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Assessment of Communications Infrastructure and Protocols for Smart Grid Metering by Game Theory Concept

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Abstract

Smart grid dependent on various class of innovation, for example, PC based remote control and computerization of power or energy grid and in another way, it would be a way in which transmission & distribution are controlled by computer and information technology based system. In this paper game theory concept is used for assessment and analysis of communication infrastructure and protocols for smart grid metering. The paper presents concepts of game theory inneighborhood area Network and home area network based smart metering. Further smart metering communication, meter acting as an interface and controller acting as an interface is optimized with the help of game theory based gambit software.

Keywords: *Smart grid, Game theory, Gambit software, Smart meter*

INTRODUCTION

Over the last 100 years a traditional power system have developed to transmit and distribute power from supply side to the load terminal with the help of step up and step down transformer and in general way this is a transmission and distribution system of overall electrical energy system. In traditional grid system some limitation are occur in the terms of consumer are uninformed and do not participate with supply end, poorly integrated whole sale market and slow response to power quality issues. All these limitation try to compensate by a grid which is called modern grid, micro grid and also smart grid, which is defines a self healing network equipped with dynamic optimization technique that use real time measurement to reduce network losses, control voltage regulation, increase reliability & profitability and improve asset management. The essential part of the electrical energy system supplying power by high-quality communication links to make sureits effective operation to enable market transaction to maintain the security of the system and to facilitate the integrated operation of the electrical generator and the transmission system[1-2].

The modern grid or smart grid is an opportunity to use new information and communication technology (ICT) to transformthe electrical energy system. The gratitude that ICT offers significant opportunities to renew the operation of the electrical networks has agree with an thoughtful that the power sector can only be de-carbonized at a sensible cost, if it is monitored and proscribed effectively. Certain application require the transmission of data from one point to another and other use may require the transmission of data from one point to another point. There are three communication interfaces, wide area network (WAN), neighborhood area network (NAN) and home area network (HAN). Game theory is the branch of arithmetic concerned with the analysis of

strategy for dealing with spirited situations where the product of a participant's choice of action depends critically on the actions of the other participants. Specifically it is the study of arithmetical models of conflict and cooperation between intelligent balanced decision makers. Game theory is the process of modeling the strategic interaction between two or more players in a circumstancecontaining set rules and outcomes[3-5]. *Reka et al.*presented a demand rejoinder framework for household consumers in smart grid environment using game theory based energy scheduling optimization technique. In this article, demand response structure method is proposed for household consumers using game theory algorithm as Generalized Tit for Tat (GTFT) Dominant Game based Energy Scheduler[6]. *Saad et al.* described game theoretic method for smart grid. This paper is an overview on the probable of applying game theory for address pertinent and timely open problems in three emerging areas that pertain to the smart grid, micro-grid systems, demand-side management and communications[7]. *Ahat et al.* described optimization of smart grid by game theoretic technique. In this paper, we propose a complex system based approach to the smart grid modeling, accentuating on the optimization by combining game theoretical and classical methods in different levels[8]. *Hong et al.* presented game-theory-based move toward for energy routing in a smart grid network. In this article present an approach utilizing the game theory for effectual and well-organized energy routing, which is a narrative and demanding process for a smart micro grids network[9]. *Khare et al.* analyzed application of game theory in solar wind hybrid renewable energy system. In this work, a game approach is employed to analyze solar wind hybrid system some methods are studied and compared and such as GAME theory logic, Nash equilibrium,cooperative and non cooperative GAME theory[10]. *Khare et al.*presented hybrid renewable energy system involving solar energy and wind energy system model with the help of very novel concept GAME theory based Cournot's Model of solar-Wind hybrid renewable energy system[11]. *Khare et al.* described optimization of hydrogen based hybrid renewable energy system using HOMER software, big bang big crunch and game theory based gambit software.The results are compared with that of BIG BANG CRUNCH (BBC) algorithm and GAME Theory based concept[12].

