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Fuzzy Majority Domination Number of Fuzzy Trees and Fuzzy Complements

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Abstract: *The concept of majority domination plays an important role in everyday life. Fundamental concepts and theoretical results related to majority dominating sets have been studied in fuzzy graphs. This research paper extends these ideas by finding fuzzy Majority Domination Number for fuzzy trees and complement of fuzzy graphs.*

Key Word: *Fuzzy Tree; Complement; Fuzzy Majority Domination Number; Effective Edges; Total Effective Neighborhood Degree.*

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I. Introduction

Graph theory is used to model a wide range of problems. In graph theory it is assumed that the vertices, edges, weights etc., are certain. But the real world is full of uncertainties. To address such situations, A. Rosenfeld introduced the "fuzzy graph" in 1975 [2]. Like set theory, the background of fuzzy graph theory is the fuzzy set theory developed by L. A. Zadeh in 1965. The game of chess, a globally renowned strategy board game, inspired the concept of domination in graph theory, which emerged around 1850 [1]. In 1962, Ore introduced the idea of domination in graph theory [3]. In 1977, Cockayne and Hedetniemi, further discussed and expanded the concept of theory of domination in graphs [4]. Harary et al, explored a novel application in voting situations making use of the idea of domination in graphs [4]. The study of domination in graphs, has largely centred on vertex domination, which encompasses several types of domination. In 1998, Somasundaram and Somasundaram proposed the idea of domination in fuzzy graphs making use of effective edges [5]. They have presented some properties of domination for crisp graphs which is also true for fuzzy graphs. They also have discussed independent domination, total domination, independent domination number and total domination number of fuzzy graphs [5]. In 2007, Nagoorgani and Chandrasekaran investigated domination applying strong arcs in fuzzy graphs [6].

The idea of the majority domination number of certain families of graphs was presented by Tara S. Holm in 2001 [7]. V. Swaminathan and J. Joseline Manora introduced the concept of majority dominating set in Graphs. They also found the majority domination number and bounds for majority domination numbers [8]. They developed the concept to some extent. The majority domination number in fuzzy graphs have been studied and developed in recent years.

This paper presents an extension of the study on a fuzzy majority domination number in fuzzy trees and complement of fuzzy graphs.

II. Preliminaries

Definition 2.1[1]. A fuzzy graph $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ is a non-empty set $\mathcal{V}$ together with a pair of functions $\sigma : \mathcal{V} \to [0,1]$and $\mu : \mathcal{V} \times \mathcal{V} \to [0,1]$ such that for all $v_i, v_j \in \mathcal{V}$, $\mu(v_i, v_j) \leq \min\{\sigma(v_i), \sigma(v_j)\}$ where $\sigma(v_i)$ and $\mu(v_i, v_j)$ represent the membership values of the vertex v_i and edge (v_i, v_j) in $\mathcal{G}$.

Definition 2.2[1]. An edge (v_i, v_j) of a fuzzy graph $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ is called an effective edge if $\mu(v_i, v_j) = \sigma(v_i) \wedge \sigma(v_j)$. The vertices v_i and v_j are called effective neighbours. The set of all effective neighbours of v_i is called effective neighbourhood of v_i and is denoted by $EN(v_i)$.

Definition 2.3[1]. Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph. The order p and size q of $\mathcal{G}$ are defined by $p = \sum_{v_i \in \mathcal{V}} \sigma(v_i)$ and $q = \sum_{(v_i, v_j) \in \mathcal{V} \times \mathcal{V}} \mu(v_i, v_j)$

Definition 2.4[4]. Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph and $S \subseteq \mathcal{V}$. Then the fuzzy cardinality of S is defined to be $\sum_{v \in S} \sigma(v)$.

Definition 2.5[9]. Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph with order p and size q. A subset $S \subseteq \mathcal{V}(\mathcal{G})$ of vertices in a fuzzy graph $\mathcal{G}$ is called a fuzzy majority dominating set if at least half of the order of vertices of $\mathcal{V}(\mathcal{G})$ are either in the cardinality of vertices of S or the cardinality of vertices of $N[S]$.

$$(i.e)|N[S]| = \sum_{v_i \in N[S]} \sigma(v_i) \geq \frac{p}{2}$$

Definition 2.6[9]. A fuzzy majority dominating (FMD) set S of $\mathcal{G}$ is minimal if no proper subset of S is fuzzy majority dominating set.

