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The Application of Asymmetric Game in the Electrical Power Market

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***Abstract* – This paper introduces the importance of the real-world relevant issues of the electrical power market regarding 2 × 2 strategic games, which have pointed out the optimization of the facing problems concerning game theoretical approach. Based on 2×2 game, the electrical power market presuming two players named power generator (PG) X and Y with two strategies; higher and lower production, show the possible strategies of game theoretical approach relying on the payoff matrix related to the different game classes; Prisoner's Dilemma (PD), Trivial, Chicken (CH), and Stag-hunt (SH). The negotiations for choosing the best strategies can be determined by the Prisoner's Dilemma (PD), and Stag-hunt (SH) that hinge on the demand of the situation. The Trivial game would prefer for agreement whereas Chicken (CH) game can be played in terms of risks associated situation by the game players along with different related power issues to achieve for individual benefit. Another possible solution to adopt the best strategies would be either Nash equilibrium or Maxi-min strategy (or sometimes both) which indicate the better suggestion for the market power issues.**

***Keywords-component; Electrical power market; Game theory; Asymmetric game; Nash equilibrium; Maxi-min equilibrium*.**

I. INTRODUCTION

The electrical power market has become a dynamic evolutionary process accomplished by the complex characteristics of the behaviors of the market economy. Electrical power market is involved into the energy prosumers [1], which are combined with energy producers and energy consumers. The rational power market mechanisms (i.e., power internet [2]; one of the mechanisms) play a significant role in the competitive power market society [3], which is beneficial for the participants to make the right decisions and control the stability of the market performance which is called market equilibrium [4].

In Evolutionary game theory, a symmetric game [5] is one of the branches of the game in which all players possess the same strategy [6]. In contrast, the asymmetric game is such a type of game in which players bear their gains unequally. So, it can be said that the asymmetry games are aroused from individual differences, phenotype variations such as speed, size, wealth, strength, and environmental variation which is observed in our natural life; the evolutionary concept of J. M. Smith's [7] based on the stable strategy was that the best natural action of the plant or animal relied on what the other was doing, in addition, J. M. Smith et al. [8] revealed the sex war game based on gene frequencies to go for a stable situation, R. Selten stated that the paper [9] worked on the asymmetric information relied on animal conflicts in terms of the evolutionary stable strategies, P. Hammerstein [10] indicated that the animal contestants showed the dominant aspect decisions of animals in the evolutionarily stable strategy, T. Guimaraes et al. [11] depicted that the more significant benefits of the business relied on a higher degree of environmental stewardship than the organizations which showed the lowest compliance with the government regulations, S. J. DeCanio et al. [12] exposed the solution of climate problems based on game theoretical diplomacy from the scientific point of view, Y. Wang et.al.[13] analyzed the game behaviors of the interaction between the government and the manufacturing enterprise concerning the carbon emission policies, Q. H. Zhu et al. [14] dealt with games between the governments and the core enterprises to implement the green supply chain based on governments rules and regulations, Z. Jianya et al. [15] analyzed the relation between the e-marketplace and sellers to better understand their effects based on the game theoretical approach, K. Madani [16] described the water resource problems and solutions based on dynamic structure, C. M. García Mazo et.al.[17] explored the relationship between two energy resources: wind and water, by the strategic investment to satisfy the demand for the market, S. Janjua et.al.[18] showed the relevant bankruptcy rule with the Nash bargaining theoretical approach to propose the algorithm for addressing of the supply-demand of power sector mismatches in Pakistan, B. Bruns et al. [19] expressed that the archetypal model of the interdependence would help to percept institutional diversity as well as the potential transformations of the social-ecological systems, L. Jin et al. [20] addressed that the mechanism of performance guarantee can strongly prevent the electricity market risks by adopting the Cournot duopoly model to obtain the Nash equilibrium, A.F. Isnawati et al. [21] stated that the target SINR achieving issue by proposed power control game (PCG) method which was better than other methods regarding the combination network between small cell and macro cell, G. Wang et al.[22] described that this potential work relied on the evolutionary game theoretical (EGT)approach to show the verification of applicability and feasibility of the evolutionary game theoretical method concerning the practical examples, and M.A Habib et al. [23] stated that presuming two asymmetric game models by coupling photovoltaic (PV) power and the coal-fired (CF) power system to analyze the benefit-cost-subsidy in the power system. Presume, one of the simplest possible asymmetric 2 × 2 games called 2-player and 2-strategy game, in which two players are considered as the "column" and "row" having two strategies; higher and lower production, which is shown in Table I. So, the upper-left cell of the matrix "e" shows the payoff for the row if row adopts the higher production and similarly, column's payoff "k" indicates the higher production, as well. The payoffs of each player are represented as $\{e, f, g, h\}$ and $\{k, l, m\, n\}$, respectively. Dilemma strength for 2 × 2 game based on payoff matrix was introduced in [5-6], regarding game theory and evolutionary game-theoretical approach,

