Game Theoretic Demand Side Management – Methods and Approaches: A State-of-the-Art Survey

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Abstract

Smart Grid is a state of art power system integrating control methodologies, advanced communication and sensing technologies at transmission and distribution level so to supply electricity in a user-friendly way. Demand side management is an integral component of electric utility and it deals with the consumer side optimization, which can delay the installations of new generation plants with an alternate solution. Mostly dynamic programming, linear programming, and other methods, which are heuristic, which can handle DSM, based optimization issues. To avoid the disadvantage of all the conventional procedures and heuristics a novel strategic and situation-based method of game theory is the latest fascinated topic of research in power system. Various researchers have taken different problem scope with DSM, which aims to include game theory in smart grid. This paper surveys different game theo- retic approaches for various applications in DSM. This survey can influence the researchers to use game theory efficiently in decision making for the future Intelli - grid network

Keywords Game Theory (GT) · cooperative game · Smart Grid · Peak to Average Ratio (PAR) · Demand Response Aggregator (DRA) · Demand Side Management (DSM) · Nash Equilibrium · Peak to Average Ratio (PAR) ·

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Introduction

The concept of a smart grid is gaining momentum all throughout the world as the people are fast moving towards a revolution in the energy sector. With the advent of smart meters and advanced communication technologies within the power system area of smart grid is much more fascinated in the research domain. In future residential energy consumption may exceed 40% of total energy consumption. As electricity cannot be stored largely and the supply is under the control of consumers, DSM is an important concept in an energy management (Gellings and Chamberlin, 1987) for the upcoming smart electric grid. DSM supports the smart grid in many areas, especially in electrical distribution side with the infrastructure development, energy sources decentralization and also in the control of electricity market. Proper management of the energy and thereby reducing peak demand profile enhances electric grid sustainability and eventually reduce the overall cost of energy. Along with energy management DSM (Esther and Kumar, 2016) is the restructuring of policies and regulations in the electrical domain to decrease peak energy utilization which can postpone the construction of new electrical plant with respect to electrical generation and transmission along with distribution system. Further addition of renewable along with storages is also possible and a matter of concern. The aim of DSM in the electric grid which are automated is to increase the sustainability, security and overall grid efficiency thereby improving the effectiveness of the present installations, which can connect with less carbon systems with the grid. Moreover, the DSM (Reddy and Parikh, 1997) can be done with a centralized, decentralized and user comfort based strategy using various optimization methods. Game theory is the best option for the DSM with an objective of reducing PAR, cost savings and integration of renewable with storages.

The concept of game theory mathematically (Rubinstein and Osborne, 1994) analyses conflict of interest between independent consumers who are active enough to improve their benefits after discussing with each other. GT can handle independent and interdependent decision towards an optimal solution. Even depending on the players' interest, GT can react to the situations of conflict with or without cooperation in the field of smart grid. Researchers and power engineers to deal DSM, which is an integral part of smart grid, can effectively use game theory. Hence, this paper brings forth a survey on game theoretic developments done so far related to DSM in smart grid.

The content of the paper is as

Section 2 briefly discusses the DSM model along with its fundamental concepts.

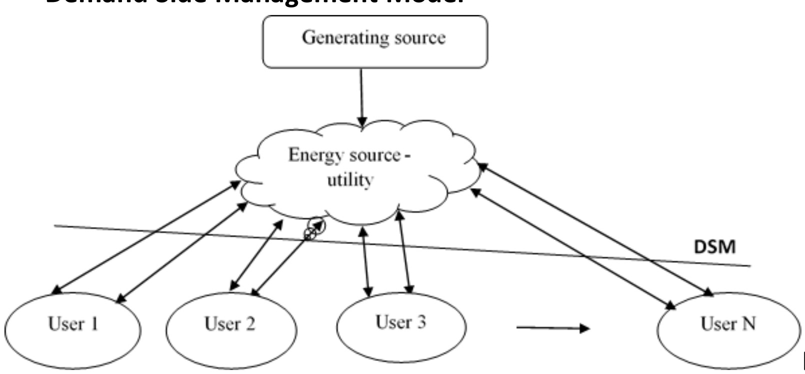
Section 3 overviews the basics of game theory along with history, classificationand models.

Section 4 reviews the different perspectives of game theory in the DSM.