GAME THEORY BASED SMART GRID

A game is a competitive activity between two or more persons each of whom makes the decision to defeat others abiding a set of rules and at the end of which each player gets some benefits or suffers a loss. When the game takes lay flanked by two competitors only, it is called a two person game. When it is between ***n*** persons, the game is called an ***n***-person game.

An approach of a player is a rule or a programmer, which tells the player what to do in each person move depending on the situation at hand. Strategies are determined by a player in two ways: once all the moves of one player are known to the other, the players can decide upon the strategies to be adopted by them. Such a situation in which a player has a definite strategy against his opponent is referred to as deterministic situation and the strategies are then referred to as pure strategies. But when the moves are known, but which specific move to be adopted by the opponent cannot be ascertained, then the situation is described as a probabilistic situation.

A game with an entire information in which each player known the game $G= (M, S, U)$ in which the set of player M, the set of strategies S and the set of pay off function U. So based on above definition

we consider in smart grid system, neighborhood area Network (NAN) and home area network (HAN) as two players. Home area network is an integrated system of smart meters, in home display, micro generation, smart appliances, smart sockets, HVAC facilities and plug in hybrid-electric vehicles.

The primary function of the neighborhood area network is to transfer consumption readings from smart meters. The NAN should also facilitate diagnostic messages, firmware upgrades and real time or near real time messages for the power system supports [9 -10].

Figure 1 shows connectivity of player with network.

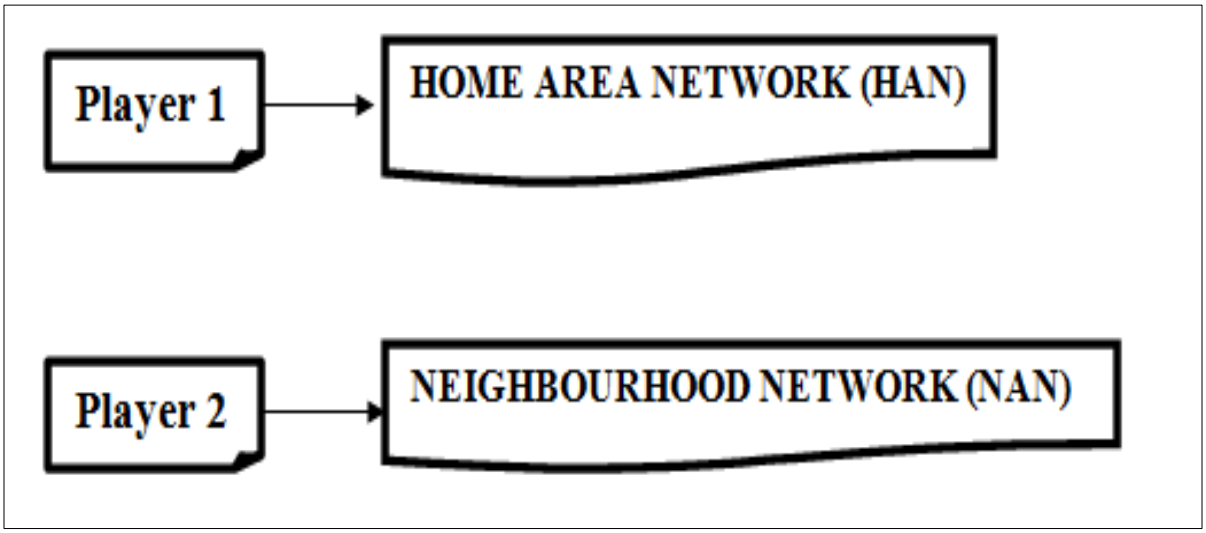

Figure 1:*Connectivity of Player with Network.*

Set the Strategies *S*of Smart Grid Network with Game Theory Concept

1. When the Home area network is sufficient to satisfy the communication infrastructure and protocols. The neighborhoods area networks are inactive even as the wide area network is in also inactive mode.
2. The home area network is not enough to satisfy the communication infrastructure & protocols and then neighborhood area network is set to follow a security request in place of the home area network.
3. The home area and the neighborhood area are providing sufficient amount of security & communication infrastructu -re and the wide area network is set to inactive for that purpose.
4. If power security through smart grid is higher than the power available from energy sources. The wide area network automatically on hybrid controller to provide sufficient amount of power security.

