# The Game Theory Modeling of the Conflict between the Jammer Set, and the ARM Missile with the Search Radar Set and the Missile Equipped with HOJ to Find the Best Response of the Parties

Houman Akbarzade KhoshkeRood[1*], Seyed Mohammad Alavi[2], Yaser Norouzi [3]
1- Faculty of Electronic Warfare Engineering, Imam Hussein University, Tehran, Iran.
Email: houman.akbarzade@ihu.ac.ir (Corresponding author)
2- Imam Hussein University, Tehran, Iran.
Email: malavi@ihu.ac.ir
3- Department of Electrical Engineering, AmirKabir University (Polytechnique), Tehran, Iran.
Email: y.norouzi@aut.ac.ir

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**ABSTRACT:**
None of these methods of electronic warfare can be the absolute winner of the battlefield, and the person who uses them can't consider himself the undisputed winner of this war because it can be said that there is a method of confrontation for almost every technique. Using a technique to attack the enemy electronically can be very effective, but when the enemy can deal with it in an effective way, the same method can become a weakness. Therefore, knowing the correct time to use electronic warfare techniques due to sufficient knowledge of the opponent can play a significant role in superiority. Game theory is one of the best tools for making strategic battlefield decisions that can be used to examine the decision-making process between two or more decision makers and analyze the results. In this paper, the selection of the best response in different stages of the conflict to solve different problems is obtained. The main purpose of this article is to present a new approach to adopting a strategy on the battlefield. The choice of radar technique, destructive response in case of incomplete information and the use of mathematical and algorithmic methods for better performance of the parties are other goals of this article.

**KEYWORDS:** Radar, Game Theory, Electronic Warfare.

## 1. INTRODUCTION

The issue under consideration is the battle scene between two players in the field of electronic warfare. One of the basic assumptions used in this modeling is that all the tools discussed in the problem have the ability to perform a variety of known techniques and used in electronic warfare, and therefore there are no restrictions on them. The problem is that the first player turns on his radar with the aim of collecting information from the area (the meaning of the radar is search and track type) and by sending the appropriate power, he covers the desired area. The second player, as the enemy of the first player, tries to disrupt the work of the radar and prevent information from reaching it as much as possible, and for this purpose, he uses ECM methods, whether soft or hard. The tool is a soft jamming disorder (here we mean noise jamming and not jamming deceit) which, by sending noise power in accordance with the radar spectrum, ultimately reduces the radar range and limits its detection range. If necessary, anti-radiation missiles are used for hard destruction, which targets the radar transmitter. The first player can also take ECCM protection measures to protect themselves, which is an effective tool for radar, the use of anti-glare missiles. The scene of the clash between the two players is as follows.

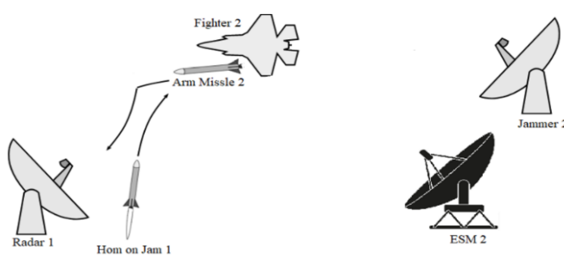


**Fig. 1.** Scene of conflict between players and agents modeled



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in the game.

The issues raised were all influential and important factors in the issue. In the following, we will deal with more details and model this issue in the form of game theory.

## 2. TEAM COMBAT ORGANIZATION

The game consists of two teams, the radar with the ARM missile as the first player, the gem and its support system with the ARM missile and the infiltrating bird as the second player. In the first step, the hypotheses that have been considered in the problem are mentioned:

- The listening system that supports the jammer is able to detect and detect the parameters of the radar signal (for almost every power transmitted by the radar).
- Radar means a search and track radar that has a signal transmitter and a receiver. For convenience, the transmitter and receiver are assumed to be in the same place (mono static radar).
- The radar threshold surface is assumed to be placed in a radial direction automatically, just above the noise level or disturbance of the surrounding cell environment (CFAR system).
- Antennas of all systems, including transmitter and receiver in radar and listening, are directional antennas that can rotate (mechanical or electronic) at different angles. (It may cover the whole 360 degrees or part of it, but it does not affect the whole problem).

