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Theory of Edge Domination in Graphs-A Study

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Abstract—As the study of graphs came around there was even study of domination in graphs was developed with Claude Berge in 1958, in which he introduced the "Coefficient of external stability", which is known as domination number of a graph. Oystein Ore introduced the terms "Dominating Set" and "Domination Number" which was published in 1962. Since then lot of paper were published, and has been studied extensively. The paper focus on different types of edge dominating set which are being studies along with dominating set where only vertex is worked on or considered.

Keywords—dominating set, Domatic number.

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I. INTRODUCTION

This paper identifies the concept of edge domination in the field of graph theory was studied by many eminent researchers and still the work is continuing on the domination like Claude Berge in the early 1960's introduced Perfect graph. Vizing's Conjecture, Lovasz and Mihok, Mitchell and Hedetniemi. Prof V R Kulli, Prof Jayaram and Prof Sigarkanti have worked and independently established on lower and upper bounds for $\gamma'(G)$. Domatic number was introduced by Cockayne and Hedetniemi.

II. STUDY OF DEFINITIONS

A. Graphs

Graphs have valued functions in the field of domination theory. This paper includes definitions and few fundamental results in the form of theorems and propositions. Prof. V R Kulli, Niranjan and Janakiram introduced a new class of intersection graphs in the field domination theory [1].

A graph $G = (V,E)$ consists of a set V of vertices and set E of edges. Consider a simple graph as which contain no loops and no repeated edges i.e., E is a set of unordered pairs $\{u,v\}$ is distinct elements from V. The order of G is $|v(G)| = n$, and the size of G is $|E(G)| = m$. If $e = \{ v_i, v_j \} \varepsilon E(G)\}$, then v_i and v_j are adjacent. Vertex v_i and e are said to be incident

B. Dominating Graph

The dominating graph $D(G)$ of a graph $G = (V, E)$ is a graph with $V(D(G))\ \ V \cup S$, where S is the set all minimal dominating sets of G and with two vertices $u, v \epsilon V(D(G))$ adjacent if $u \epsilon v \ and \ v = D$ is a minimal dominating set of G containing u. In the figure showing Graph G and the minimal dominating set $D(G)$ are $\{2,3\}\{2,4\}\{3,5\}\ \{1,4\}$.

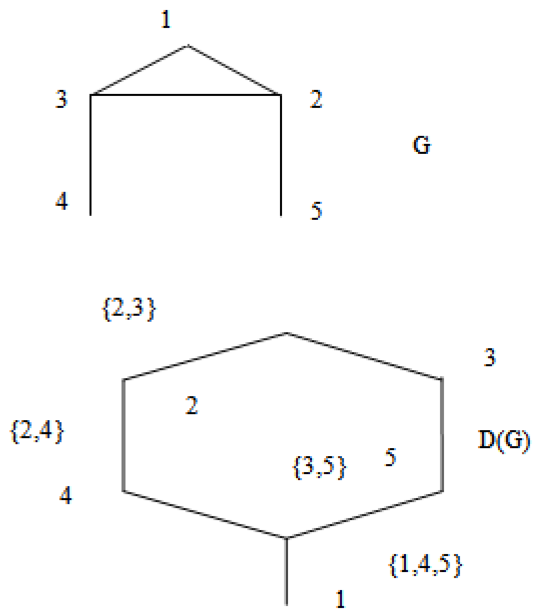

Figure: Graph   and its Dominating Graph

Theorem 1 The D graph D(G) of a graph G is a complete bipartite graph if and only if $G = \overline{K_p}$

Observation For any $G, D(G)$ is a bipartite. Suppose $D(G)$ is a complete bipartite graph and $G \neq \overline{K_p}$ then there exists a component G_1 in G is not trivial. For some vertex $u \epsilon G_1$, there exists 2 minimal dominating sets D and $D`$ such that $u \epsilon D$ $and$ $u \notin D`$, a contradiction. Hence $G = \overline{K_p}$.

C. *Domatic Number*

Definition Let $G = (V, E)$ be a graph and Δ be a partition of its vertex set $v(G)$ is a domatic partition of G if each class of Δ is a dominating set in G. If there are a maximum number of classes of domatic partition of G then it is called domatic number of G and is denoted by *d(G)* [17].