Section 5 expose the researchers the future work direction and

The paper gets concluded with summary in Section 6

- **Demand Side Management Model**



DSM

Fig. 1 Demand Side Management scenario

is the concept of influencing customer electric demand throughout 24 hours by encouraging their electrical energy usage during off peak hours. If the users employ conservation measures and utilize energy in off peak hours their overall energy consumption bill will get reduced. DSM not only saves money, but also increases the quality of service to customers. DSM (Gellings and Chamberlin, 1987), (Siano, 2014; Vardakas et al., 2015; Deng et al., 2015) need customer cooperation for overall benefit maximization. Load management is the capacity to get the detailed customer energy consumption pattern along with loads and empowering them with appropriate pricing options, user control and awareness. Fig 1 depicts the DSM general scenario.

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Two technologies (Et-Tolba et al., 2013) involved with demand side load control are smart metering and building automation. Meters need to be smarter and intelligent in smart metering technology to handle all latest features in the electrical system. Building automation includes distributed generation in coordination with wind, solar or biomass and having storage facilities like battery and fuel cell. Smart meters communicate bidirectional with the central unit. Consumption requirements can be sent to the meter from appliances. These meters can also communicate with the utility for further commands and requests. The components of smart meter in shown as Fig 2

DSM needs to be involved to all categories of load like base line, regular and burst loads. However, power sector issues, mainly arises due to regular and burst loads. In order to overcome the issue DSM focus on these loads by applying various DSM techniques which includes load shifting, peak clipping,

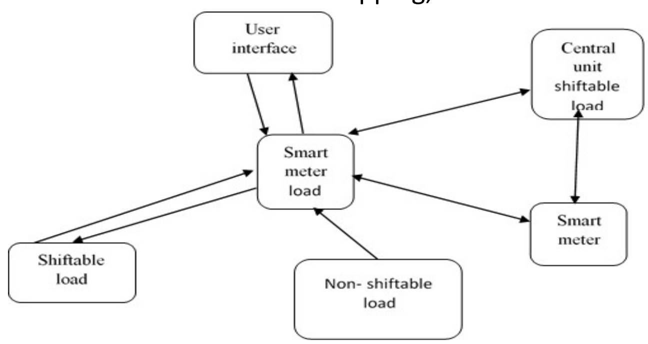

Fig. 2 Smart meter components

strategic conservation, flexible load shape etc., DSM, which is a part of smart grid, can be viewed as a layered architecture with subsystems as shown in Fig 3

Layer 1	Micro grid		Micro grid		Micro grid	
Layer 2	Load balancer		Load balancer		Load balancer	
Layer 3	DSM 1	DSM 2	DSM 1	DSM 2	DSM 1	DSM 2

Fig. 3 DSM as a part of smart grid architecture

- **Background and Game Theory fundamentals**

This section provides an insight of game theory, history, terms and definitions, types along with the models.

- **History**

The general concept of making decisions is important in a competitive market.GT yield a framework which is conceptual for formulating and analyzing those situations in a simple way. Game theory is a mathematical tool that can be used along with social and behavioral aspects of any problem.

The birth of game theory (Rubinstein and Osborne, 1994) was in the way back 18th century, but the major development began only after 1920 when Emile Borei and John Von Neumann actually started their explorations on it. Later in 1950 John F Nash suggested a key concept of Nash equilibrium and the study on bargaining. Then onwards game theory intruded in various domains of science and engineering where the decision making

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process is prioritized. In prior mathematical analysis have to be considered, then Waldegrave had analyzed a game using the minimax mixed strategy in 1713, well ahead of Cournot's analysis in 1838. The same year Antoine Cournot started the work with the first game theoretic modelling. In 1921 mathematician, Emile Borel made game theory to be an official and structured which was then carried forth by John Neumann as a decision-making logic theory similar to parlour games in 1944. In a situation where the players communicate, game theory tries to find the optimal behavior with the benefits and cost involved. This paper tries to explore the possibilities of using game theory with DSM so to make the future smart grid interactive and intelligent.

- **Terms and Definitions**

Game: It is the tactical interface between cooperating and non-cooperating players where the payment and restrictions for an activity are also involved. **Participant:** A major player in the game whom are assigned with the activity selections. A participant can be an individual or the group of individuals in a game.

Activity: In a set of game an activity is a part of a move.

Payoff: A payoff is a value given to a player for a cause. When a product is unsystematic, payments are with respect to the likelihood and are biased. These include the player's method of approach too.

Strategy: It is a participant activity when the game is in tactical form. In a distant based game strategy is the complete group selection and are one as a decision of each participant.

Mixed strategy: It is the randomization of specific possibility as per the participant's choice. The mixed strategy is deterministic and are with clean strategies.