Definition 2.7[9]. The minimum fuzzy cardinality of a minimal fuzzy majority dominating set is called a fuzzy majority domination number. It is denoted by $\gamma_M(\mathcal{G})$ (Lower fuzzy majority domination number). The maximum fuzzy cardinality of a minimal fuzzy majority dominating set is called the upper fuzzy majority domination number. It is denoted by $\Gamma_M(\mathcal{G})$.

Definition 2.8[6]. A fuzzy graph $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ is called fuzzy forest if it has a fuzzy spanning subgraph $F = (\mathcal{V}, \sigma, \nu)$ which is a forest, where all arcs (x, y) not in F, $\mu(x, y) < \nu^{\infty}(x, y)$. In other words, if $(x, y) \in \mathcal{G}$ but $\notin F$, there is a path in F between x and y whose strength is greater than $\mu(x, y)$. A connected fuzzy forest is called a fuzzy tree.

Definition 2.9[1]. The complement of a fuzzy graph $\mathcal{G}$ is denoted by $\mathcal{G}^c = (\mathcal{V}, \sigma^c, \mu^c)$ where $\sigma^c(a) = \sigma(a)$ for all $a \in \mathcal{V}$ and $\mu^c(a, b) = [\sigma(a) \wedge \sigma(b)] - \mu(a, b)$ for all $a, b \in \mathcal{V}$.

Theorem 2.10[9]. *Let $\mathcal{G}$ be a fuzzy graph without isolated vertices and $|\mathcal{V}| \geq 4$. Then $\gamma_M(\mathcal{G}) \leq \frac{p}{4}$.*

Corollary 2.11[9]. *Let $\mathcal{G}$ be a fuzzy graph with only isolated vertices. Then $\gamma_M(\mathcal{G}) \geq \frac{1}{2} \sum_{v_i \in V} \sigma(v_i)$.*

Theorem 2.12[9]. *If $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a FG with atleast two effective edges then $\gamma_M(\mathcal{G}) < \frac{p}{2}$.*

Proposition 2.13[9]. *Let $\mathcal{G} = K_\sigma$ be a complete fuzzy graph. Then $\gamma_M(\mathcal{G}) = \min_{v_i \in V} \sigma(v_i)$.*

III. Fuzzy Majority Domination Number of Fuzzy Trees

Theorem3.1. *Let $\mathcal{G} = FDS(r, s), r \leq s$ be a fuzzy double star with bi-centres v_i and v_j having $p_1 = tdeg_{EN}(v_i) - \sigma(v_j)$ and $p_2 = tdeg_{EN}(v_j) - \sigma(v_i)$. Then*

$$\gamma_M(\mathcal{G}) = \begin{cases} \sigma(v_i), if\ p_1\ is\ maximum \\ \sigma(v_j), if\ p_2\ is\ maximum \end{cases}$$

Proof. Let $\mathcal{G}$ be a fuzzy double star with all effective edges and having v_i and v_j as their centres. Let $\{v_{i_1}, v_{i_2}, \dots, v_{i_r}\}$ be the vertices incident on v_i and $\{v_{j_1}, v_{j_2}, \dots, v_{j_s}\}$ be the vertices incident on v_j. Let $O(\mathcal{G}) = p = p_1 + p_2$ where $p = \sum_{v \in \mathcal{V}} \sigma(v)$.

Case 1. Suppose $p_1 > p_2 \Rightarrow p_1 = p_2 + r \Rightarrow p_2 = p_1 - r \Rightarrow p = p_1 + p_1 - r = 2p_1 - r \Rightarrow \frac{p}{2} = p_1 - \frac{r}{2} \Rightarrow p_1 = \frac{p}{2} + \frac{r}{2} \Rightarrow p_1 > \frac{p}{2} \Rightarrow t\ deg_{EN}(v_i) > \frac{p}{2}$. Choose $S_1 = \{v_i\}$ and $|N[S_1]| > \frac{p}{2}$. Hence S_1 forms a fuzzy majority dominating set for $\mathcal{G}$. Thus $\gamma_M(\mathcal{G}) = \sigma(v_i)$, if $p_1 > p_2$.