Theorem 2 For any graph F, $d(G) \leq \delta(G) + 1$.

Proof A graph G is domatically full if $d(G) = \delta(G) + 1$. If T is a tree with $p \geq 2$ vertices, then it is domatically full. If C_p is a cycle of length p and p is divisible by 3 then p is domatically full.

D. *Minimal Dominating Graphs*

As specified that V R Kulli and Janakiram introduced intersection graphs in domination theory. The minimal dominating graphs of a graph G is the intersection graph defined on the family of all minimal dominating sets of vertices in G.

Theorem 3 For any graph G with at least two vertices, $MD(G)$ is connected if and only if $\Delta(G) < p - 1$.

Proof Let $\Delta(G) < p - 1$ let D_1 and D_2 be two disjoint minimal dominating set of graph. Considering the case

Case 1 : Suppose there exist 2 vertices $u \epsilon D_1 and$ $v \epsilon D_2$ such $u \epsilon v$ since D_3 is also a minimal dominating set; implies that D_1 and D_2 are connect to $MD(G)$ through D_3.

E. *Common Minimal Dominating Graphs*

The common minimal dominating $CD(G)$ a graph G is the graph having the same vertex set as G with 2 vertices adjacent in $CD(G)$ if and only if there exists a minimal dominating set in G contains them.

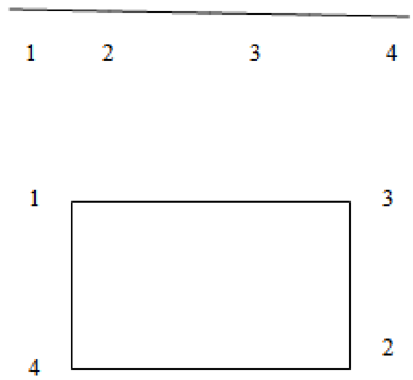

Figure 1: Graph G and common minimal dominating

Prof V R Kulli and Prof B Janakiram characterized the graphs G for which $\overline{G} = CD(G)$.

Theorem 4 For any graph G, $\overline{G} \subseteq CD(G)$. Furthermore, $\overline{G} = CD(G)$ if and only if every minimal dominating set of G is independent.

Proof If $(u, v) \epsilon\, E(\overline{G})$, then extend $\{u, v\}$ to maximal independent set S of vertices in G. since S is also a minimal dominating set of G, obtain $\overline{G} \subseteq CD(G)$. Suppose $\overline{G} = CD(G)$, it implies in the same minimal dominating set S are not adjacent in G. Thus S is independent.

Conversely, suppose every minimal dominating set of G is independent. Then two vertices adjacent in G cannot be adjacent in $CD(G)$. Thus $CD(G) \subseteq \overline{G}$ and since $\overline{G} \subseteq CD(G)$, $\overline{G} = CD(G)$ i.e. minimal dominating sets are connected.

F. Total Minimal Dominating Graph

Total minimal dominating graph $M_tD(G)$ of a graph G is defined to be the interaction graph of all total minimal dominating set of vertices in G. This concept was introduced by V R Kulli and Iyer [2].

Proposition 1 If G is a cycle of order $p \geq 5$ and $p \neq 4_n$ then $M_t(G)$ is a complete graph.

Proposition 2 If G is a $(p-2)$ - regular graph, then $L(G) = M_t(G)$.

Proposition 3 If G is a $(p-2)$ - regular graph, then $\gamma\big(M_t(G)\big) \leq \alpha_0(G)$.

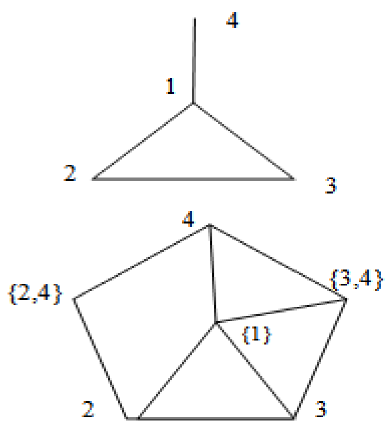

Figure 2 : Graph G and Vertex Minimal Dominating Graph

G. Vertex Minimal Dominating Graph

The vertex minimal dominating graph $M_vD(G)$ of a graph $G = (V, E)$ is a graph with $V(M_vD(G)) = V` = V \cup S$, where S is the collection of all minimal dominating set of G with 2 vertices $u, v \epsilon V`$ are adjacent if either they are adjacent in $G\ or\ v = D$ is a minimal dominating set of G containing $u.$ This concept was also introduced by V R Kulli, Janakiram and Niranjan.