$$D_g = g - e \quad (1) \qquad D_r = h - f \quad (2)$$

where D_g indicates the gamble-intending dilemma (GID) where two players can exploit each other, and D_r represents the risk-aversion dilemma (RAD) that shows the two players are never trying to be exploited. So, different game classes [24] with respect to dilemmas can be expressed as; Prisoner's Dilemma (PD) ($D_g > 0$ & $D_r > 0$), Trivial ($D_g < 0$ & $D_r < 0$), Chicken (CH) ($D_g > 0$ & $D_r < 0$), and Stag Hunt (SH) ($D_g < 0$ & $D_r > 0$). In contrast, the game-theoretical approach addresses the optimal solution by the Nash equilibrium [25] or Maxi-min equilibrium. Nash Equilibrium can help to choose the best strategies from the preferable action of the competing power industries [26]. A Nash equilibrium can be defined as the output that neither column nor row can increase their payoff by changing their outcome unilaterally if another player continues to play for the equilibrium strategy. Again, the Maxi-min equilibrium is such type of strategy in which the worst possible outcome is at least as good as the worst outcome from the other player strategy. The Maxi-min payoff is the maximum outcome that a player can guarantee herself [27].

It can be said that during the play of Maxi-min strategy, row will not choose the row with the minimum outcome and column will not adopt the column with the lowest outcome. In fact, the player is completely driven by his own decision using the Maxi-min strategy. It should be noted that the players might well choose the Maxi-min strategy due to the risk-averse situation.

TABLE I : ASYMMETRIC 2× 2 PLAYER GAME

		Column's strategy	
		High production	Low production
Row's strategy	High production	e, k	f, l
	Low production	g, m	h, n

There are so many research papers that are evolved with the asymmetrical electrical power market approach; J. Mays et al. [28] revealed that this study developed the algorithm to solve for large-scale stochastic equilibrium due to the structures of the market might be ill-suited to finance low-carbon resources, P. K. Narayan et al. [29] stated that this paper evaluated the asymmetric behavior of the industrial as well as the demand for residential electricity for G7 countries by using the entropy test, A. Kakhbod et.al.[30] depicted that this paper studied how an asymmetrical approach based on learning technologies affects the trade market to improve its efficiency, K. Sieberg et.al.[31] suggested that this experimental study investigated the influence of the asymmetrical power in the bargaining game model to reach the demand, and L. Cheng et al. [32] showed that this paper tried to solve the incomplete information based on game issues to the electricity market. Furthermore, it should be mentioned that M.A. Habib [33] applied the symmetrical game theoretical approach to the game model as 2 × 2 games to analyze the different power market scenarios related with different dilemma situations; PD, CH, Trivial, and SH game. In this research paper, not only the asymmetric game with power market has been presumed, but also the implementation procedure is quite different from the other previous studies were done. Moreover, the focus of this study is relevant with the asymmetrical approach than that of symmetrical [33] case.

This research paper focuses on the asymmetric 2 × 2 game model to analyze the power generation concerning different game classes; PD, Trivial, CH, and SH that have a strong relationship with the power market. So, the research aim is to choose the various best strategies of the electrical power market against the different situations regarding game theory. So, as the matter of fact is that this study provides possible different design patterns of cooperation and conflict overall based on the different international relations and policies; PD, Trivial, CH, and SH, are developed relied on a power system and encourages the discrepancy in choices as strategies for the game players as power generator companies. In brief, a summary of the research is represented as the flowchart in Figure 1.

The remaining of the paper proceeds as follows: Section II contains the conditional design of the power generators based on power market operator; Section III summarizes different asymmetric games with power market; and the last one is considered as the research conclusion.