Case 2. Similarly, if $p_2 > p_1 \Rightarrow p_2 > \frac{p}{2} \Rightarrow t\ deg_{EN}(v_j) > \frac{p}{2}$. Hence $S_2 = \{v_j\}$ and $|N[S_2]| > \frac{p}{2}$. Therefore S_2 forms a fuzzy majority dominating set for $\mathcal{G}$. Thus $\gamma_M(\mathcal{G}) = \sigma(v_j)$, if $p_2 > p_1$.

Case 3. If $p_1 = p_2 \Rightarrow |N[S_1]| = |N[S_2]| = \frac{p}{2}$, then $\gamma_M(\mathcal{G}) = \min\{|S_1|, |S_2|\} = \sigma(v_i) \wedge \sigma(v_j)$.

Hence the theorem.

Theorem 3.2. *Let $\mathcal{T} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy tree. Then $\gamma_M(\mathcal{T}) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$ if and only if there exists a vertex v_i with minimum $\sigma(v_i)$ and $t\ deg_{EN}(v_i) \geq \frac{p}{2}$.*

Proof. Let v_i be a fuzzy pendant of $\mathcal{T}$ with $\sigma(v_i)$ is minimum. If $t\ deg_{EN}(v_i) \geq \frac{p}{2}$ then $S = \{v_i\}$ forms a fuzzy majority dominating set for $\mathcal{T}$. Therefore $\gamma_M(\mathcal{T}) = |S| = \min_{v_i \in \mathcal{V}} \sigma(v_i)$.

Let v_i be an intermediate vertex with $\sigma(v_i)$ is minimum. If $t\ deg_{EN}(v_i) \geq \frac{p}{2}$ then $S = \{v_i\}$ forms a fuzzy majority dominating set for $\mathcal{T}$ and $\gamma_M(\mathcal{T}) = |S| = \min_{v_i \in \mathcal{V}} \sigma(v_i)$.

Conversely, let $\gamma_M(\mathcal{T}) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$. Then $S = \{v_i\}$ is a fuzzy majority dominating set and $|N[S]| \geq \frac{p}{2}$. This implies that $t\ deg_{EN}(v_i) \geq \frac{p}{2}$.

Proposition 3.3. *Let $\mathcal{T} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy tree. Then $\gamma_M(\mathcal{T}) < \frac{p}{2}$.*

Proof. Let us prove the result by using induction on fuzzy pendants. Let e be the total number of pendants in $\mathcal{T}$.

Suppose $e = 1$, then $\mathcal{T} = K_2$ and $\gamma_M(\mathcal{T}) = \sigma(v_1) \wedge \sigma(v_2) < \frac{p}{2}$. Let $e = 2$. Then $\mathcal{T}$ has two fuzzy pendants and one intermediate vertex. Then $|N[v_i]| \geq \frac{p}{2}$ for all $v_i \in \mathcal{V}$. Hence $\gamma_M(\mathcal{T}) = \min_{v_i \in \mathcal{V}} \sigma(v_i) < \frac{p}{2}$ .Suppose $e = 3, 4, \ldots, (n-1)$. Since $\mathcal{T}$ has no fuzzy isolates, by Theorem (2.10), $\gamma_M(\mathcal{T}) \leq \frac{p}{4} < \frac{p}{2}$. Hence $\gamma_M(\mathcal{T}) < \frac{p}{2}$.

Remark 3.4. If $\mathcal{T} = (\mathcal{V}, \sigma, \mu)$ is a fuzzy tree with $|\mathcal{V}| \geq 4$ then $\gamma_M(\mathcal{T}) \leq \frac{p}{4}$.

IV. Fuzzy Majority Domination Number of Complements

The following example shows the relation between $\gamma_M(\mathcal{G})$ and $\gamma_M(\mathcal{G}^c)$.

Example 4.1.