Theorem 5 For any graph G, $M_vD(G)$ connected.

Proof Since for each vertex $v \epsilon V$, there exists a minimal dominating set containing v, every vertex in $M_vD(G)$ is not an isolated vertex. Suppose $M_vD(G)$ is disconnected G_1 and G_2 are 2 components of $M_vD(G)$. Then there exists 2 non vertices $u, v \epsilon V$ such that $u \epsilon V(G_1) and\ v \epsilon V(G_2)$. This implies that there is minimal dominating set in G containing $u\ and\ v,$ a contradiction. This shows that $M_vD(G)$ is connected. If observed that if $M_vD(G)$ is complete, the G is complete and has exactly one minimal dominating set, implies that $G = K_1$.

Observation Vertex minimal dominating set $M_vD(G)$ of G is complete if and only if G is K_1.

H. Edge Dominating Set

Definition A set F of edges in a graph $G = (V, E)$is called an **edge dominating set** of G if every edge in $E - F$ is adjacent to at least one edge in F. It can also be defined as a set F of edges G is called an edge dominating set of G if for every edge $e \in E - F$, there exists an edge $e_1 \in F$ such that e and e_1 have a vertex in common. The domination number $\gamma'(G)$ of a graph G is the minimum cardinality an edge dominating set of G.

It is clear from the definition that if G has at least one edge, $1 \leq \gamma'(G) \leq q$, if $\gamma'(G) = 0$ then the graph G has no edges.

I. Edge Domatic Number

Edge domatic partition of G is a partition of $E(G)$, all of whose classes are edge dominating set in G, hence edge domatic number of graph is denoted by $d'(G)$ has maximum number of classes an edge partition of G.

Connected edge domatic partition of G is a partition of $E(G)$, all of whose classes are connected edge dominating sets in G. $d'_c(G)$ is a connected edge domatic number of G which has maximum number of classes of a connected edge partition.

Theorem 6 If P_p is a path with $P \geq 3$ vertices, then $d(P_p) = 2.$

J. Connected Edge Dominating Set

An edge dominating set F of a graph G is a connected edge dominating set if the induced subgraph <F> is connected. The connected edge domination number $\gamma'_c(G)$ of G is the minimum cardinality of a **connected edge dominating set**.

Theorem 7 An edge dominating set F is minimal if and only if for each edge $e \in F$, one of the following conditions are

1) $N(e) \cap F = \emptyset$

2) There exists an edge $e_1 \in E - F$ such that $N(e_1) \cap F = \{e\}.$

Theorem 8 If F is an independent edge dominating set, then F is both a minimal edge dominating set and a minimal independent set. Conversely if F is a maximal independent set, then F is an independent edge dominating set of G[8,9].

K. ***Total Domatic Number***

Total domatic number was introduced by Cockayne, Hedetniemi and Dawes, it is a partition Δ of a vertex set V of G is total domatic partition of G if each class of Δ is a total dominating set of G. A graph is a total domatic number if maximum number of classes is there in total domatic partition of G i.e. $d_t(G)$ [16]. Total domatic number can be found only for graphs without isolated vertices, otherwise the graph has no total dominating set hence no total domatic partition.

Theorem 9 For any graph G without isolated vertices $d_t(G) \leq d(G)$.

Proof For every graph G without isolated vertices, each total dominating set is a dominating set, thus each total domatic partition is a domatic partition. Hence $d_t(G) \leq d(G)$.

L. ***Total Dominating Set***

A set F of edges in a graph $G = (V, E)$ is called a total dominating set of G if for every edge in E is adjacent at least one edge if F. The total edge domination number $\gamma'_t(G)$ a graph G is the minimum cardinality of a total edge dominating set of G [1].

M. ***Total Edge Domatic Number***

It was introduced by V R Kulli and Patwari and even worked by Zelinka, $d'_t(G)$ of G is the maximum number of sets in a partition of edge set $E(G)$ of G into total edge dominating sets [11,15].