Static Game: This involves a single game where each participant can decide his deed and the other participant choices are taken concurrently. That means no participant will know the plan of other participant.

Dynamic Game: this is a game with more than a phase, each player can replicate his or her deeds, and the measurement are done in choice making of successive mode.

Rationality: It is a term that a player to be a rational as he plans to play and take most of the payment and every player ought to have the similar information in the play.

Zero-sum game: In this play the payment totality is zero. With a two player game the win of one participant is considered to be the failure of the other participant and the net benefit get reduced drastically.

Nash equilibrium: This is a group of policy and are a strategic equilibrium so that no participant can change his strategy to get a better payment thanthe other player.

Stochastic Game: The game will have series of state, which will have a probabilistic behavior with many changes. When started the game allow a participant to choose his activity depending on the present state and then changes to a new state with respect to the present state and the player's activity.

Bayesian Game: This game use Bayesian study to predict the result and the payment and tactics of players are handled in partial where the allotment are made in the start of the game.

- **Types of games**

Different game types are (1) differential game (2) relay game (3) continuous and discontinuous game (4) collaborative and non -collaborative game (5) zero sum and non – zero sum (6) symmetric and asymmetric game (7) perfect in- formation and non-perfect information game (8) Simultaneous and

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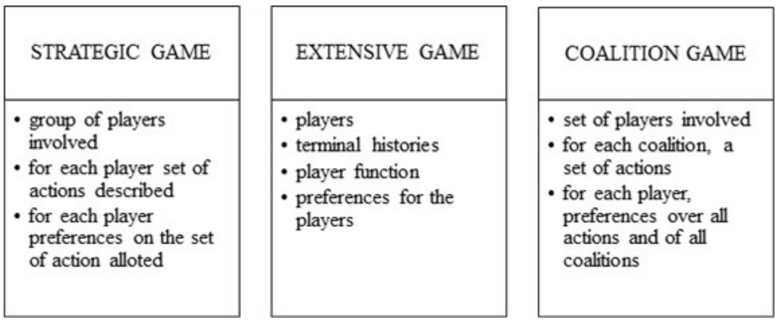
sequential game (9) population game (10) combinational game (11) pooling game (12) population game (13) stochastic game.

- **Models of game theory**

Game theory constitute model collection. A model is an abstraction to under- stand experiences and observations. The game theory models are an expression of ideas that are presented verbally. Game theoretic modelling began with an idea related to the interaction of decision makers. The next step is to dis- cover its implications (analysis) whether it is right or wrong. The implications and idea should be appropriate and need to improve the understanding of the situation.



The game theory can be modelled as an extensive game or a strategic game or a coalitional game as shown in Fig 4. Firstly, a model of interacting decision makers is termed as strategic. It has a set of players, in which each player has a set of actions and then each player prefers over the set of active profiles. Secondly, the model of an extensive game elaborates the sequential structure of decision making specifically which allow situations the decision maker is free to change their decision as events unfold. It has 4 components, namely the players, player function, terminal histories and preferences for the players. Thirdly, a model of interacting decision maker's deal on the behavior of players are termed as coalition game. It includes a set of actions with every group of players unlike an individual player as strategic and extensive games. It has a set of players, for every coalition with a set of action to be followed by each player where the preferences on the action within coalitions in which the person is a member. Each group of players form a coalition and the combination of coalition with players are called grand coalition. Coalitional gaming can be the preferred choice with the implementation of DSM models.

Fig. 4 Models of game theory

The major concept of game theory is related to static and dynamic games wherein static game players react simultaneously to the situation whereas the dynamic games players are self-interested and are allowed to adopt some strategies to the outcome. The mathematics tools can be used in various areas related to the cooperative and non-cooperative behavior. Game theory handles multiple person choice towards a game and whenever the participant plans the activities which can result as a best output for a person, while anticipating the effective activity from other players. A player/participant is a key element in a game who can make decision and can do the activities. The game of a player will replicate the communication, which then has the disadvantages of, and payments for, activities the players can involve, but not about the actual activity they need to play. This result in a best policy with results as a methodical manner. This also involve the significance the decision maker has done.