## 3. RADAR EQUATION

As mentioned, the purpose of the radar is to obtain information from the area. The more power it sends, the wider it will be able to detect and obtain more information. The area covered by the radar depends on the transmit power of the transmitter and the jamming power of the receiver. The relation known as the radar equation determines the relation of these factors:

$$SNR_{RT} = \frac{P_R \sigma c^2 [G_R(\theta_T - \theta)]^2}{(4\pi)^3 kTBF_n f^2 r^4} \quad (1)$$

Since scanning the radar antenna changes the power received from the target, and the radar processing calculates the target angle at the maximum return when the target is in the antenna axis or $\theta = \theta_T$, so usually in the radar equation instead of the phrase $[G_R(\theta_T - \theta)]$ Only the phrase ${G_R}^2$ is used, which means the antenna gain in the direction of its axis or its maximum gain.

The maximum radar range $r_{max}$ is in the condition that the power received from the target is equal to the level of the radar detection threshold, which is usually a few decibels higher than the system noise floor. This value is more than the threshold $SNR_{req}$ or the signal to the required noise. It is also certain that we will have the most range in the direction of the main axis of the antenna, which has the most gain. Given the above relationship, the maximum range is as follows:

$$[r_{max}(P_R)]^4 = \frac{\sigma c^2 {G_R}^2}{(4\pi)^3 kTBF_n f^2 SNR_{req}} P_R \quad (2)$$

By rotating the antenna and covering the surrounding 360 degrees, the area covered by the radar is as follows:

$$S_{cover} = \pi {r_{max}}^2 = \frac{c}{f}\sqrt{\frac{\sigma {G_R}^2}{4^3 \pi kTBF_n SNR_{req}} P_R} \quad (3)$$

The jamming power received by the $P_{RJ}$ radar can be calculated using the power relationship in the link of a point-to-point path:

$$P_{RJ} = \frac{P_J c^2 G_R(\theta_J - \theta) G_J(\theta_R)}{(4\pi)^2 f^2 {R_{JR}}^2} \quad (4)$$

If the power applied to the radar receiver by the jammer is higher than the internal noise of the radar ($P_{RJ} > P_{thr}$), the minimum noise and therefore the radar detection threshold is determined by the jammer, in other words, the radar range depends on the jammer. Otherwise, the jammer will have no effect on the radar range. In other words, the radar range depends on the power received by the radar from the jammer, and in addition to the transmitted power and frequency of the jammer, it depends on the angles of the radar antenna and the jammer and their relative position. Assuming full compliance of the frequency and bandwidth of the jammer with the radar and adjusting the angle of the jammer antenna on the radar and scanning 360 degrees of the radar, we know that at the angle of the scan where the radar antenna is in front of the jammer, we receive a lot of jammer power. The rest of the angles receive less power from the jammer and the threshold level and the maximum radar range are determined accordingly, so that the maximum radar range in the presence of the jammer is not the same at all angles and is obtained.

$$r_{max}(\theta.\theta_J.P_J.P_R.R_{JR}) = \begin{cases} \sqrt[4]{\frac{\sigma c^2 {G_R}^2}{(4\pi)^3 kTBF_n f^2 SNR_{req}} P_R} & P_J < \eta(R_{JR}.\theta_J.\theta) \\ \sqrt[4]{\frac{\sigma {G_R}^2 {R_{JR}}^2}{4\pi G_R(\theta_J - \theta) G_J(\theta_R) F_n SNR_{req}} \frac{P_R}{P_J}} & P_J \geq \eta(R_{JR}.\theta_J.\theta) \end{cases}$$

$$\eta(R_{JR}.\theta_J.\theta) = \frac{(4\pi)^2 f^2 {R_{JR}}^2 kTB}{c^2 G_R(\theta_J - \theta) G_J(\theta_R)} \quad (5)$$

## 4. RADAR RANGE

Suppose the radar antenna gain is angled as shown below (assuming the jammer is at a 30 degree angle and the antenna gain is drawn with the antenna facing the jammer, otherwise the antenna gain is only an angular shift becomes different).