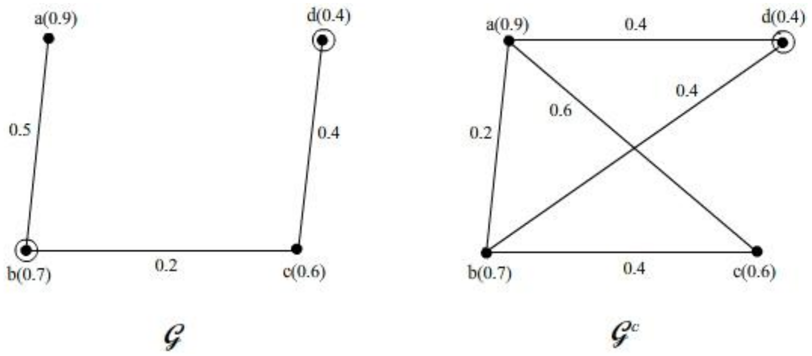

Figure 1. Complement Fuzzy Graph

Consider the fuzzy graph $\mathcal{G}$ with order $p = 2.6 \Longrightarrow \frac{p}{2} = 1.3 \Longrightarrow \frac{p}{4} = 0.65$
$\gamma_M(\mathcal{G}) = 1.1 < \frac{p}{2}$ and $\gamma_M(\mathcal{G}^c) = 0.4 < \frac{p}{4}$. Hence $\gamma_M(\mathcal{G}^c) < \gamma_M(\mathcal{G})$.
Observation 4.2. If $\mathcal{G}$ has more effective edges than $\mathcal{G}^c$ then $\gamma_M(\mathcal{G}) < \gamma_M(\mathcal{G}^c)$ and vice versa.

Proposition 4.3. *No edge can be effective simultaneously in $\mathcal{G}$ and $\mathcal{G}^c$.*

Proof. Let (u, v) be an effective edge in $\mathcal{G}$. Then $\mu(u, v) = \sigma(u) \wedge \sigma(v)$ … … … … … … … (1)
But $\mu^c(u, v) = [\sigma(u) \wedge \sigma(v)] - \mu(u, v) = 0$ [By (1)]. Hence there is no edge between u and v in $\mathcal{G}^c$.

Similarly, let (u, v) be an effective edge in $\mathcal{G}^c$. Then $\mu^c(u, v) = \sigma(u) \wedge \sigma(v)$ … … … … … … … (2)
But $\mu(u, v) = [\sigma(u) \wedge \sigma(v)] - \mu^c(u, v) = 0$ [By (2)]. $(i.e)$ There is no edge between u and v in $\mathcal{G}$. Hence any effective edge in $\mathcal{G}$ cannot be an effective edge in $\mathcal{G}^c$ and vice versa.

Proposition 4.4. *Let $\mathcal{G} = K_\sigma$ be a complete fuzzy graph. Then $\gamma_M(\mathcal{G}^c) \geq \frac{p}{2}$.*

Proof. If $\mathcal{G}$ is a complete fuzzy graph then the complement $\mathcal{G}^c$ has no effective edges. Hence by Corollary (2.11), $\gamma_M(\mathcal{G}^c) \geq \frac{p}{2}$.

Proposition 4.5. *Let $\mathcal{G} = \overline{K_\sigma}$ be a totally disconnected fuzzy graph. Then $\gamma_M(\mathcal{G}^c) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$.*

Proof. The resultant graph $\mathcal{G}^c$ becomes a complete fuzzy graph. Hence by Proposition (2.13), $\gamma_M(\mathcal{G}^c) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$.

Proposition 4.6. *In a complete fuzzy graph $\mathcal{G}$, if S is a minimum fuzzy majority dominating set then $(\mathcal{V} - S)$ is a fuzzy majority dominating set of $\mathcal{G}^c$.*

Proof. Let $\mathcal{G}$ be a complete fuzzy graph with n vertices. Then by Proposition (2.13), $\gamma_M(\mathcal{G}) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$ and $S = \{v_i\}$ is a fuzzy majority dominating set of $\mathcal{G}$. Let $\sigma(v_i)$ be the minimum membership value in $\mathcal{G}$. Thus $p = n\,\sigma(v_i) + r, r > 0$. It implies $\frac{p}{2} = \frac{n}{2}\sigma(v_i) + \frac{r}{2}$ and $(\mathcal{V} - S) = \{v_1, v_2, \dots, v_{i-1}, v_{i+1}, \dots, v_n\}$. Thus $|\mathcal{V} - S| = \sigma(v_1) + \sigma(v_2) + \cdots + \sigma(v_{i-1}) + \sigma(v_{i+1}) + \cdots + \sigma(v_n) = (n-1)\sigma(v_i) + r > \frac{p}{2}$. Therefore $(\mathcal{V} - S)$ is a fuzzy majority dominating set of $\mathcal{G}^c$ as $\mathcal{G}^c$ contains only fuzzy isolates.