A preferential game has the significance of the model with the decision of each participant participating in the game. A participant with a complete plan of activities in all situations is preferred and termed as a good player. A strategy is said to be a pure strategy if it takes the tactics with distinctiveness. The states of a likelihood dissemination for all the activity in a state, are denoted as a mixed strategy. The Nash equilibrium explains firm rule of the game so that no player can modify the tactic so to reduce the payments done to all other participants following the prearranged strategy. This conception defines the firm state alone not including the stable state, which was achieved. The Nash equilibrium is the most renowned equilibrium, in spite of that are many other answers, which are used rarely. All game theory approaches lead to a general solution, called Nash equilibrium. Game theory has 2 components.

First each player selects the action as per the model of rational choice (action taken by a decision maker is at least as good to their preferences as every action available action) as described by the other player's action. Second every player's belief about the other player's actions are correct. These two actions are combined as a Nash equilibrium. "A Nash equilibrium is an action profile a* with the property that no player i can do better by choosing an action different from a*i given that every other player j adheres to a*j". The concept of Nash equilibrium most commonly used with DSM problems for cases of games with perfect information as well as imperfect information. With a description of game theory, the paper is further focused on the limited literature available to the DSM, which is the most essence in the electrical grid.

- **Game Theory in DSM: Different Perspectives**

Game theory contributions to solve challenges in the DSM is an important concept in smart grid. DSM modifies energy load distribution on the demand side to reduce peaks in energy usage. After the introduction of game theoretic concepts, (Vardakas et al., 2015; Charilas and Panagopoulos, 2010) it becomes possible to mathematically describe DSM problem and to find a solution. This section reviews the various game theoretic approaches used in DSM, which aims at minimizing the peak to average ratio as well as the cost for the utility and consumers. For better understanding, the literatures are sectioned

- as the approaches which are used to reduce PAR and cost
- various approaches related to different pricing strategies
- cooperative and non-co-operative approaches.

- **Game theoretic approach to reduce PAR and cost in DSM**

DSM approaches need to reduce PAR and also the consumption cost.

With the intension (Mohsenian-Rad et al., 2010) discusses autonomous and distributed DSM with Game-Theoretic Energy Consumption Scheduling (GTES) for the future Smart Grid. Players are the consumers and the daily schedule of the appliances are the strategies where both of them play a game to attain Nash Equilibrium with prices assumed from the utility. The advantages are a privacy of usage pattern is maintained and incentives are added on tothe participating users.

(Nguyen et al., 2012) proposes a smart power system with distributed users where the utility update the dynamic pricing, which depends on the load profile of the user. The user and the utility try to reduce PAR- Peak

Average Ratio by charging their battery during off period and using energy at high demand period. A distributed algorithm with a game theoretical approach minimizes its total energy cost.

(Stephens et al., 2015) suggests distributed energy generation with storage. Game Theoretic model predictive control (GT MPC) is suggested for the real

Table 1 Summmary on Review of Game theoretic approach to reduce PAR and cost inDSM

S.No	Author	Objective	Problem Formulation	Methodology Used	Advantages / Disadvantages
1.	Amir et al	Autonomous DSM Based On GT- ECS for the Future Smart Grid	GT formulates an ECS game, where the players are the users and their strategies involve their home appliance and load schedule. Assumption: Service provider may have different pricing tariffs so to differentiate the energy usage in level and time.	Nash equilibrium based ECS formulated for a multiple user and a utility company so to reduce energy cost and to access performance Every player need to apply their best strategy to the existing load and tariffs. Users can maintain privacy. Incentives were given to user for their active participate in the ECS.	The energy usage is decreased and the domestic load is also controlled when many users share common energy source.
2	Hung Khanh et al	DSM to reduce PAR using GT in Smart grid	A novel pricing model is developed that propose a distributed algorithm which can achieve Nash equilibrium in NECS game where each player can reduce their energy bill to a service provider by appropriate decision	Distributed users submit their energy profile to the service provider and the provider handle the energy prices depending on user load profile. The consumer can reduce PAR by charging and discharging the energy at off peak and peak load periods. Distributed algorithm with game based where the player can decrease their total energy bill	With the usage of battery and RES users can minimize their energy bill to the energy provider. This proposed model have no option for the users to sell energy back to the service provider.