Nash Equilibrium in Smart Grid

In the general majority of games cannot be solved by the iterated ascendancy techniques. Each of the players or security network system has two probable conditions provide secure electricity with communication infrastructure and protocols (1) or unsecure electricity output is zero (O). As the smart grid is shared a simultaneous generation of both players leads to a collision. To solve the game of smart grid introduce the concept of best response , if player HAN accesses the electricity security demand, then the best response of player NAN is to wait. Conversely if player HAN waits then NAN is better off generating electricity.

Table 1:*Pay-off Matrix of HAN-NAN based Network System.*

Neighborhood Area Network	Home Area Network (HAN)		
		Good	Bad
	Good	1,1	1,0
	Bad	0,1	0,0

We consider game strategy in HAN-NAN based network system as shown in Table 1. Security system provide better pay off if HAN and NAN security system is good, then pay off of both players is 1, 1. If HAN provide better security but NAN is unsecure then pay off of both player is 1, 0, conversely it is 0, 1[10].

Payoff Function *U* of Smart Grid with Game Theory

In any game payoff is a figure which represents the motivation of players and it may signify profit, quantity, utility or other incessant measures or may simply rank the attractiveness of outcomes. In order to get the payoff of each player, many factors should be considered, such as the income from power selling, government subsidy, salvage value and ancillary service and the cost for initial invest, process and preservation cost, energy not supplied, etc. It should be mentioned that dissimilar from home area network and neighborhood network, wide area network usually take the task of reducing peak security, and smoothing power generation [13-15].

There are two power security networkhome area network and neighborhood area network producing a security infrastructure within a smart grid based energy system. The cost of development of the security system of electricity is a constant **c**.if a home area network 'i' develop the security level ofestimated frame size q_i, then the cost of home area network is cq_i. If the home area networkdevelop estimated frame size q_1 and neighborhood network produces q_2 for a total of $Q = q_1 + q_2$, the estimated frame size is for some constant a.Figure 2showsstrategies of player 1 and 2.

$P(Q)=a-Q \quad if \quad 0\leq Q\leq a \quad \& \ 0 \ if \ Q> a$(1)

The payoffs for the two players such as HAN and NAN are the profits represented by U_1 and U_2, where payoffs mean "how do players evaluate outcomes of the game". P represents the price of monopoly and duopoly.

$U_1(q_1, q_2)= q_1P(q_1+ q_2) - cq_1 = q1(a-q_1-q_2)^+ - cq_1$(2)

$U_2(q_1, q_2) = q_2P(q_1 + q_2) - cq_2 = q_2(a-q_1-q_2)^+ - cq_2$(3)