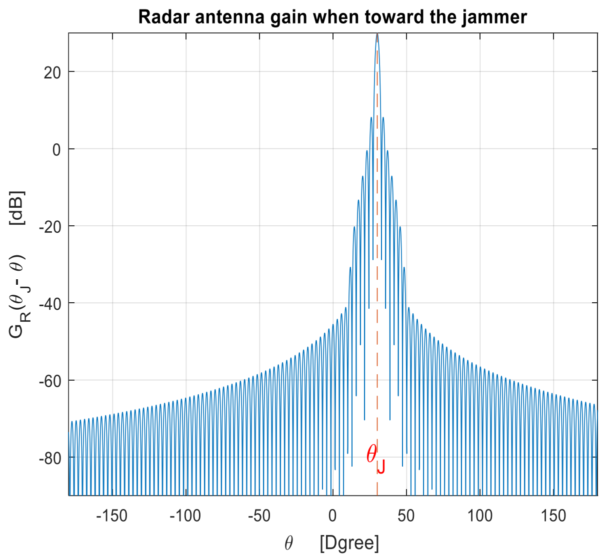


**Fig. 2.** Radar antenna gain in terms of angle.

In this case, the radar range in different angles will be polar and Cartesian as follows.

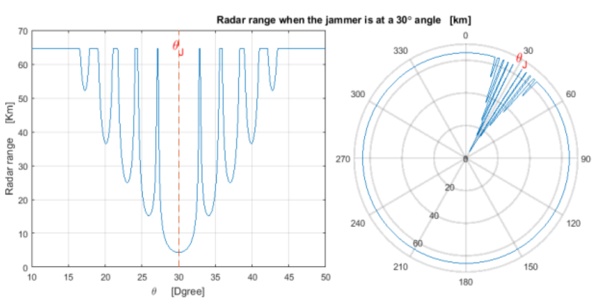


**Fig .3.** Radar range at different angles, both polar and Cartesian.

## 5. UTILLITY COEFFICIENT

As a reasonable assumption, it can be assumed that the information value of the area is not the same in different places, so it can be assumed that the radar utility of coverage in each direction increases in proportion to its depth of view in meters (proportionality coefficient). We consider $\alpha_R$.) Also, the utility that is obtained in exchange for covering the environment in the most probable direction of the attacker (player 2) entering the radar (the first player) is higher than the coverage of the environment in other directions. Therefore, the proportion $\alpha_R$ can be considered a function of $\theta$ (which we denote by $\alpha_R(\theta)$, and when the target enters from a more probable direction, around $\theta = \theta_T$ This coefficient is higher, which indicates the importance of the direction of entry of the attacker). And it is also the cost that is imposed on the jammer (the second player) whose ratio is proportional to the depth of view of the radar in each direction with $\alpha_J(\theta)$. These coefficients of importance should, of course, be determined by the officers and commanders of operational planning, taking into account the potential danger in each direction and the strategic areas and facilities of the region. Here we assume the above coefficients are as follows.

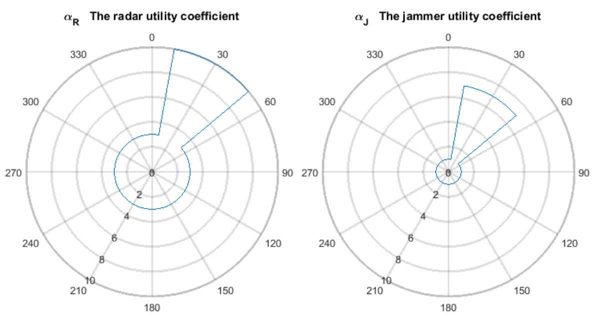


**Fig. 4.** Radar utility coefficient and jammer utility coefficient.

On the other hand, if a rival ARM missile is present in the area and decides to receive the transmitter (radar or jammer), it will be able to locate and destroy the transmitter. If the transmitter is lost, the cost of losing this utility will be imposed on the player. If we call the probability of the transmitter being destroyed by the ARM $P_{Eliminate}$ , $P_{Eliminate}$ the probability of the presence of an anti-radiation missile $P_{Exit}$ in the danger zone around the transmitter, the probability of firing $P_{Fire}$ and the probability of the missile hitting the transmitter $P_{Hit}$ . If the signal reaching the missile receiver is detectable beyond a certain limit, which is called the minimum detectable signal or the sensitivity of the missile receiver $S_M$, the strength of the signal received by the missile $P_M$ is obtained as follows:

$$P_M = \frac{P_J G_J(\theta_M - \Theta) G_M c^2}{(4\pi)^2 f^2 {R_{MJ}}^2} \quad or \quad \frac{P_R G_R G_M c^2}{(4\pi)^2 f^2 {R_{MR}}^2} \tag{6}$$

The first relation is for the jammer and the second relation is for the radar. Note that in the case of jammer, we assume that the direction of the antenna $\theta$ is fixed towards the radar, but in the case of radar, the antenna $\theta$ is rotating and scanning, and each time the missile is scanned, it receives the maximum power for a while and takes it into account in its calculations. So in the case of radar, we have used $G_R(\theta_M - \Theta)$ instead of $G_R$. In this calculation, it is assumed that the direction of the transmitter before firing is calculated by the support systems and the missile launcher is located in that direction (or in air missiles at the beginning of the route after firing, the missile adjusts its direction to the transmitter), so Gain The missile antenna in the direction of the transmitter is the maximum value of the gain profile. If it is $P_M \geq S_M$, the missile will be able to detect and fire. In other words, if the missile is in the $S_{Detect}$ area around the transmitter, it will be able to detect the transmitter signal.

$$S_{Detect-J} = \frac{\theta_{J-A}}{2} {R_{MJ}}^2 = \frac{P_J G_J(\theta_M - \Theta) G_M \theta_{J-A} c^2}{2(4\pi)^2 f^2 S_M} \quad (7)$$

$$S_{Detect-R} = \pi {R_{MR}}^2 = \frac{P_R G_R G_M \, c^2}{4^2 \pi f^2 S_M} \quad (8)$$

$\theta_{J-A}$ The width of the antenna side of the jammer. Since we assume that the radar antenna is rotating and the missile can observe it from all angles around the radar, the area $S_{Detect-R}$ for the radar is a circle around the radar .But for the jammer, since we assumed that its antenna is fixed and does not rotate, the area $S_{Detect-J}$ is a segment of the circle equal to the angle of the jammer antenna.

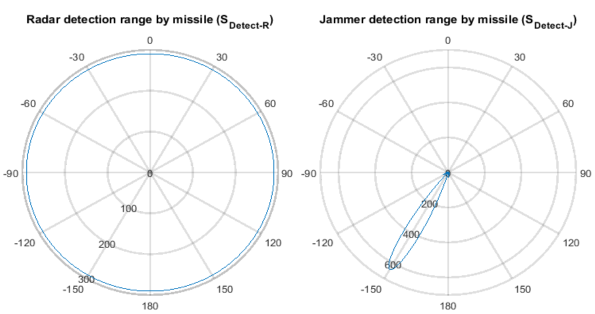


**Fig. 5.** Radar detection range by missile and Jammer detection range by missile.

Also, if the range of the missile is $R_M$, the area around the transmitter, which is at a distance from the range of the missile $S_{RM} = \pi {R_M}^2$, and the areas with direct visibility with the transmitter are at ground level (for ground-based missiles) and at the flight level of the platform. (For surface-to-air missiles) $S_{LOS}$ It is important that this area is fully relevant to the geography and GIS of the area of operation. The subscription of this area is for the transmitter $S_{Risk}$.

$$S_{Risk-R|J} = S_{Detect-R|J} \cap S_{RM} \cap S_{LOS} \quad (9)$$

Assuming areas where ARM missiles are likely to be present, all dark areas have LOS $S_{Risk-R|J}$.