3.	Edward R. Stephens et al	GT – MPC for Distributed Energy DSM	Game Theoretic Model Predictive Control algorithm develops sub game perfect equilibrium strategies	GT MPC model when applied to distributed generation with storage and forecast details is more precise than the day ahead forecast scheme with lesser mean forecasting errors	The proposed robust and continuous approach decrease forecasting errors and electricity cost savings along with PAR reduction.
4	Zubair et al	GTES method to reduce PAR with the user's energy schedule optimization	This method encourages the communication between the user and energy provider as a novel energy price model as a function of total energy consumption. Also, the objective function is to optimize the variation between the energy consumption and the cost involved.	The energy provider deals consumers in a round-robin fashion, and give the consumer the energy price and current consumption pattern Each player can optimize their own schedule and communicate to the supplier, so to get energy price before the next user. A two-step centralized game as GTES is proposed	PAR and energy consumption are reduced The power company can estimate the energy cost by predicting the per hour total energy consumption. Due to this the user energy bill can be reduced.

time data with sub game perfect equilibrium strategies with prefect forecasting information. This method looks better than day ahead optimization.

(Fadlullah et al., 2011, 2014) introduces novel two step centralized game with the interaction between users and utilities. The objective function deals the difference between value and cost of energy in a round robin fashion. The table 1 summarizes the review on this particular concern on PAR and cost reduction in the DSM.

(Pal et al., 2018) have addressed the optimal fair scheduling environment for multiple users by preserving the demand supply balance ratio. Consumer demand response is formulated as a game theoretic model with an additional feature that if the customer deviate the usage pattern no benefits are taken. Minimization of energy cost is by correlated Nash equilibrium as an energy consumption schedule game. The results validate 31.4% of PAR and remark- able cost benefit to the users. Smart grid started using demand response and interactive technologies to maximize the mutual benefit to the power companies and energy users.

(WangJidong et al., 2018) relate the interactive behavior as a game theoretic process to solve the load shifting and electricity pricing. By shifting only, the thermal load simulation shows 11% of cost reduction along with financial benefits to both providers and users.

- **Game theoretic approach for different pricing strategies in DSM**

DSM approaches also based on different pricing strategies. Most common time based pricing can be with respect to

- Time of Use (ToU) – It's the pricing pattern where the users know the price in advance for the period of usage.
- Critical Peak Pricing (CPP) – It's similar to the ToU except for peak days.
- Real Time Pricing (RTP) – It's the dynamic pricing which changes hourly
- Peak Load reduction credits is applicable for large consumers with some peak load agreement.

(Yang et al., 2013) proposes a GT approach with ToU pricing strategy. Utility functions are designed between the utility and user parameters and Nash equilibrium is achieved through backward induction. Model of costs is used as user parameter and model of user satisfaction as a difference of their demand and actual consumption are also taken into consideration.

(Baharlouei et al., 2013) discusses the autonomous demand response with an optimality and fairness. The centralized DR system is taken as a standard and smart electricity billing is done in a decentralized way by coordinating the operation of ECS devices.

(Meng and Zeng, 2014) uses RTP model with the retailer as leader and customers as N follower Stackelberg game and equalized with Nash equilibrium strategies. Leader undergoes GA based RTP where the customer receives in-formation and are satisfied with the pricing.

Table 2 Summmary on reviews of various pricing strategies in the DSM

Sl. No	Author	Objective	Problem Formulation	Methodology Used	Advantages / Disadvantages
1.	Peng Yang et al	Game based Time of Use pricing strategies	The problem is for the utility functions of 'n' users designed as a Nash equilibrium with the backward induction.	Modelling is done with cost from service provider considering the user comfort with the user consumption pattern are proposed	Though it has an effect in leveraging the user demand with ToU prices, but decreases energy providers cost and benefit the user
2.	Zahra et al	Achieving Optimality and Fairness in autonomous DR	Each player is given an ECS device to control the consumer's load pattern and to reduce the energy cost.	A centralized DR model which act as benchmark with a billing system is developed to have fairness and optimality with an autonomous DR in a decentralized system.	Fairness and optimality both are considered whereas the other methods dealt only with optimality
3.	Fan-	An Optimal	The provider	The communication	Both the customer and