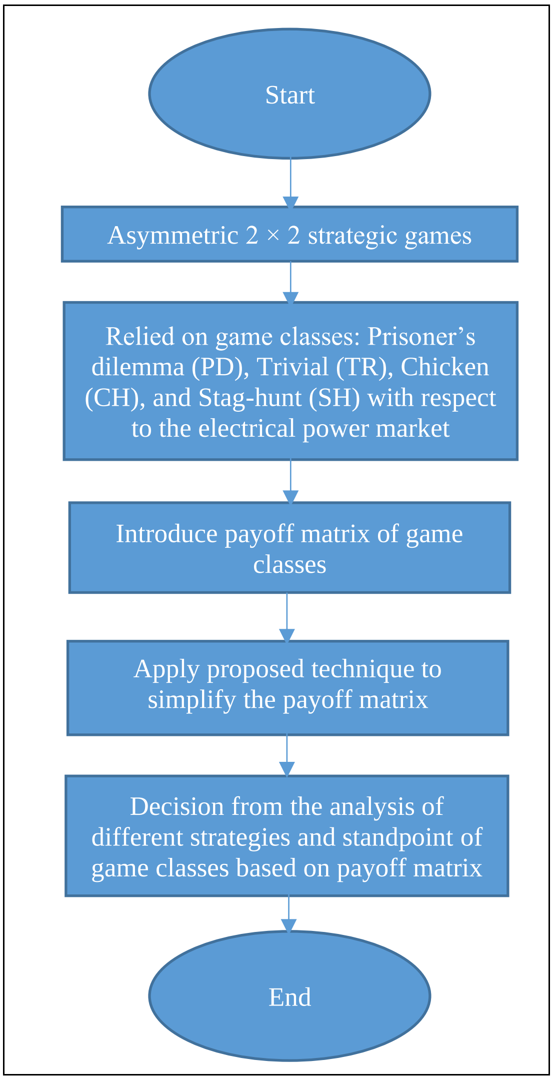


Figure 1. Flowchart of the research

II. Conditional Design of the Power Generators Based on Power Market Operator

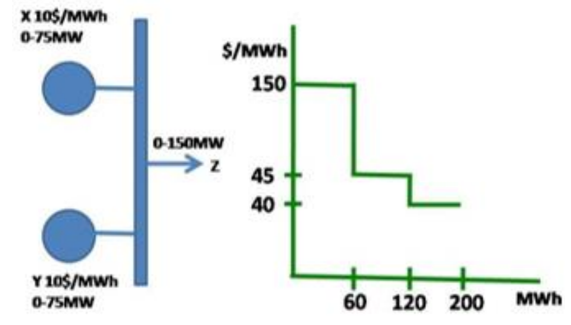
Presuming a game model having two power generators, $X(0-75\ MW)$ as well as $Y(0-75\ MW)$ and the load $Z\ (0-150\ MW)$ with the incremental cost ($\$10/MWh$) is accomplished to illustrate the real scenarios of the power market which is depicted in Figure 2 (b) [34]. The market prices are determined by the power market operator, shown in Figure 2 (a) & (b) [34]; i) if the total demand of power $< 60MW$, price will be as $150\$/MWh$, ii) if $60MW \leq$ total power demand $\leq 120MW$, then price is set as 45$/MWh, iii) if $120MW <$ total power demand $< 200MW$, price will be set as $40\$/MWh$. The power generators can choose the best strategy either higher or lower production level to achieve their maximum profit. As instance, assume a power generator company needs a sign to generate total 80 MWh (i.e.(40, 40) means each company can produce 40MW) electricity with other company, in which cost is set as 45$/MWh with the incremental cost ($\$10/MWh$) (described in Figure 2). In this case, each generator would earn

$$= (\text{Set cost} - \text{incremental cost}) \times \text{power generation} \quad (3)$$

$= (45-10) \times 40 = 1400\$$ as profit.

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

(a)



(b)

Figure 2. The game between two power generators for (a) the price is set up by the market operator, and (b) equivalent of (a) with load production [34].

III Different Asymmetric Games with Power Market

Different games such as Prisoner's dilemma, Trivial, Chicken and Stag-hunt game with asymmetric mode in terms of power market are discussed as follow.