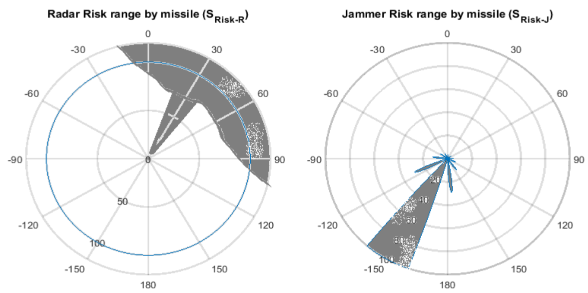


**Fig.6.** Radar Risk range by missile and Jammer Risk range by missile.

The probability of an enemy ARM missile in the area $S_{Risk-R|J}$ around the transmitter (radar or jammer) Firstly, it depends on the probability of equipping the enemy with ARM missiles (in the case of air-based missiles, equipping the infiltrating bird with this missile) and secondly, on the density distribution of the geographical probability of ARM missiles, $p(x.y)$ in relation to ground-based missiles. This probability distribution depends on several factors, including natural complications. Given this probability distribution and the area $S_{Risk}$around the transmitter, the probability of having an ARM missile in the area $S_{Risk}$ around the transmitter is thus obtained.

$$P_{Exit} = \int_{S_{Risk}} p(x.y) ds \quad (10)$$

By obtaining the probability of existence and setting the probability of the missile firing to a constant value $P_{Fire} = p_F$, the probability of the missile hitting also depends on several factors such as the accuracy of the missile and the deception and counter-missile techniques used, such as using the transmitter dock or shutting down the transmitter It depends on the rocket and so on. If no technique is used against the ARM missile, the probability of it hitting is called a fixed value $p_{hit}$. If the T-technique is used against the ARM missile attack to deceive and mislead it, and the probability of success of that technique is $P_{suc}(T$ (in the case that the ARM missile is not used, we consider it a T=1 condition and $P_{suc}(T = 1) = 0$. This is how the missile will hit.

$$P_{Hit} = p_{hit}(1 - P_{suc}(T) \quad (11)$$

Therefore, the probability of destroying the transmitter by ARM missile will be like this.

$$P_{Eliminate}\left(P_{R|J}.\overbrace{\Theta.\theta_M}^{for\ jamer}.R_{M(R|J)}.S_{LOS}.T\right) = P_{Hit} \times P_{Fire} \times P_{Exit} \quad (12)$$

If we define the coefficient β as the conversion factor of the probability of destruction risk to the cost imposed on it ninety, the cost functions of each party will be as follows.

$$u_R = \int_{2\pi} \alpha_R(\theta) r_{max}\big(\theta.\theta_J.P_J.P_R.R_{JR}\big)\, d\theta - \beta_R P_{Eliminate}(P_R.R_{MR}.S_{LOS}.T) \quad (13)$$

$$u_J = -\int_{2\pi} \alpha_J(\theta) r_{max}\big(\theta.\theta_J.P_J.P_R.R_{JR}\big)\, d\theta - \beta_J P_{Eliminate}\big(P_J.\Theta.\theta_M.R_{MJ}.S_{LOS}.T\big) \quad (14)$$

## 6. SIMPLIFICATION FOR PARAMETRIC SOLVING

To solve the parametric, we have to do a lot of simplifications. Here, in order to better understand how it works and recommend the game output, we solve it parametrically.

We assume that no technique is used to counter the ARM missile, so we consider the case T = 1 and know $P_{suc}(T=1)=0$, so:

$$P_{Eliminate} = p_{hit} p_F P_{Exit} \quad (15)$$

We also assume that the geographical distribution of the probability of having a ground-based ARM missile is uniform for the first player, so:

$$P_{Exit} = \int_{S_{Risk}} p(x.y)\,dxdy \;\propto\; S_{Risk} \Rightarrow \quad P_{Exit} = p_e S_{Risk} \quad (16)$$

We also assume that the range of the missile is equal to or greater than the detection range, and due to the smooth geographical area, the area with direct view around the transmitters is much wider than the detection range. so:

$$S_{Risk} = S_{Detect-R|J} \cap S_{RM} \cap S_{LOS} = S_{Detect-R|J}$$
$$S_{Risk-J} = \frac{P_J G_J(\theta_M - \Theta) G_M \theta_{J-A}}{2(4\pi)^2 f^2 {S_M}^2}$$
$$S_{Risk-R} = \frac{P_R G_R G_M}{4^2 \pi f^2 {S_M}^2} \quad (17)$$