	Lin et al	RTP for DSM using Stackelberg Game and Genetic Algorithm is proposed	decides the cost of energy and inform the user with a smart meter. The user can operate their appliances to the proposed so to increase their own benefits.	with the provider and customers are modelled as a 1-leader, N-follower Stackelberg game Appliances at home are considered to be non shiftable, non-interruptible, interruptible and curtailable models. Then genetic algorithms are used to find Stackelberg solutions.	retailer are benefited because of current energy pricing programs, so to reduce the increasing energy bills, and change their energy usage patterns. In all the existing work there exists a two way communication infrastructure between the provider and its customers.
4.	Henry Chen et al	Autonomous DSM based on ECS and Instantaneous Load Billing is proposed.	Game theoretic DSM program based on ECS. Distributed synchronous agreement-based algorithm and a distributed asynchronous gossip-based algorithm developed so that the users can have NE with the exchange of information with the next user	Variational inequality theory, checks the conditions for the existence and uniqueness of NE. A central unit finds and transfer the real-time average load to all users, a one timescale distributed iterative proximal point algorithm that achieve the NE of the game.	Numerical results Showed that the developed algorithms can quickly converge to the NE of the formulated game and efficiently convince the consumers to shift their on-peak consumption, which are beneficial to both the consumers and the whole grid.
5.	Firooz et al	Game Theory and Pricing Strategies for DSM is proposed	The problem is formulated as a binary linear programming problem for a single utility with multiple users. DAP is followed by the utility.	The service provider sets the price for different hour electricity use and communicate it to the users. When the consumer get the price information from the energy provider, they increase the utility	Results indicate that the users can reduce their electricity bills by 25% when they use the proposed scheduler to react to DAP pricing strategy.

				functions independently, resulting in global optimization.	

(Chen et al., 2014) proposed distributed synchronous agreement based and distributed asynchronous gossip based algorithm for selfish consumers with an instant load billing. Variation inequality theory analyses Nash equilibrium and time scale distributed iterative proximal point algorithm is used to achieve Nash equilibrium.

(Saghezchi et al., 2014) discusses DSM with day ahead pricing for a single utility and multiple consumers and solved by binary linear programming.

The table 2 reviews the various pricing strategies in the DSM.

(Esfahani et al., 2019) have suggested hierarchical game theoretic optimization approach for a multi agent based energy market in a micro grid system with a three level market framework. Double auction for day ahead forecast is the first level and the other levels are optimal rescheduling for the hour ahead and inter micro grid reverse auction for the real time market.

As the demand response has the potential to mitigate power imbalance (Yu et al., 2019) has considered grid operator who can perform resource trading at a minimal cost. Stackelberg game theory identifies the distinct behavior and coordinates various decision makers. The author has demonstrated minimal cost with the approach.

(Khazeni et al., 2019) have proposed bi-level game between retailers and consumers in a multi carrier energy system. Retailers tend to increase the profit whereas customers try to reduce their electricity bill subsequently. Mixed integer nonlinear programming problem formulated is solved to an epsilon Nash point. Results prove with the maximized gain and reduced bill.

(Vahid-Ghavidel et al., 2019) have proposed self-scheduling concept for DR aggregators. Taking the uncertainties from the market pricing and consumers the information gap decision theory assure profit and reduce the complications of stochastic approaches. Reward based and Time of Use are the strategies used and are solved by General Algebraic Modeling System.

(Lu et al., 2018) considered renewable energy uncertainty and operational quality as a two level pricing mechanism for a coupled micro grid. In the upper level operational quality is taken care and in the lower level actual transactions between network happen. Uncertainties are handled with stochastic programming and time varying game vector and energy strategy deal with micro grid.

(Motalleb et al., 2018) deals with game theory that model competition between DRA to sell energy from storage devices in a market environment. Dynamic economic dispatch updates the supply demand with an optimal bid- ding strategy. RTP and ToU are used with dynamic programming. The method confirms reduced operation cost as well as fuel cost.

(Marzband et al., 2018) have proposed long term planning in industrial micro grid which is connected to a distribution network. The long term planning and the short term operations are combined in a game theoretic framework that allow conflicting situations and can satisfy the objective of stake holders. The tool provides economical and technical positive outputs in an industrial micro grids.

(Lu et al., 2019) has proposed Stackelberg game for a distribution market operator between DRA's. The two stage framework handles the price response of loads and the estimated load given to multi follower stochastic Stackelberg game. Case studies were also presented by the author.

- **Game theoretic approach for cooperative and non-cooperative strategiesin DSM**

As game theory is a popular decision making tool the decision makers can play cooperative as well as non-cooperative games. Both the approaches are mentioned as a review in this section.

(Song et al., 2014) discusses DSM between self-motivated consumers as a game of repetition . Optimal non stationary strategies allow customers to use power at peak hours at a lower price. Hence, billing cost and customer's discomfort are reduced to drastically

(Zhu et al., 2012) proposed dynamic, distributed DSM as a two-layer optimization problem. At the lower level appliance scheduling is done and at the upper level interaction among players through market price with respect to the market price is done as N person non zero sum stochastic differential gameto achieve Nash equilibrium.