Theorem 10 For any graph G,$d'_t(G) \leq q/\gamma'_t(G)$.

N. ***Total Edge Dominating Set***

A total edge dominating set F of the edge set E of $G = (V, E)$ is said to be a secure total edge dominating set of G if for every $e \in E - F$, there exists an edge $f \in F$ such that e *and* f are adjacent and $(F - \{f\}) \cup \{e\}$ is a total edge dominating set of G [10].

The **secure total edge domination** number $\gamma_{ste}(G)$ of G is the minimum cardinality of a secure total edge dominating set of G.

Proposition 1. Let *G* be a graph without isolated vertices and isolated edges. Then $\gamma_{te}(G) \leq \gamma_{ste}(G)$ and this bound is sharp.

Proof: Clearly every secure total edge dominating set is a total edge dominating set. The graph $K_{1,4}$ achieves this bound.

Proposition 2. If *F* is a secure total edge dominating set of a graph *G*, then *F* is a secure edge dominating set of *G*.

Proof: Suppose *F* is a secure total edge dominating set of G. Then *F* is a total edge dominating set of *G*. Therefore *F* is an edge dominating set of *G*. Let $e \in E - F$. Then there exists $f \in F$ such that *e* and *f* are adjacent and $(F - \{f\}) \cup \{e\}$ is an edge dominating set of *G*. Thus *F* is a secure edge dominating set of *G*.

Proposition 3. If K_1, *p* is a star with $p \geq 2$ vertices, then $\gamma_{ste}(K_{1,p}) = 2$.

Proof: Let *E* be the edge set of $K_{1,p}$, where $E = \{e1, e2, \ldots, ep\}$. Let $F = \{e1, e2\} \subseteq E$. Then *F* is a secure total edge dominating set of $K_{1,p}$. Then $\gamma_{ste}(K_{1,p}) \leq 2$. Suppose $\gamma_{ste}(K_{1,p}) = 1$ without loss of generality, $F_1 = \{e1\}$. Then F_1 is not a secure total edge dominating set, so that $\gamma_{ste}(K_{1,p}) = 1$. Without loss of generality $F_1 = \{e1\}$. Then F_1 is not a secure total edge dominating set, so that $\gamma_{ste}(K_{1,p}) = 1$.

Thus the result follows the double star $S_{m,n}$ is the graph obtained from joining centers of two stars $K_{1,m}$ and $K_{1,n}$ with an edge.

Proposition 4. If $S_{m,n}$ is a double star with $1 \leq m \leq n$ vertices, then $\gamma_{ste}(S_{m,n}) = 3$.

Proof: Let E be the edge set of $S_{m,n}$ where $E = \{e, e_1, e_2, .., e_m, f_1, f_2, .., f_n\}$. Let $F = \{e, e_1, f_1\} \subseteq E$. then *F* is a secure total edge dominating set of $S_{m,n}$ then $\gamma_{ste}(S_{m,n}) \geq 3$. Suppose $\gamma_{ste}(S_{m,n}) = 2$. Without loss of generality, $F_1 = \{e, e_1\}$. Clearly F_1 is not a secure total edge dominating set, so that $\gamma_{ste}(S_{m,n}) = 3$. Thus the result follows.

O. Inverse Edge Domination Number

It was first introduced by V R Kulli and Soner it was called as complementary edge domination number, to be the minimum number of edges in an inverse edge dominating set of G.

Let F be a minimum edge set of G. If $E - F$ contains and edge dominating set F' of G; then F' is called an inverse edge dominating set of G with respect to F which is denoted by $\gamma_e^{-1}(G)$ [13].

Let F be a minimum edge dominating set of G. If $E - F$ contains an edge dominating set F', then $F'$is called an **Inverse Edge Dominating Set** of G with respect to F. The inverse edge domination number $\gamma_{ste}^{-1}(G)$ of G is the minimum cardinality of an inverse edge dominating set of G [13].

Theorem 11 Let F be a minimum edge dominating set of G if for each edge $e \in F$, the induced subgraph $< N(e) >$ is a star then $\gamma'(G) = \gamma_e^{-1}(G)$.

Proof Let F be a minimum edge dominating set of G then under the hypothesis $F' = \{e' : e' \text{is adjacent to } e \in F\}$ is a minimum inverse edge dominating set. Thus $\gamma_e^{-1}(G) = |F'| = |F| = \gamma'(G)$.