Proposition 4.7. *If $t\,deg_{EN}(v_i) \leq \frac{p}{2}$ for any v_i in $\mathcal{G}$ with all effective edges then $t\,deg_{EN}(v_i) \geq \frac{p}{2}$ for corresponding v_i in $\mathcal{G}^c$.*

Proof. By definition of complement fuzzy graph, we know that the set of effective adjacencies in $\mathcal{G}$ is transformed into non-effective adjacencies in $\mathcal{G}^c$ and vice versa. This implies that if $t\,deg_{EN}(v_i) \leq \frac{p}{2}$ for $v_i \in \mathcal{G}$ then $t\,deg_{EN}(v_i) \geq \frac{p}{2}$ for $v_i \in \mathcal{G}^c$.

Remark 4.8. The converse of this result is not true. The following example shows that.

Example 4.9. The following fuzzy graph $\mathcal{G}$ has order $p = 1.1 \Longrightarrow \frac{p}{2} = 0.55$
In $\mathcal{G}$:

i. $t\,deg_{EN}(v_1) = 0.3 < \frac{p}{2}$
ii. $t\,deg_{EN}(v_2) = 1.1 > \frac{p}{2}$
iii. $t\,deg_{EN}(v_3) = 1.0 > \frac{p}{2}$

In $\mathcal{G}^c$:

i. $t\,deg_{EN}(v_1) = 0.9 > \frac{p}{2}$
ii. $t\,deg_{EN}(v_2) = 0.2 < \frac{p}{2}$
iii. $t\,deg_{EN}(v_3) = 0.9 > \frac{p}{2}$

For v_3, $t\,deg_{EN}(v_3) > \frac{p}{2}$ in $\mathcal{G}$ and also $t\,deg_{EN}(v_3) > \frac{p}{2}$ in $\mathcal{G}^c$.

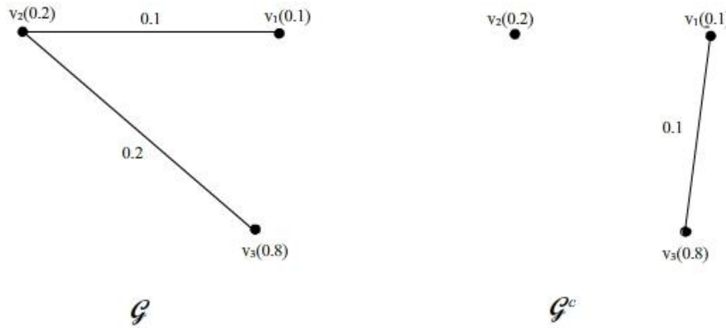

Figure 2. Total Effective Neighborhood Degree of Vertices

Proposition 4.10. *If S is a fuzzy majority dominating set of $\mathcal{G}$ then the same set S need not be a fuzzy majority dominating set of $\mathcal{G}^c$.*

Proof. Let S be a fuzzy majority dominating set of $\mathcal{G}$. Since the complement does not preserve the effective neighborhood degree of a vertex, S is not necessarily a fuzzy majority dominating set of $\mathcal{G}^c$.

The following example proves the previous result.

Example 4.11.