(Belhaiza and Baroudi, 2015) developed a new non cooperative game theoretic model considering the packet rate. Three objectives of the game (mentioned in the table) are computed as 0-1 mixed programming to achieve Nash equilibria.

(Chapman et al., 2013) focused on non-cooperative residential demand response. As given in the table with four assumptions the author has constructed a framework for the reality approach.

(Soliman and Leon-Garcia, 2014) implemented two games which are non-cooperative in the residential consumer side and also a Stackelberg game be- tween utility and consumers to reduce PAR.

(Atzeni et al., 2014, 2013a, b) addressed the DSM as a non- cooperative optimization problem with distributed energy source along with storage. A day ahead pricing strategy is followed and the optimization done with two perspectives.

And hence this review is summarized in table 3 as a quick reference with an intention to make the work easier for the researchers in this domain for future.

Active distribution has evolved with communication infrastructure, demand flexibility, storage generation and new generation.

(Marzband et al., 2016) focus on the management of network with market based retail electricity market based on game theory. Nikaido-Isoda Relaxation Algorithm (NIRA) in a non-cooperative gaming used to deal the gaming with an appropriate statistic. The method promotes local generation and increase the profit of all participants.

(Zhang et al., 2018) has dealt with nonlinear quadratic differential game theory to multiple micro sources. Non cooperative feedback Nash equilibrium

Table 3 Summmary on reviews of cooperative and non-cooperative strategies in DSM

Sl. No	Author	Objective	Problem Formulation	Methodology Used	Advantages / Disadvantages
1.	Linqi Song et al	Stationary strategies for consumers	The energy scheduling game is among the self-	Non stationary optimal based DSM where the	The method used can reduce the total cost which includes billing

		minimize their short-term billing and discomfort costs	interested user to decrease their long-run total costs	consumers can have their routine and power consumption pattern along with the past pattern.	and discomfort costs up to 50% when compared to the existing DSM strategies
2.	Quanyan et al	Differential Game Approach to DSM	Dynamic games are frame worked in 2 levels Sticky price model characterization for market price and N person nonzero sum considered to be in NE simulations	The user appliances are scheduled at the lower level as per the consumption pattern and in the upper level dynamic game deal with the interaction among users according to market price	The user's demand affect dynamically the market price and the power consumption gets optimized to reduce the cost
3.	Slim Belhaiza et al	New non cooperative game theoretic model for the DSM with the consideration of packet error rate	Mixed programming with 0-1 approach to find Nash equilibrium is proposed	The three objectives are : to maximize the minimum sum of proportions of the game users; maximize the minimum utility of the users and to maximize the minimum utility of the energy providers	The results which were computed are based on randomly generated DSM games with variable size the highlight the instantaneous errors on heterogeneous users if it is not considered
4.	Archie et al 2013	Deals the framework of non–cooperative game	Four assumptions on RDR suggested so to apply on the real time issue by the aggregators and household for the future energy system	(i) The household energy use are hybrid and discrete values (ii) Each household has a private state of electricity consumption (iii) Households may have state based private preferences (iv) the behaviour of Household is strategic, at the algorithmic design level with an	Many assumptions are with the control schemes for a residential demand response (RDR)

				equilibrium analysis	
5.	Hazem M. et al	GT with storage are discussed as Non-cooperative Stackelberg game	A non-cooperative game which is played within the residential consumers are considered first and then the Stackelberg game between the utility provider and consumers are taken Cost function for selling back stored energy is also considered	Two algorithms which are centralized and distributed to solve and to reduce PAR are used to solve the Stackelberg game.	The algorithm reduce the total cost and PAR when considered with storage It is better to give storage only to specific users instead of all users
6.	Italo Atzeni et al-	Non cooperative day ahead DSM with distributed generation and storage to reduce cost	The author tackled the energy pricing and optimization design in two perspectives as user-based optimization with a holistic-based design	Each player usage is formulated as the grid optimization problem which are the non-cooperative game, building on the theory of variational inequalities. Cooperation within the user is better than the joint optimization among the users. For the distributed and iterative algorithms users optimal production and storage strategies with their convergence properties considered	The algorithms which are used flatten the demand curve and reduce the requirement of carbon-intensive and costly power plants

is structured to the problem and the simulation results prove worth to the disturbance of various parameters considered in the system.

(Du et al., 2018) has suggested cooperative game theory to a coalition of micro grids to reduce its operational cost. Focused on the cooperative behavior to the cost allocation Benders decomposition algorithm is used in the distribution level. A linearized optimal power flow for distribution model is applied rather than the conventional ACOPF model to reduce computational complexity to maintain the accuracy.