List of inverse edge domination number of some standard graphs are

- $\gamma_e^{-1}(K_p) = \lfloor p/2 \rfloor, p \geq 3;$
- $\gamma_e^{-1}(P_p) = \lfloor p/3 \rfloor, p \geq 3;$
- $\gamma_e^{-1}(C_p) = \lceil p/3 \rceil, p \geq 3;$
- $\gamma_e^{-1}(W_p) = \lceil (p+2)/3 \rceil, p \geq 4;$
- $\gamma_e^{-1}(K_{m,n}) = m, 1 \leq m, 2 \leq n, m \leq n;$

In all the above cases, $\gamma'(G) = \gamma_e^{-1}(G)$, upper bound on $\gamma_e^{-1}(G)$ was given by V R Kulli and Soner.

Definition The **Upper Inverse Secure Total Edge Domination Number** $\Gamma_{ste}^{-1}(G)$ of *G* is the maximum cardinality of an inverse secure total edge dominating set of *G*.A γ_{ste}^{-1} —set is a minimum inverse secure total edge dominating set of *G*.

Example. For the graph $K_{1,4}$, $\gamma_{ste}(K_{1,4}) = \gamma_{ste} - 1(K_{1,4})$.

Theorem 12 Let *F* be aγ_{ste} -set of a connected graph *G*. If a γ_{ste}^{-1}-set exists, then *G* has atleast 4 edges.

Proof: Let *F* be a γ_{ste} -set of a connected graph *G*. Then $\gamma_{ste}(G) = |F| \geq 2$. If a γ_{ste}^{-1}-set exists, then $E - F$contains a secure total edge dominating set with respect to *F*. Hence $|E - F| \geq 2$. Thus *G* has at least 4 edges.

Theorem. If $K_{1,p}$, is a star with $p \geq 4$ vertices, then $\gamma_{ste}{}^{-1}(K_{1,p}) = 2$.

Proof: Let F be a γ_{ste}-set of $K_{1,p}$. By Proposition 3, $|F| = 2$. Let $F = \{e, f\}$. Then $S = \{x, y\}$is a $\gamma_{ste}{}^{-1}$-set of $K_{1,p}$for $x, y \in E(K_{1,p}) - \{e, f\}$. Thus $\gamma_{ste}{}^{-1}(K_{1,p}) = 2$.

Proposition 12. For any star $K_{1,p}, p \geq 4,\ \gamma_{ste}(K_{1,p}) = \gamma_{ste} - 1(K_{1,p}) = 2$.

Theorem 3.13 If $S_{m,n}$, is a double star with $3 \leq m \leq n$ vertices, then $\gamma_{ste}{}^{-1}(S_{m,n})$ = 4.

Proof: Let $E(S_{m,n}) = \{e, e_1, e_2, \ldots\ldots, e_m, f_1, f_2, \ldots, f_n\}$. By Proposition5, $F = \{e, e_1,, f_1\}$ is a$\gamma_{ste} - set\ of\ S_{m,n}$. Then $F_1 = \{e_z, e_3, f_2, f_3\}$ is an inverse secure total edge dominating set of$S_{m,n}\ in\ E - F$. Then $\gamma_{ste}{}^{-1}(Sm, n) \leq 4$. Suppose $\gamma_{ste}{}^{-1}(S_{m,n}) = 3$. Without loss of generality, $F_2 = \{e_2, e_3, f_2\}$. Clearly F_2 is not an inverse secure total edge dominating set, so that $\gamma_{ste}{}^{-1}(S_{m,n})\ {}^3\ 4$. Hence the result follows.

P. Secure Edge Dominating Set

Definition A **Secure Edge Dominating Set** of $G$is an edge dominating set $F \subseteq E$ with the property that for each $e \in E - F$, there exists $f \in F$ adjacent to e such that $(F - \{f\}) \cup \{e\}$ is an edge dominating set. The secure edge domination number $\gamma s'(G)$of G is the minimum cardinality of a secure edge dominating set of G [15].