A. *Prisoner's dilemma (PD) game with asymmetric power*

Presuming the most prominent Prisoner's dilemma (PD) game based on 2×2 game which has the quintessential behavior of the non-zero-sum game rely on conflict situation. The PD game is played between two electric power generators as players considered X and Y, respectively in which each power generator has sovereign entities; higher production as well as lower production. The PD game supports Robinson and Goforth's NPT [27] which shows the other games including payoff structures very similar to PD and have the same logic shown at Case 1; (a) and (b) in Table II, having the maximum and minimum output

TABLE II: CASE 1; OUTPUT DECISIONS OF X AND Y FOR PRISONER'S DILEMMA GAME IN TERMS OF (a) AND (b) [27], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [34], CASE 3; PROFITS OF X AND Y, REGARDING $(a^{/})$, AND $(b^{/})$ WHICH IS COME FROM (a) AND (b). $+$ = MAXI-MIN EQUILIBRIUM, $*$ =NASH EQUILIBRIUM, DS= DOMINANT STRATEGY.

Case 1

(a)

Output (MW)		PG Y	
		High	Low
PG X	High	$60, 80$	$20, 60$
	Low	$80, 20$	$40, 40$

(b)

Output (MW)		PG Y	
		High	Low
PG X	High	$80, 60$	$20, 80$
	Low	$60, 20$	$40, 40$

Case 2

(c)

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

Case 3

($a^{/}$)

Profit ($)		PG Y	
		High	Low
PG X	High	$1800, 2400$	$700, 2100$
	Low	$2800, 700$	$1400, 1400^{+*}$

DS = Profit for the row's strategy with low

($b^{/}$)

Profit ($)		PG Y	
		High	Low
PGX	High	$2400, 1800$	$700, 2800$
	Low	$2100, 700$	$1400, 1400^{+*}$

DS = Profit for the column's strategy with low

production level as 80MW and 20MW. Case 2 of Table II provides market price according to the power market operator [34]. In Table II, Case 3 with $(a^{/})$ and $(b^{/})$ arises from (a) and (b) that shows the outcome when both plays for higher production is Pareto-superior to the Nash equilibrium and Maxi-min strategy. However, profit with low production is the dominant strategy of the players in the game, consequently, players always have an incentive to go for low production from the (high production, high production) outcome. So, it can be said that both generators least preferred choice is to get profit along with higher production while the other adopts profit with low production; both care about deeply based on the situation demand. For instance, regarding Table II in case 3 at ($a^{/}$), when both two power generators will go for low productions, then their achieved profit from the strategy (i.e. Nash equilibrium & maxi-min equilibrium) is 1400$ each. This is due to the low production of power that causes less emission with respect to the environment. As a result, the novelty of this game occurs when the application of game settings is more persuasive regarding social dilemma situations compare to the symmetrical approach [33] concerning the PD game. This is because the world focuses more on the asymmetrical approach rather than the symmetrical story [33].

B. Trivial game with asymmetric power

The attainment strategy (higher production, higher production) pair of trivial game is achieved due to the playing of two rational players named power generator X and Y, after following the Nash equilibrium, shown in Table III. The different asymmetric payoffs of power generators from Robinson and Goforth NPT [27] are provided in Table III at Case 1; $(a), (b), (c)$ and (d), in which the higher and lower production

TABLE III: CASE 1; THE OUTPUT DECISIONS OF X AND Y FOR TRIVIAL GAME IN TERMS OF (a), (b), (c) & (d) [27], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [34] , CASE 3; PROFITS OF X AND Y, REGARDING $(a^{/})$, $(b^{/})$, $(c^{/})$, AND $(d^{/})$ THAT IS COMING FROM (a), (b), (c) & (d). + = MAXI-MIN EQUILIBRIUM, * =NASH EQUILIBRIUM, DS= DOMINANT STRATEGY.