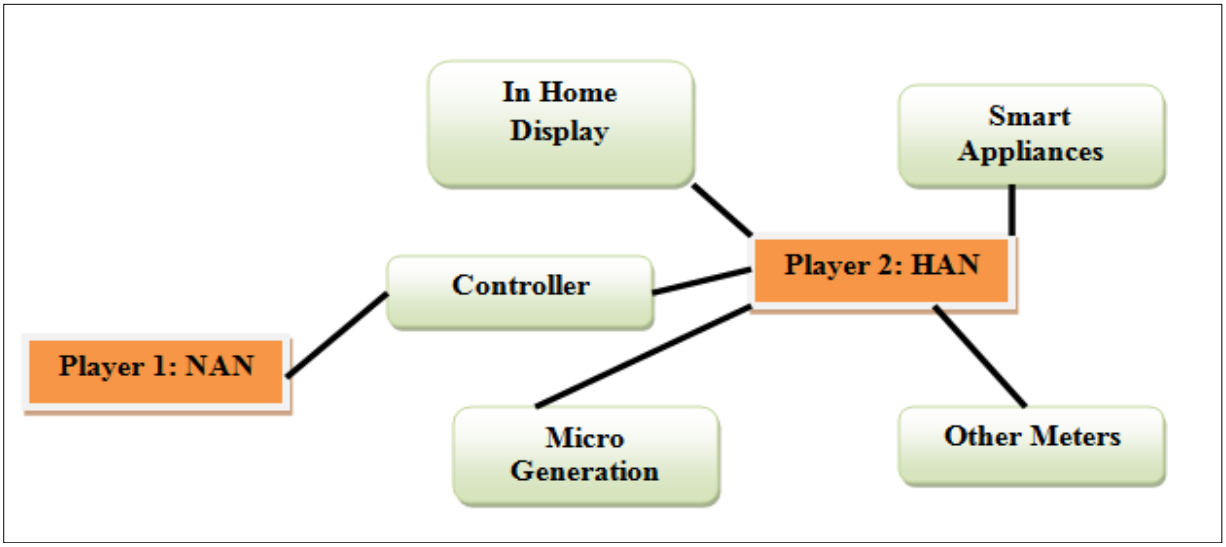

Figure 2: *Strategies of Player HAN and NAN.*

This defines the strategic form of games. We assume that c<a, since otherwise the cost of security network would be at least as great as any possible return. In monopoly case we consider only one security network. Suppose $q_2 = 0$, Then return to home area network system, if it produces q_1 unit is $U(q_1) = q_1(a - q_1)^+ - cq_1$. The home area network will choose q_1 to maximize this quantity. The maximum will occur for $0<q_1<a$; in this case $U(q_1) = q_1(a-c) - q_1^2$and we find the point at which the maximum occurs for $0<q_1<a$[11, 16, 17]. The resulting equation is;

$U^*(q_1) = a-c-2q_1 = 0$(4)
&$q_1 = (a-c)/2$(5)

The monopoly price is $P((a-c)/2) = (a+c)/2$ *and* the monopoly profit is $U((a-c)/2) = (a-c)^2/4$.But in a duopoly, we consider hybrid network security system, we find simultaneously maximum value of q_1 and q_2 by setting the partial derivatives to zero [12].
$d/dq_1U_1(q_1,q_2)=a - 2q_1 - q_2 - c= 0$ (6)
$d/dq_2U_2(q_1,q_2)=a - q_1 - 2q_2 - c = 0$ (7)

by solving these equation $q_1^* = (a-c)/3$
and $q_2^* = (a-c)/3$
$U_1(q_1^*,q_2^*) = (a-c)^2/9$ (8)

This means that if the security system were allowed to cooperate or worked as a hybrid smart grid security network system with the help of HAN and NAN, they could improve their profit by agreeing to share the production and profits.

On the other hand hybrid system price is $P(q_1^* + q_2^*) = (a+2c)/2$, which is less than the single energy security system (monopoly) $(a+c)/2$ since c<a. Thus the consumer is better off under a duopoly than under a monopoly. It means aif home area network and neighborhood network worked together is better than single energy security network.

Application of Gambit Technique in Smart Grid

GAMBIT is a software implement for game theory and it is a set of tool for doing computation on finite and infinite games. The Gambit venture was established in the mid 1980s by Richard Mckelvey at the California foundation of innovation. This innovative execution was written in BASIC with a simple graphical interface.

Interactive cross platform graphical interface, command line tools for computing equilibria and extensibility & interoperability is the main feature of gambit software. The gambit tool read and writescase formats which are textual and recognized, making them manageable across systems and able to interrelate with external tools.