So:

$$P_{Eliminate-J} = \frac{\overbrace{p_{hit} p_F p_e G_J(\theta_M - \Theta) G_M \theta_{J-A}}^{\gamma_J}}{2(4\pi)^2 f^2 {S_M}^2} P_J = \gamma_J P_J$$

$$P_{Eliminate-R} = \frac{\overbrace{p_{hit} p_F p_e G_R G_M}^{\gamma_R}}{4^2 \pi f^2 {S_M}^2} P_T = \gamma_R P_R \quad (18)$$

Thus:

$$u_R\big(P_R.P_J\big) = \kappa_{R1} \sqrt[4]{\frac{P_R}{P_J}} + \kappa_{R2} \sqrt[4]{P_R} - \beta_R \gamma_R P_R$$
$$u_J\big(P_R.P_J\big) = -\kappa_{J1} \sqrt[4]{\frac{P_R}{P_J}} - \kappa_{J2} \sqrt[4]{P_R} - \beta_J \gamma_J P_J$$
$$\gamma_R = \frac{p_{hit} p_F p_e G_R G_M}{16\pi f^2 {S_M}^2} . \gamma_J(\Theta) = \frac{p_{hit} p_F p_e G_J(\theta_M - \Theta) G_M \theta_{J-A}}{2(4\pi)^2 f^2 {S_M}^2}$$
$$PJF\big(P_J.R_{JR}.\theta_J.\theta\big) = \begin{cases} 1 & P_J \geq \eta\big(R_{JR}.\theta_J.\theta\big) \\ 0 & P_J < \eta\big(R_{JR}.\theta_J.\theta\big) \end{cases}$$
$$\kappa_{R|J1}\big(P_J.R_{JR}.\theta_J\big) = \sqrt[4]{\frac{\sigma {G_R}^2 {R_{JR}}^2}{4\pi G_J(\theta_R) F_n SNR_{req}}} \int_{2\pi} PJF\big(P_J.R_{JR}.\theta_J.\theta\big) \frac{\alpha_{R|J}(\theta)}{\sqrt[4]{G_R\big(\theta_J - \theta\big)}} d\theta$$
$$\kappa_{R|J2}\big(P_J.R_{JR}.\theta_J\big) = \sqrt[4]{\frac{\sigma c^2 {G_R}^2}{(4\pi)^3 kTBF_n f^2 SNR_{req}}} \int_{2\pi} \big[1 - PJF\big(P_J.R_{JR}.\theta_J.\theta\big)\big] \alpha_{R|J}(\theta)\, d\theta$$
$$\eta\big(R_{JR}.\theta_J.\theta\big) = \frac{(4\pi)^2 f^2 {R_{JR}}^2 kTB}{c^2 G_R\big(\theta_J - \theta\big) G_J} \quad (19)$$

## 7. SOLVE THE GAME

Based on the assumption of rationality about players, each player makes a decision that has more utility for him, that is, to maximize the value of the utility function. When a player is aware of a competitor's decision, he performs an action based on the utility function, which is called the player's best response to the opponent's action. In the present problem, the best answer of the players can be obtained by deriving the utility function of each player towards his own action:

$$\frac{\partial u_R}{\partial P_R} = 0 \;\Rightarrow\; BP_{P_R}\big(P_J\big) = \left[\frac{\kappa_{R1} + \kappa_{R2} {P_J}^{1/4}}{4\beta_R \gamma_R {P_J}^{1/4}}\right]^{4/3}$$
$$\frac{\partial u_J}{\partial P_J} = 0 \;\Rightarrow\; BP_{P_J}(P_R) = \left[\frac{\kappa_{J1} {P_R}^{1/4}}{4\beta_J \gamma_J}\right]^{4/5}$$

$${P_R}^* = \left[\frac{\kappa_{R1} + \kappa_{R2} {P_J}^{*1/4}}{4\beta_R \gamma_R {P_J}^{*1/4}}\right]^{4/3} \qquad {P_J}^* = \left[\frac{\kappa_{J1} {P_R}^{*1/4}}{4\beta_J \gamma_J}\right]^{4/5} \quad (20)$$

Also, by finding the maximum point $P_J$ relative to $u_R$ and also the maximum point $P_R$ relative to $u_J$ numerically and their intersection point, the Nash equilibrium of this game is obtained.