Case 1

(a)

Output (MW)		PG Y	
		High	Low
PG X	High	80, 80	20, 40
	Low	60, 60	40, 20

(b)

Output (MW)		PG Y	
		High	Low
PG X	High	80, 80	60, 60
	Low	40, 20	20, 40

(c)

Output (MW)		PG Y	
		High	Low
PG X	High	80, 80	20, 60
	Low	60, 40	40, 20

(d)

Output (MW)		PG Y	
		High	Low
PG X	High	80, 80	40, 60
	Low	60, 20	20, 40

Case 2

(e)

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

Case 3

($a^{/}$)

Profit ($)		PG Y	
		High	Low
PG X	High	2400, 2400*	700, 1400
	Low	2100, 2100+	1400, 700

DS = Column supports profit with higher production

($b^{/}$)

Profit ($)		PG Y	
		High	Low
PGX	High	2400, 2400 *	2100, 2100+
	Low	1400,700	700, 1400

DS = Row supports profit with higher production

($c^{/}$)

Profit ($)		PG Y	
		High	Low
PG X	High	2400,2400*	700, 2100
	Low	2100,1400+	1400, 700

DS = Column supports profit with higher production

($d^{/}$)

Profit ($)		PG Y	
		High	Low
PG X	High	2400,2400*	1400, 2100+
	Low	2100,700	700, 1400

DS = Row supports profit with higher production

TABLE IV: CASE 1; THE DECISIONS COMING FROM X AND Y FOR CHICKEN (CH) GAME IN TERMS OF $(a), (b), (c)$ & (d) [27], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [34] , CASE 3; PROFITS OF X AND Y, REGARDING $(a^{/}), (b^{/}), (c^{/})$, AND $(d^{/})$ THAT IS COMING FROM $(a), (b), (c)$ & (d). + = MAXI-MIN EQUILIBRIUM, * =NASH EQUILIBRIUM, DS= DOMINANT STRATEGY.

Case 1

(a)

Output (MW)		PG Y	
		High	Low
PG X	High	60, 80	50, 50
	Low	80, 60	10, 10

(b)

Output (MW)		PG Y	
		High	Low
PG X	High	80,60	60, 80
	Low	50, 50	10, 10

(c)

Output (MW)		PG Y	
		High	Low
PG X	High	60, 80	50, 60
	Low	70, 50	10, 10

(d)

Output (MW)		PG Y	
		High	Low
PG X	High	80, 60	50, 70
	Low	60, 50	10, 10

Case 2

(e)

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

Case 3

$(a^{/})$

Profit ($)		PG Y	
		High	Low
PG X	High	1800, 2400+	1750, 1750
	Low	2400, 1800*	1400, 1400

DS = Column relies on higher production with profit

$(b^{/})$

Profit ($)		PG Y	
		High	Low
PGX	High	2400, 1800+	1800, 2400*
	Low	1750, 1750	1400,1400

DS = Row relies on higher production with profit

$(c^{/})$

Profit ($)		PG Y	
		High	Low
PG X	High	1800, 2400+	1750, 2100
	Low	2450, 1750*	1400,1400

DS = Column relies on higher production with profit

$(d^{/})$

Profit ($)		PG Y	
		High	Low
PG X	High	2400,1800+	1750, 2450*
	Low	2100,1750	1400,1400

DS = Row relies on higher production with profit

TABLE V: CASE 1; THE OUTPUT DECISIONS OF X AND Y FOR STAG-HUNT (SH) GAME IN TERMS OF $(a), (b), (c)$ & (d) [27], CASE 2; PRICES CORRESPONDING TO OUTPUT DECISIONS AT (C) [34], CASE 3; PROFITS OF X AND Y, REGARDING $(a^{/}), (b^{/}), (c^{/})$, AND $(d^{/})$ THAT IS COMING FROM $(a), (b), (c)$ & (d). + = MAXI-MIN EQUILIBRIUM, * =NASH EQUILIBRIUM.

Case 1

(a)

Output (MW)		PG Y High	PG Y Low
PG X	High	80, 80	20, 40
PG X	Low	60, 20	40, 60

(b)

Output (MW)		PG Y High	PG Y Low
PG X	High	80, 80	20, 60
PG X	Low	40, 20	60, 40

(c)

Output (MW)		PG Y High	PG Y Low
PG X	High	80, 80	10, 10
PG X	Low	60, 50	50, 60

(d)

Output (MW)		PG Y High	PG Y Low
PG X	High	80, 80	50, 60
PG X	Low	10, 10	60, 50

Case 2

(e)

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

Case 3

($a^{/}$)

Profit ($)		PG Y High	PG Y Low
PG X	High	2400, 2400*	700, 1400
PG X	Low	2100,700	1400, 2100 + *

($b^{/}$)

Profit ($)		PG Y High	PG Y Low
PG X	High	2400, 2400*	700, 2100
PG X	Low	1400,700	2100, 1400+*

($c^{/}$)