The Gambit software is a structure for the explanation and execution of strategic interaction among two or more than two players. The objective of the gambit infrastructure is to provide a highly configurable, highly scalable framework for the system in terms of core domain concepts and system feature mapped to examination design elements[12, 18, 19, 20].

In gambit software simulink model considers 1 chance and 2 players are used. In this analysis chance is considered as a smart grid security system. Home area network (HAN), Neighbourhood area is represented by player1, player 2 respectively.Smart meter is an important strategic decision based criteria for efficient working of communication infrastructure of smart grid. Electricity meters are used to measure the quantity of electricity supplied to customers aswell as to calculate energy and transportation charges for electricity retailers and networkoperators. Smart meters are even more sophisticated as they have two-way communicationsand provide a real-time display of energy use and pricing

information, dynamic tariffs andfacilitate the automatic control of electrical appliances.Figure 3 shows strategies of smart meter. In gambit technique HAN and NAN provide strategies according to three payoff condition which are smart grid, smart meter and their controller and their payoff value is in between 0 to 1. Figure 4 shows structure of gambit software. Figure 5 shows payoff value of smart grid, smart meter and controller based on HAN and NAN. Optimized value shows payoff value equally distributed among both player HAN and NAN and shows we provide better communication infrastructure and protocols when HAN and NAN work together for effective smart grid performance. Figure 6 tabulated value of payoff value of both players.

Assume an initial payoff value of smart grid and number of smart meter. Start from the HAN and move forward towards the NAN and lateral ends while calculating

$$I_i^{(k)} = \left[\frac{S_i}{V_i^{k-1}}\right] (9)$$

Where S_i is power, I_i is current and V_i is voltage of smart grid.

Start from the NAN and lateral ends towards the HAN while calculating

$$V_i^{k+1} = V_j^k + Z_{ij} I_{ij}^k (10)$$

where j is the adjacent downstream NAN to HAN '***i***'and two network are connected by a branch having impedance of Z_{ij}.

Termination criterion through calculating the power mismatches

$$\Delta S_i^k = s_i - V_i^k [I_i^k] \leq \varepsilon (11)$$

$\varepsilon$is given threshold.

Based on above analysis regression analysis is given by

$$F(t) = a + \sum_{i=0}^{N} b_i x_i(t) (12)$$

Where F(t) is the forecast value at time t, $x_i(t)$ is the i[th] influence factor at time t, a &b_i are regression factor and N is the number of influence factor considered.

Based on the Equation 9 to 12 we consider payoff value in Figure 4 and optimized with gambit software.