Q. Secure Total Edge Dominating set

Definition Let F be a minimum **Secure Total Edge Dominating set** of G. If $\mathrm{E} - \mathrm{F}$ contains a secure total edge dominating set $\mathrm{F}'$of G, then F' is called an inverse secure total edge dominating set with respect to F. The inverse secure total edge domination number $\gamma_{ste}{}^{-1}(\mathrm{G})$ of G is the minimum cardinality of an inverse secure total edge dominating set of G [14].

R. Secure and inverse secure fuzzy domination

A fuzzy graph $G = (V, \sigma, \mu)$ is a non-empty V together with a pair of functions $\sigma : V \rightarrow [0,1]\ and\ \mu : V \times V \rightarrow [0,1]$ such that $\mu(u, v) \leq \sigma(u)\ \hat{}\ \sigma(v)$ for all $u, v \in V$. We say that *u* dominates *v* in *G* if $\mu(u, v) = \sigma(u) \hat{}\ \sigma(v)$.

Definition. Let *G* be a fuzzy graph. let $u, v \in V$. A subset *D* of *V* is called a **Fuzzy Dominating Set** if for every $v \in V - D$, there exists a vertex $u \in D$such that *u* dominates *v*. The minimum cardinality of a fuzzy dominating set of *G* is called the fuzzy domination number of *G* and is denoted by $\gamma_f(G)$, [12,13]

S. Secure Fuzzy Dominating Set

Definition. Let *G* be a fuzzy graph. A **Secure Fuzzy Dominating Set** of a fuzzy graph *G* is a fuzzy dominating set $D \subseteq V$with the property that for each $u \in V - D$there exists $v \in D$adjacent to *u* such that $(D - \{v\}) \cup \{u\}$ is a fuzzy dominating set. The secure fuzzy domination number $\gamma_{sf}(G)$ of *G* is the minimum cardinality of a secure fuzzy dominating set of *G*.

Definition. Let *G* be a fuzzy graph on (V, E). Let Fbe a minimum secure fuzzy edge dominating set of a fuzzy graph *G*. If $E - F$ contains a secure fuzzy edge dominating set$F'\ of\ G$, then F' is called an inverse secure fuzzy edge dominating set with respect to *F*. The **secure fuzzy edge domination number** $\gamma_{sfe}{}^{-1}(G)$ of *G* is the minimum cardinality of an inverse secure fuzzy edge dominating set in *G*.

T. Inverse Secure Fuzzy Dominating Set

Definition. Let *G* be a fuzzy graph. Let *D* be a minimum secure fuzzy dominating set of a fuzzy graph *G*. If $V - D$contains a secure fuzzy dominating set D' $of\ G,$ then D' is called an **inverse secure fuzzy dominating set** with respect to *D*. The inverse secure fuzzy domination number $\gamma_{sf}{}^{-1}(G)$ of *G* is the minimum cardinality of an inverse secure fuzzy dominating set in *G*.

U. Fuzzy Edge Domination Number

An edge $e = u\,v$ of a fuzzy graph is called an effective edge if $\mu(uv) = \sigma(u)\wedge\sigma(v).$

Definition. Let *G* be a fuzzy graph on (V, E).A subset *F* of *E* is called a fuzzy edge dominating set if for every edge in $E - F$ is adjacent to at least one effective edge in *F*. The minimum cardinality of a fuzzy edge dominating set of *G* is called the **Fuzzy Edge Domination Number** of *G* and it is denoted by $\gamma_{f_e}(G)$[11].

V. Secure Fuzzy Edge Dominating Set

Definition. Let *G* be a fuzzy graph on (V, E). A **Secure Fuzzy Edge Dominating Set** of a fuzzy graph *G* is a fuzzy edge dominating set $F \subseteq E$ with the property that for each edge $e \in E - F$, there exists $f \in F$ adjacent to *e* such that $(F - \{f\}) \cup \{e\}$ is a fuzzy edge dominating set. The secure fuzzy edge domination number $\gamma_{sf_e}(G)$ of *G* is the minimum cardinality of a secure fuzzy edge dominating set of *G*.

II. CONCLUSION

To conclude the paper it discusses various types of edge domination in theory of domination according to graph theory; few information about the evolution and the researchers of the concept. Topics in the paper shows about defining, propositions, theorems, observations related to domination, edge domination, total edge domination, inverse edge domination, minimal domination with its domination graph, domination number and dominating set.

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