Profit ($)		PG Y High	PG Y Low
PG X	High	2400, 2400*	1400, 1400
PG X	Low	2100,1750+	1750, 2100*

($d^{/}$)

Profit ($)		PG Y High	PG Y Low
PG X	High	2400, 2400	1750, 2100+
PG X	Low	1400,1400	2100, 1750 *

power rate is 80MW and 20MW. Case 2 represents the market rate of electricity by the power market operator in Table III [34]. The four games ($i.e.$ Case 3; $(a^{/}), (b^{/}), (c^{/})$, and $(d^{/})$ in Table III) show the profit of the higher production as for the dominant strategy of both power generator systems and the Maxi-min equilibrium is the sub-optimal case for those games when both generators play for the profit with higher production then each generator would obtain their best outcome. So, agreement for the best possible solution by achieving the benefit from the higher production for both generators shows the pareto-superior than any other outcome.

For example, regarding Table III in case 3 at ($c^{/}$), if both players try to help each other to save the environment, they share their profits as (2400, 2400), which is called Nash equilibrium. This is because, as the production rate is high, then, the profit becomes higher. For this reason, the Nash equilibrium is found higher for both power companies. Again, for maxi-min equilibrium, (PG X, PG Y) = (2100, 1400); if one player (PG Y) chooses higher production, in contrast, the other player (PG X) adopts lower production. This is happened because of the sacrificed mind. Therefore, it is found that the Trivial game's implementation is more logistic than that of [33] 's trivial game.

C. Chicken (CH) game with asymmetric power

Presume the 2 × 2 Chicken game based on the Robinson and Goforth numbers [27] as payoff matrices in which 2 players called power generator X and Y which has two strategies; the maximum and minimum output production level = (80 MW and 10 MW), shown in Table IV at Case 1; (a), (b), (c) and (d), respectively. The price rate (Case 2 of Table IV) of the output production is determined by the market operator [34]. If CH game goes through the risk-aversion situation, then either Nash equilibrium or the Maxi-min equilibrium is achieved as for the best indicator to depict the appropriate situation. The behavior of risk-averse players can reach at the Maxi-min equilibrium (Profit at higher production, Profit at higher production) at Case 3 in Table IV which is different from the Nash equilibrium of Chicken game; the Chicken game has two Nash equilibria — one player generates higher production with its profit while the others in reverse. It is noted that highly risk-averse players might reach the Maxi-min equilibrium rather than the Nash equilibria, this is because, Maxi-min equilibrium is the robust optimization without any loss for any player. It is noted at Case 3 in Table IV that column has the dominant strategy for $(a^/)$,and $(c^/)$, which hinge on higher production with their profit, while row has the higher production for $(b^/)$, and $(d^/)$ with their profit as dominant strategy. Neither power generators have the dominant strategy in the Chicken game. So, it can be predicted from the analysis that it is quite possible to think about negotiations serving for the function of persuading power generators inclined to lower production of the dire-averse risks imposed by the demand of situation. For instance, regarding Table IV in case 3 at ($a^/$), based on different sophisticated situations in the real-world life, the Nash equilibrium is seen as (2400, 1800), and the maxi-min equilibrium is (1800, 2400). Because unexpected situations have been occurred in the real sense of view due to the demand of the critical situation. The justification of the chicken (CH) game is more realistic regarding environmental issue compare to the symmetric game [33] of CH.

D. Stag-hunt game with asymmetric power

Assuming, 2 × 2 game for Stag-hunt in which two power generators; X and Y, act as players that have two strategies; higher and lower production with maximum and minimum limit for (a) , and (b) = (80MW, 20MW) whereas for (c) , and (d) = (80MW, 10MW) in Case 1 regarding Table V [27].This game indicates two Nash equilibria: either both power generators play for higher production or both play lower production in which the best result for both of them is to play jointly higher production and the next-to-worst outcome for both power generators is that they both play for low production; there is the significant risk regarding this situation. Case 2 in Table V represents the power production rate for the consumer in accordance with the power market operator [34]. Case 3; $(a^/)$, $(b^/)$, $(c^/)$, and $(d^/)$ regarding Table V, holds the outcome for the Pareto-optimal as (profit at higher production, profit at higher production), where one of the Nash equilibria represents the mutual cooperation by the agreement, in contrast, relatively sudden risk for the power generators show the mutual profit at lower production which is another expression of the Nash equilibrium. As a result, the negotiation of the power generators characterizes the situation perfectly. It should be mentioned that the risk-averse power generators would like to play Maxi-min strategy to keep on the safe position. For example, case 3 of Table V at ($a^/$), two power generators carry two options; higher production (i.e. 2400, 2400) and lower production (i.e.1400, 2100), as well which are named as Nash equilibrium. These equilibrium situations support higher production with higher profit as well as lower production with less emission to the environment. The most important fact for the SH game is more acceptable regarding safety and social cooperation compared to SH's symmetrical game [33].