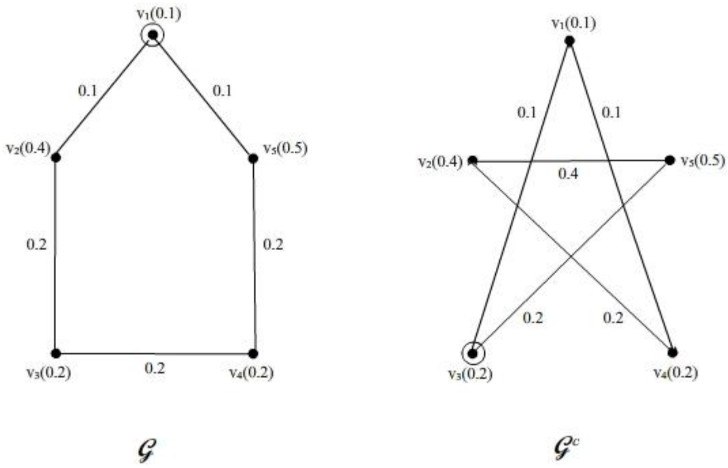

Figure 3. FMD Sets of $\mathcal{G}$ and $\mathcal{G}^c$

Consider the fuzzy graph $\mathcal{G}$ with order $p = 1.4 \Longrightarrow \frac{p}{2} = 0.7$
In $\mathcal{G}$, $S = \{v_1\}$, $|N[S]| = 1.0 > \frac{p}{2}$, thus $\gamma_M(\mathcal{G}) = 0.1$
In $\mathcal{G}^c$, $S = \{v_1\}$, $|N[S]| = 0.5 < \frac{p}{2}$. Hence S is a FMD set of $\mathcal{G}$ but S is not a FMD set of $\mathcal{G}^c$.
Theorem 4.12. *Let $\mathcal{G}$ be a complete fuzzy graph or totally disconnected fuzzy graph. Then $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) > \frac{p}{2}$.*

Proof. If $\mathcal{G}$ is a complete fuzzy graph then $\mathcal{G}^c$ is a totally disconnected fuzzy graph and vice versa.

Case 1. If $\mathcal{G}$ is a complete fuzzy graph then by Proposition (4.4) and (4.5), $\gamma_M(\mathcal{G}) = \min_{v_i \in V} \sigma(v_i)$ and $\gamma_M(\mathcal{G}^c) \geq \frac{p}{2}$
.

Case 2. If $\mathcal{G}$ is a totally disconnected fuzzy graph then by Proposition (4.4) and (4.5),$\gamma_M(\mathcal{G}) \geq \frac{p}{2}$and $\gamma_M(\mathcal{G}^c) = \min_{v_i \in V} \sigma(v_i)$.

In both cases, $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) > \frac{p}{2}$.

Remark 4.13.

1. Let $\mathcal{G}$ be a complete fuzzy graph or totally disconnected fuzzy graph.
   Then $\max\{\gamma_M(\mathcal{G}), \gamma_M(\mathcal{G}^c)\} \geq \frac{p}{2}$.
2. Let $\mathcal{G}$ be a complete fuzzy graph or totally disconnected fuzzy graph.
   Then $\min\{\gamma_M(\mathcal{G}), \gamma_M(\mathcal{G}^c)\} = \min_{v_i \in \mathcal{V}} \sigma(v_i)$.

Theorem 4.14. *Let $\mathcal{G} \neq K_\sigma$ be a fuzzy graph without isolated vertices. Then $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) \leq \frac{p}{2}$.*

Proof. Since $\mathcal{G}$ has all effective edges, $\mathcal{G}^c$ also contains only effective edges.Then by Theorem (2.10), $\gamma_M(\mathcal{G}) \leq \frac{p}{4}$ and $\gamma_M(\mathcal{G}^c) \leq \frac{p}{4}$. Combining these two equations, $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) \leq \frac{p}{4} + \frac{p}{4}$. Hence $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) \leq \frac{p}{2}$.

Theorem 4.15. *Let $\mathcal{G}$ be a FG with atleast two effective edges. Then $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) < p$.*

Proof. Since $\mathcal{G}$ has some effective edges, $\mathcal{G}^c$ also contains some effective edges. Then by Theorem (2.12), $\gamma_M(\mathcal{G}) < \frac{p}{2}$ and $\gamma_M(\mathcal{G}^c) < \frac{p}{2}$. Thus, $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) < \frac{p}{2} + \frac{p}{2}$. Hence $\gamma_M(\mathcal{G}) + \gamma_M(\mathcal{G}^c) < p$.

Remark 4.16.

1. Let $\mathcal{G} \neq K_\sigma$ be a fuzzy graph without isolated vertices. Then $\gamma_M(\mathcal{G}).\gamma_M(\mathcal{G}^c) < (\frac{p}{4})^2$.
2. Let $\mathcal{G}$ be a fuzzy graph with atleast two effective edges. Then $\gamma_M(\mathcal{G}).\gamma_M(\mathcal{G}^c) < (\frac{p}{2})^2$.

V. Conclusion

The concept of domination in graphs is highly developed with significant theoretical advancements and numerous practical applications. Various domination parameters have been extensively studied by researchers. In this paper, we have extended the concept of fuzzy majority domination and applied it for fuzzy trees and fuzzy complements. Future works will present research on fuzzy majority independent sets in various types of fuzzy graphs.

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