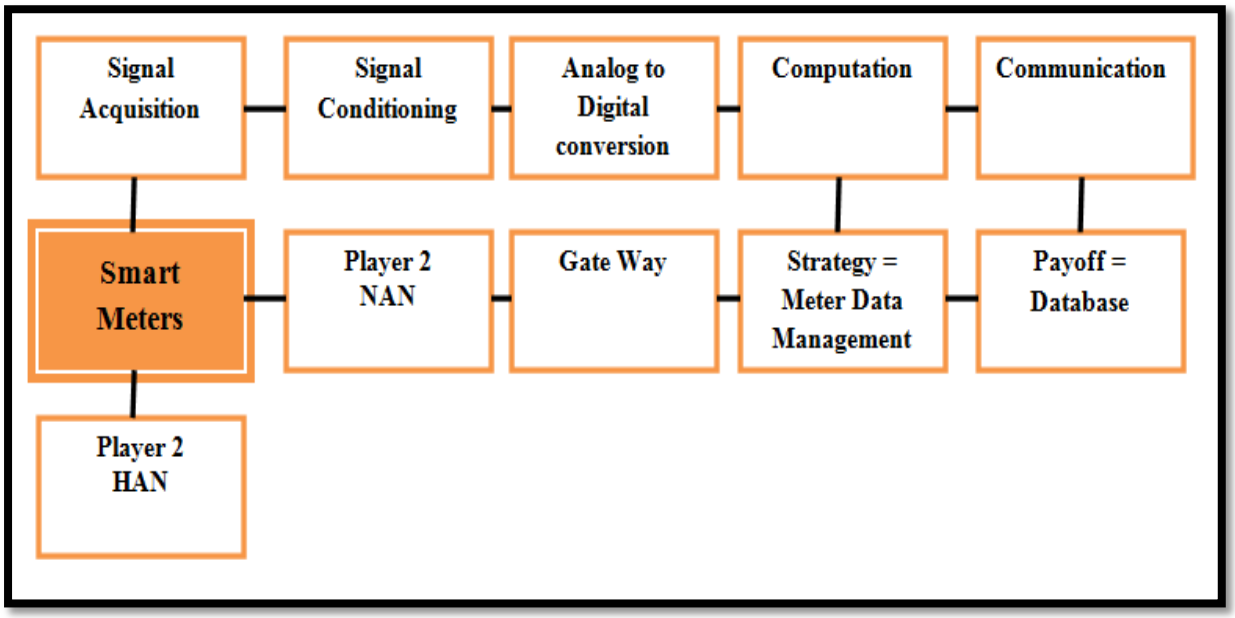

Figure 3:*Strategies of Smart Meter.*

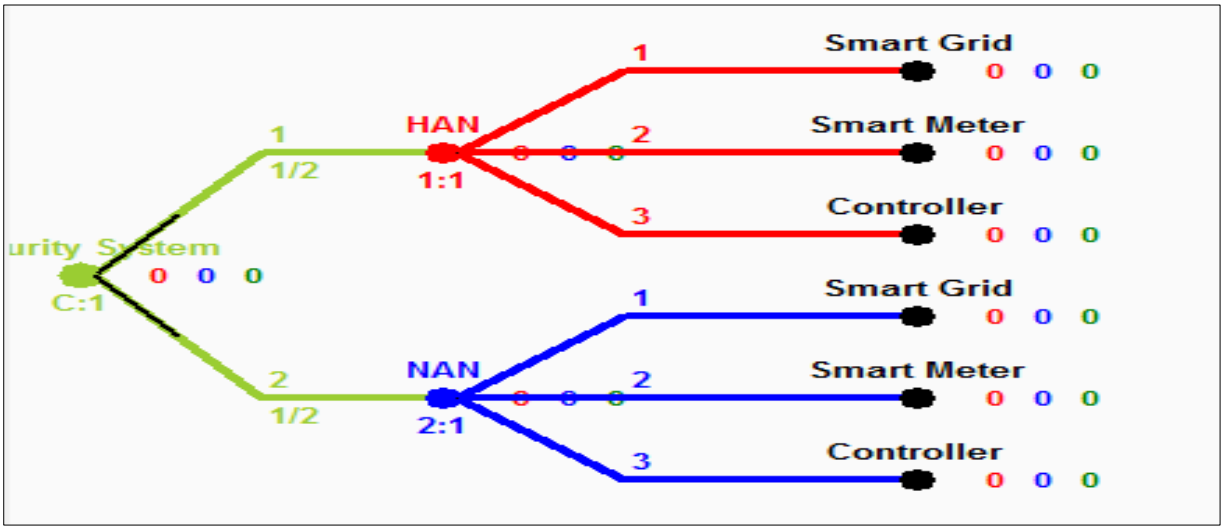

Figure 4: *Structure of Gambit Software.*

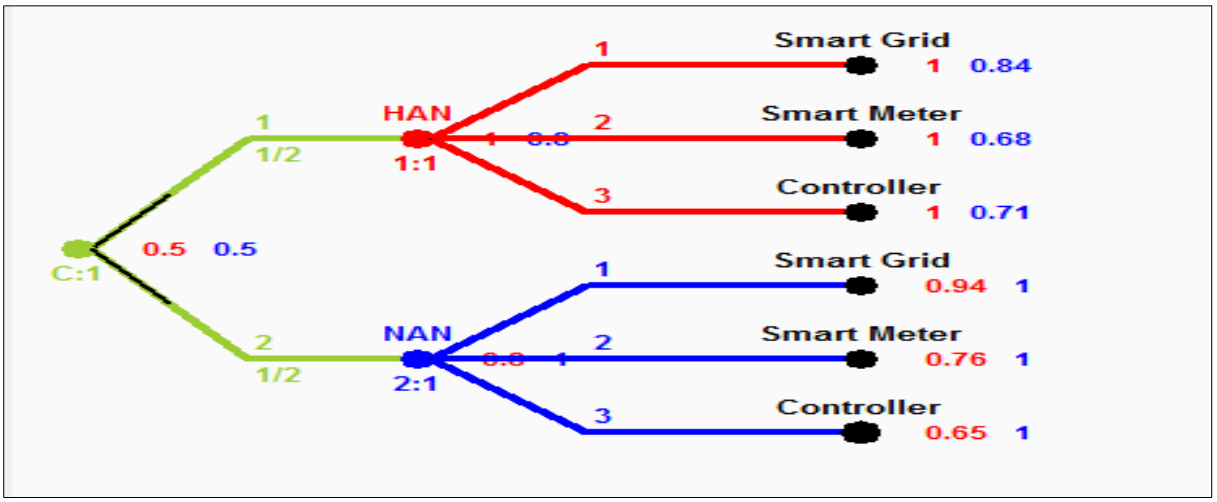

Figure 5: *Payoff Value of HAN and NAN.*

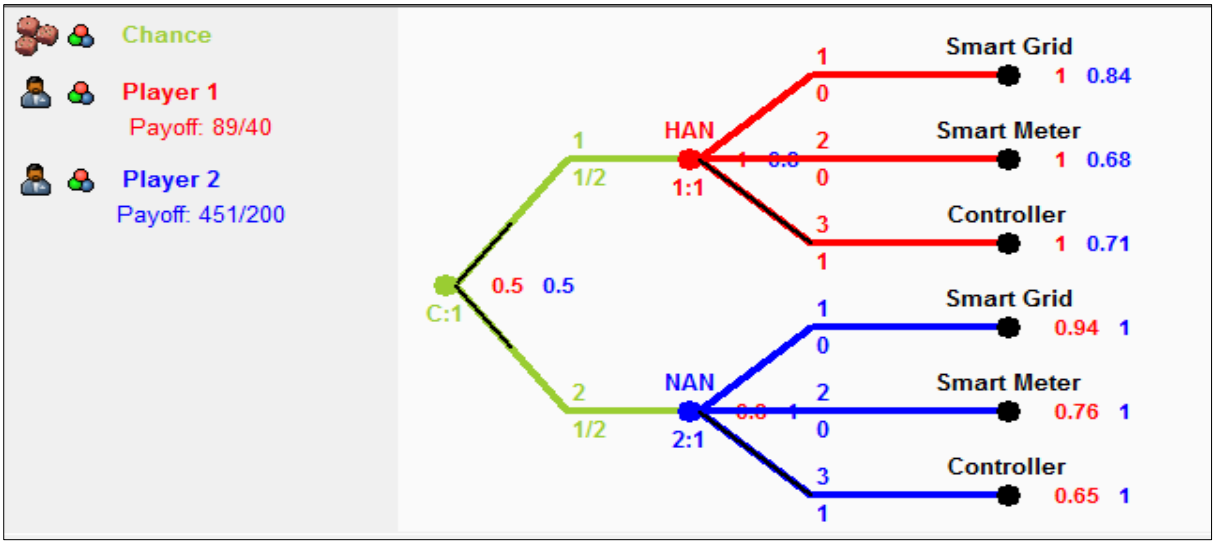

Figure 6: *Optimized value of HAN and NAN.*

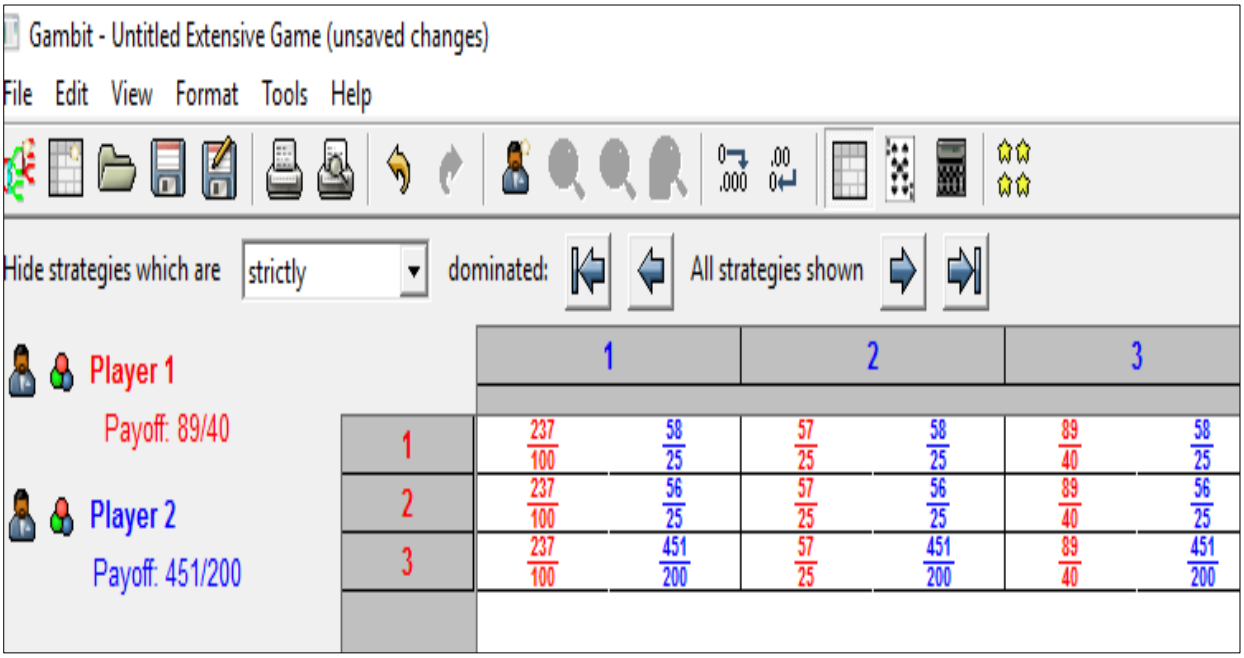

Figure 7: *Tabulated Form of Payoff Value of both Player.*

Figure 7shows payoff value of HAN and NAN w.r.t the optimized value of use the technique of smart grid in place of conventional power system, use of smart meter in place of normal conventional energy meter and essential payoff value of controller technique. Payoff value shows smart grid concept of HAN and NAN network taken highest payoff value compare to utilization of smart grid and different types of controllers. All the payoff value and strategic decision making shows, for efficient communication infrastructure of conventional power system smart grid concept with smart meter and efficient control system is necessary.

Limitaton of Game Theory in Smart Grid System

In zero-sum games situations the all advantage to all players in the amusement, for each mix of systems, dependably adds to zero (a player benefits just at the equivalent cost of others).this condition is notapplicable in smart grid system because in this system available resources can decrease or increase according to the condition and the outcome has net results greater or less than zero.

CONCLUSION

The perfect power system will ensure absolute and universal availability and energy in the quantity and quality necessary to meet every consumer needs. This study developed the application of GAME theory in communication infrastructure and protocols and provides strategic decision to find out the best response from home area network & neighborhood area network system. Duopoly concept provides keen knowledge about strategic knowledge related to the hybrid network security system for efficient operation of smart grid.

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