CONCLUSION

Presuming 2 × 2 game in which two players; power generator (PG) X and Y with two strategies called higher and lower production relied on four game classes; Prisoner's dilemma (PD), Trivial, Chicken (CH), and Stag-hunt (SH) are used to percept the real-power market scenarios hinge on asymmetrical game theoretical approach. The asymmetrical approach can represent the real insights issues of the electrical power market for understanding or resolving based on game theory which can reflect the characteristics of socio-economic, engineering, and so forth in the real sense. Achieving several results from the different 2 × 2 game analyses suggest that the Prisoner's dilemma is the best strategy selection for the market power by doing negotiations that are performed better in the real-world scenario. In the Trivial game, there is a strong relationship achieved by the agreement, which is not realistic always. The CH game indicates a more selfish strategy towards market power when the risk levels are increased in both markets. The SH game reaches the equilibrium choice by the agreement as well as negotiation rely on demand of the situation.

To determine the possible solutions in terms of power generation system based on the game theory, two possible indicators are found; one is the Nash equilibrium and another one is the Maxi-min equilibrium. In the PD game, the Maxi-min strategy reaches the Nash equilibrium which is evaluated by the rationality of the power generators. In the Trivial game, an agreement is made to overcome Maxi-min strategies and to achieve the outcome of the Pareto-optimal. The CH games show the Nash equilibrium is different from the Maxi-min strategy, as a result, the Maxi-min strategy tries to achieve the Pareto-optimal position through the risks situation. The SH games playing the Maxi-min strategy can lead to either mutually higher production or lower production in terms of long or short-run interest.

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REFERENCES

[1] S. Grijalva, and M. U. Tariq, “Prosumer-based smart grid architecture enables a flat, sustainable electricity industry”, ISGT, Jan, pp.1-6, 2011. doi: 10.1109/ISGT.2011.5759167.

[2] J. Rifkin, “The third industrial revolution: how lateral power is transforming energy, the economy, and the world”, New York, USA: Palgrave MacMillan Press, 2011.

[3] D. Streimikiene, and I. Siksnelyte, “Sustainability assessment of electricity market models in selected developed world countries”, Renew. Sustain. Energy Rev., vol . 57, pp. 72-82 , 2016.

[4] Y. Jiang, J. Hou, Z. Lin, F. Wen, J. Li, C. Ji, Z. Lin, Y. Ding, and L. Yang, “Optimal bidding strategy for a power producer under monthly pre-listing balancing mechanism in actual sequential energy dual-market in China”, IEEE Access, vol.7, pp.70986-70998, 2019.

[5] J. Tanimoto, “Fundamentals of Evolutionary Game Theory and its Applications,” Springer, 2015.

[6] J. Tanimoto, “Evolutionary Games with Sociophysics,” Springer, 2018.

[7] J. M. Smith, “Evolution and the theory of the games” Cambridge University Press,1982.

[8] J. M. Smith, & J. Hofbauer, “ The battle of the sexes: a genetic model with limit cycle behavior” Theoretical Population Biology, vol. 32 (1), pp. 1-14, 1987.

[9] R. Selten, “A note on evolutionary stable strategies in asymmetric animal conflicts.” Journal of Theoretical Biology, vol.84(1), pp. 93-101,1980.

[10] P. Hammerstein, “The role of asymmetry in animal contests.” Animal Behavior, vol. 29(1), pp. 193-205, 1981.

[11] T. Guimaraes, & O. Sato, “Benefits of Environmental Stewardship”, J. Transnatl. Manag. Dev., vol. 2(3),1996.

[12] S. J. DeCanio, & A. Fremstad, “Game theory and climate diplomacy ”, Ecological Economics, vol. 85,pp. 177–187, 2013.

