theory: Transmission constrained Cournot behavior,” IEEE Trans. on Power Syst., vol.17(1), pp.166–172, 2002.

[18] J. Contreras, M. Klusch, J.B. Krawczyk, “Numerical solutions to Nash-Cournot equilibria in coupled constraint electricity markets”, IEEE Trans. on Power Syst, vol.19(1),pp.195 – 206, 2004.

[19] K. Neuhoff, J. Barquin, M. G. Boots, A. Ehrenmann, B. F. Hobbs, F.A.M. Rijkers, and M.Vazquez , “Network-constrained Cournot models of liberalized electricity markets: the devil is in the details”, Energy Economics, vol.27(3), pp.495-525, 2005.

[20] M. Simaan, J. Cruz, “A Stackelberg solution for games with many players”. IEEE Trans. on Automatic Control, vol.18(3), pp.322 – 324, 1973.

[21] Z. Yu, F.T. Sparrow, T.L. Morin, and G. Nderitu, “A. Stackelberg price leadership model with application to deregulated electricity markets” Power Engineering Society Winter Meeting, IEEE,vol.3,pp.1814 – 1819, 2000.

[22] A. Tasnadi, “Quantity-setting games with a dominant firm”, working paper of Department of Economics, University of Bonn, Germany. http://www.bke.hu/~tasnadi/Q_DOM_W.PDF.

[23] J. Stephen DeCanio, and A. Fremstad, "Game theory and climate diplomacy," Ecological Economics, Elsevier, vol. 85(C), pp.177-187, 2013.

[24] Y.Jiang, & K.Zhou, & X.Lu, & S.Yang, , "Electricity trading pricing among prosumers with game theory-based model in energy blockchain environment," Applied Energy, Elsevier, vol. 271(C),2020.

[25] S. M.Hakimi, A.H.khani, M.S.khah, and P.S. Catalão, João, "Stochastic planning of a multi-microgrid considering integration of renewable energy resources and real-time electricity market," Applied Energy, Elsevier, vol. 298(C), 2021.

[26] H.Oh, H.Y. Chu, “Demand response in the retail electricity market. Energy Efficiency” Energy Efficiency, vol.14(6), 2021. https://doi.org/10.1007/s12053-021-09970-z.

[27] C.K. Kwong, Yi Xia, C.Y. Chan, W.H. Ip, “ Incorporating contracts with retailer into product line extension using Stackelberg game and nested bi-level genetic algorithms.” Computers & Industrial Engineering, 151(1), 2021. https://doi.org/10.1016/j.cie.2020.106976.

[28] A. Yucekaya, “Electricity trading for coal-fired power plants in Turkish power market considering uncertainty in spot, derivatives and bilateral contract market.” Renewable and Sustainable Energy Reviews,vol.159(4), 2022.

[29] J.V. Neumann, and O. Morgenstern, “Theory of games and economic behavior,” Princeton University Press, 1953.

[30] M. A. Nowak, and S. Coakle, "Evolution, Games, and God: The Principle of Cooperation,". Harvard University Press, 2013.

[31] J. Tanimoto, "Fundamentals of Evolutionary Game Theory and its Applications," Springer, 2015.

[32] J. Tanimoto, "Evolutionary Games with Sociophysics," Springer, 2018.

[33] M. A. Habib,“Can people detect dilemma strength in a 2 player 2 strategy game?:A survey game.”Proceeding of International Exchange and Innovation Conference on Engineering & Sciences (IEICES),5,2019.

[34] M. A. Habib, K M A. Kabir, J. Tanimoto, “Do humans play according to the game theory when facing the social dilemma situation?” A survey study.” Evergreen. vol.7(1), pp.7-14, 2020.

[35] M. A. Habib, M. Tanaka, J. Tanimoto,“How does conformity promote the enhancement of cooperation in the network reciprocity in spatial prisoner’s dilemma games?,” Chaos, Solitons and Fractals, 138, 1-7 (2020).

[36] H. Singh, “Introduction to Game Theory and its Applications in Electric Power Markets”, IEEE Computer Application in Power,vol.12(2), pp.18-20, 1999.

[37] T.V.Jensen, “Electricity markets and game theory” DTU, Denmark, 2018.

[38] B.Z.Orbay, and L.Svegi, “Game theory and engineering applications”IEEE Antennas and Propagation Magazine,vol. 56(3),pp.256-267,june 2014.