(Stevanoni et al., 2019) proposes the vision for a long term industrial micro grid. Different conflicts are addressed as per the stakeholder's objectives. The authors have well defined the issue as an interaction model in game theoreticalperspective.

(Nekouei et al., 2015) Proposed game theoretic framework for both the provider and the user. In the first level Stackelberg game interact between demand response aggregator and the generator model with an objective of profit maximization. User discomfort minimization is also taken care and Vickrey Clarke Groves ensures renewable integration, profit maximization as well peak demand management when the user disclose their actual consumption pattern.

(Yaagoubi and Mouftah, 2015) proposed dynamic pricing for an efficient demand side management. User consumption pattern is specified clearly with the user acceptance price. Stackelberg game is used to interact within provider and selfish user so to increase the profit and also to reduce the user price. Renewable also included to reach out the objective.

(Ibars et al., 2010) Proposed method to control peak load during peak hours as a part of distributed load management. Network congestion game is suggested to reach out Nash equilibrium. The users are considered to be selfish players and the proposed algorithm effectively manage the demand and load to reach the global optimization

(Roy et al., 2010) used game theory to protect network and the taxonomy is also explained. Game theory has a major application in smart grid and the research can be enhanced to the information security related to that.

(Cao et al., 2012) considered the residential network where the user has to update their usage pattern to the power provider. The provider does the allocation so to increase the social welfare. The users are considered to be selfish and strategic with an efficient pricing to enjoy the benefit.

(Kakhbod et al., 2012) consider dynamic spectrum access to maximize the revenue. The primary dealing is by the user dividing the resources and selling to the next level users. The secondary user utility is linear and are incentive compatible so as to maximize the revenue.

(Samadi et al., 2011) suggest real time interaction between power companies and user can have a control with the price of power. Getting the user consumption pattern is not so easy with the consumers and an efficient pricing algorithm is suggested. Vickrey Clarke Groves algorithm is used to maximize the user comfort and to minimize the cost. These algorithms have benefitted both the power providers and also the users.

(Nwulu and Gbadamosi, 2021) in the book has given an insight of modelling demand side management with control and operational issues of renewable energy systems. Optimal operational control strategies are well explained in terms of smart grid network.

(Hu et al., 2021) integrate the renewables in a micro grid as a cyber-physical system and dynamic system with non-cooperative,

cooperative and as conflict entity. The authors have reviewed the architectures, technologies and neighborhood negotiation and coordination.

(Jin et al., 2021) suggest method to improve the stability of micro grid with game theory based optimization model and a multi agent system. The economic benefit and their agent behavior are handled by game model. The Nash equilibrium is dealt as a particle swarm optimization problem to compare the effectiveness.

(Hassanpour and Roghanian, 2021) presented 2 stage stochastic programming for maintenance scheduling of power generators. In the first stage maintenance schedule is fixed and in the second stage load allocation and generation amount are found and Nash equilibrium obtained. The model was evaluatedin IEEE test system.

- **Direction for future exploration**

As there is a significant gap between what the game theory can handle in a competitive situation these conceptual tools play a supplementary role in these cases. Research is continuing to extend the success of game theory to more complex situations. The DSM approaches that are game theoretic based are focused either on game models, which are fixed games having real time data, or with the comprehensive statistics game model. But in actual situations a smart grid network needs to employ probabilistic data and dynamic games. The recent research takes an account of these points into consideration. The major disadvantage with the present research is that the game model is adaptable only with the perfect information. In addition, the game model behaves static with the computational probability with respect to the knowledge and experience. The game model also accepts with the consumer working simultaneously, which is not feasible with the real time situations. The network complexity has not been dealt and these hindrances can be rectified with the future research so to achieve the real smart grid for the future.

- **Conclusion**

The paper highlighted a number of aspects which depict the implications of game theoretic concept in DSM context. The review on game theory discuss different game modelling approaches in demand side management. The future scope for further research direction is also discussed. The concept of game theory is less used in the field of demand side management and in further can be used to an in depth level with new ideas. Game theory can establish an effective smart grid communication. Game-theoretic model incorporates the incentives and information of others that helps to develop sound decision- making. This survey reveals that game theory is an effective and simple tool in the process of repeated decision making gaming and can be effectively used in the DSM. Researchers can focus on this area with greater applicability as the coming years is going to be an era of smart electric grid with smart cities and henceforth the grid can be efficiently managed so to benefit the society.

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