[13] Y. Wang, & F. Wang, “Evolutionary Game Analysis on Production and Emissions Reduction of Manufacturing Enterprises under Different Carbon Policies,” IOP Conf. Ser. Earth Environ. Sci., vol. 199(2), 2018.

[14] Q. H. Zhu, & Y. J. Dou, “Evolutionary model between governments and core-enterprises in green supply chains,” Xitong Gongcheng Lilun yu Shijian/System Eng. Theory Pract., vol. 27(12). pp. 85–89, 2007.

[15] Z. Jianya, L. Weigang, & D. L. Li, “A game-theory based model for analyzing e-marketplace competition,” ICEIS 2015 - 17th Int. Conf. Enterp. Inf. Syst. Proc.,vol. 1, pp. 650–657, 2015.

[16] K. Madani, “Game theory and water resources,” J. Hydrol.,vol.381, pp.225–238 ,2010.

[17] C. M. García Mazo, Y. Olaya, & S. Botero, “Investment in renewable energy considering game theory and wind-hydro diversification,” Energy Strateg. Rev., vol. 28, pp.100447, 2020.

[18] S. Janjua, M.U. Ali, K.D. Kallu, M.M. Ibrahim, A. Zafar, & S. Kim, “A Game-Theoretic Approach for Electric Power Distribution during Power Shortage: A Case Study in Pakistan.” Appl. Sci., vol.11, pp.5084,2021.

[19] B. Bruns, and C. Kimmich, “Archetypal games generate diverse models of power, conflict, and cooperation.” Ecology and Society, vol. 26 ,2021. https://doi.org/10.5751/ES-12668-260402.

[20] L. Jin, Q. Liu, J. Yu, M. Wang, & W. Wu, “Research on the Development of Electricity Market Based on Performance Guarantee.” Front. Energy Res., vol.10,2022.

[21] A.F. Isnawati, & M.A. Afandi, “Performance Analysis of Game Theoretical Approach for Power Control System in Heterogeneous Network.” International Journal of Intelligent Engineering and Systems, vol. 15(3), pp.397-405, 2022.

[22] G. Wang, Y. Chao, Y. Cao, T. Jiang, W. Han, & Z. Cherr, “A comprehensive review of research works based on evolutionary game theory for sustainable energy development.” Energy Reports, vol.8, pp. 114-136, 2022. https://doi.org/10.1016/j.egyr.2021.11.231.

[23] M. A. Habib, K M A. Kabir, & J. Tanimoto, “ Evolutionary game analysis for sustainable environment under two power generation systems ” Evergreen. vol.9 (2), pp.323-341, 2022.

[24] 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

[25] 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, vol. 138, pp. 1-7, 2020.

[26] J. Nash, “Equilibrium points in n-person games”, Proceedings of the National Academy of Sciences ,vol.36, pp. 48–49, 1950.

[27] D. Robinson, and D. Goforth, “The Topology of the 2×2 Games: A New Periodic Table. Routledge”, New York, 2005.

[28] J. Mays, D.P. Morton, & R.P. O’Neill, “Asymmetric risk and fuel neutrality in electricity capacity markets”. Nat Energy, vol. 4, pp, 948–956 , 2019. https://doi.org/10.1038/s41560-019-0476-1.

[29] P. K. Narayan, & S. Popp, “Can the electricity market be characterised by asymmetric behaviour? ” Energy Policy, vol. 37, pp.4364–4372, 2009.

[30] A. Kakhbod, & G. Lanzani, “Market Power and Asymmetric Learning in Product Markets”. SSRN Electron. J. ,2020. doi:10.2139/ssrn.3596734.

[31] K. Sieberg, D. Clark, C. A. Holt, T. Nordstrom, & W. Reed, “An experimental analysis of asymmetric power in conflict bargaining”. Games, vol. 4, pp.375–397, 2013.

[32] L. Cheng, & T.Yu, “Nash Equilibrium-Based Asymptotic Stability Analysis of Multi-Group Asymmetric Evolutionary Games in Typical Scenario of Electricity Market”. IEEE Access, vol. 6, pp. 32064–32086, 2018.

[33] M. A. Habib, “Game Theory, Electrical Power Market and Dilemmas” Journal of Electrical Engineering, Electronics, Control and Computer Science –JEEECCS, vol. 8(29), pp. 33-42, 2022.

[34] 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.