From what has been said so far, it follows that no more than three PRFs will ever be needed: one to measure the range, one to clear up ambiguities, and a third to dispel the ghosts of goals that have been revealed at the same time. But it must be said that this is not the case.
Depending on how long the detection boards are and how large and spaced the PRFs are, more than one PRF (apart from the first PRF) may be needed to resolve the ambiguity.

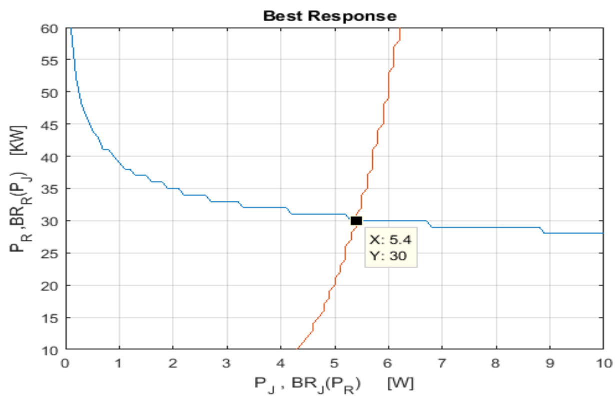


**Fig.7.** Best Response.

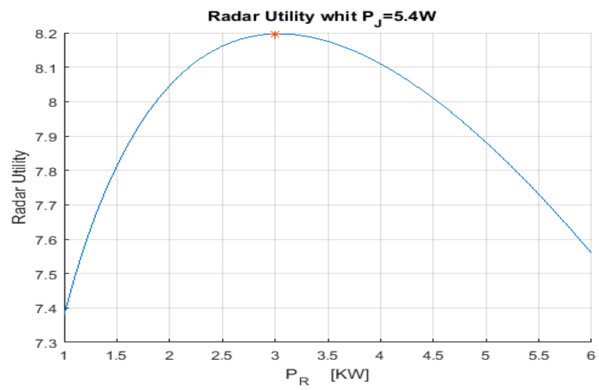


**Fig.8.** Radar utility with $P_R$ = 5.4w.

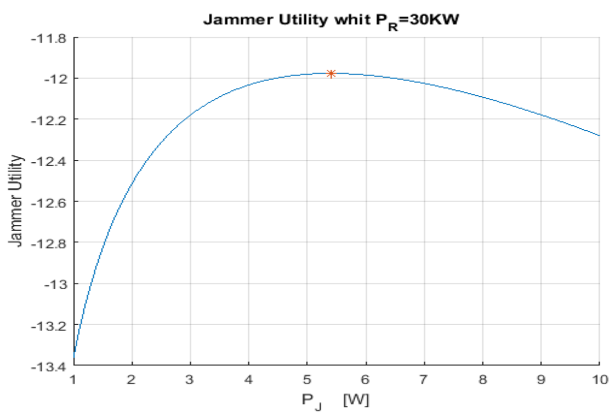


**Fig.9.** Jammer utility with $P_R$ = 30KW.

## 8. CONCLUSION

Given that the choice of strategy in electronic conflicts in the field of action and the best choice will not be possible, so the importance of a reasonable and measurable decision and calculation in choosing a strategy in real life is quite clear. Given that one of the most useful tools in the field of strategic decision analysis is game theory. With the help of this mathematical tool, the decision-making process between two or more decision-makers can be modeled and the results can be analyzed. It is also possible to observe the effect of various parameters involved in the result of the problem, and to plan the result in the desired direction. In this article, while solving the mentioned problem, how to model the battle scene and choose the best answer in different stages of the conflict to solve various such problems was obtained. Finally, this research and similar research can pave the way for providing a comprehensive algorithm for modeling and obtaining the best responses in various electronic conflict situations.

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