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The Regular Pendant Domination Number of Some Special Graphs

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ABSTRACT: This article aims to explore the concept of regular pendant domination across various distinct graph types, including complete graphs, path graphs, cycle graphs, lollipop graphs, barbell graphs, bistar graphs, Petersen graphs, fan graphs, cone graphs, helm graphs, windmill graphs and complete bipartite graphs. Additionally, we examine regular domination in relation to specific graph operations, such as the join and the corona product of two graphs.

Key Words: Domination, Regular Domination, Pendant Domination, Regular Pendant Dominating Set.

Contents

1. Introduction

Let $G = (V, E)$ be any graph with $|V(G)| = n$ and $|E(G)| = m$ edges. Then n, m are respectively called the order and the size of the graph G. For each vertex $v \in V$, the open neighborhood of v is the set $N(v)$ containing all the vertices u adjacent to v and the closed neighborhood of v is the set $N[v]$ containing v and all the vertices u adjacent to v. Let S be any subset of V, then the open neighborhood of S is $N(S) = \bigcup_{v \in S} N(v)$ and the closed neighborhood of S is $N[S] = N(S) \bigcup S$.

The minimum and maximum of the degree among the vertices of G is denoted by $\delta(G)$ and $\Delta(G)$ respectively. A graph G is said to be regular if $\delta(G) = \Delta(G)$. A vertex v of a graph G is called a *cut vertex* if its removal increases the number of components. A *bridge* or *cut edge* of a graph is an edge whose removal increases the number of components. A vertex of degree zero is called an isolated vertex and a vertex of a degree one is called a pendant vertex. An edge incident to a pendant vertex is called a pendant edge. The corona of two disjoint graphs G_1 and G_2 is defined to be the graph $G = G_1 \circ G_2$ formed from one copy of G_1 and $\mid V(G_1) \mid$ copies of G_2 where the ith vertex of G_1 is adjacent to every vertex in the ith copy of G_2. The graph containing no cycle is called a tree. A unicyclic graph is a connected graph that contains exactly one cycle. A spanning subgraph of a graph G is a subgraph that includes all the vertices of G, but may not include all the edges.

A subset S of $V(G)$ is a dominating set of G if each vertex $u \in V - S$ is adjacent to a vertex in S. The least cardinality of a dominating set in G is called the domination number of G and is usually denoted by $\gamma(G)$. If S is a dominating set of a graph G and each vertex in S has the same degree, then S is said to be a regular dominating set of G. Regular domination number $\gamma_r(G)$ of graph G is defined as the minimum among all regular dominating sets. In 2021, Prabakaran et al. [7] described regular dominating set (RDS) and regular dominating number $\gamma_r(G)$ in fuzzy graph and studied various properties and bounds of regular domination number in several fuzzy graphs. Inspiring by this idea, we assess the regular pendant domination number of some simple, connected, and undirected graphs as well as the join and corona of two graphs.

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A dominating set S in G is called a pendant dominating set if $\langle S \rangle$ contains at least one pendant vertex. The least cardinality of the pendant dominating set in G is called the pendant domination number of G, denoted by $\gamma_{pe}(G)$. The more details about the pendant domination parameter refer [5].

2. Regular Pendant Domination

Definition 2.1 Let G be a simple graph, a set $S \subseteq V(G)$ is said to be regular pendant dominating set (RPDS) of G if each vertex $v \in V(G) - S$ is adjacent to some vertex in S and each vertex in S has the same degree. The least cardinality of a regular pendant dominating set in G is called the regular pendant domination number of G and is usually denoted by $\gamma_{Rpe}(G)$.

Example 2.1 *Let G_1 be a graph as shown in Figure 1. If we consider S as $\{u_2, u_3\} \subseteq V(G_1)$ and induced subgraph of S contains a pendant vertex and $deg(u_2) = deg(u_3)$, it is implied that the set S is a regular pendant dominating set of graph G_1. Let $S' = \{u_1, u_4\}$ be the subset of $V(G_1)$. Due to the fact that S's vertices have same degree but induced subgraph doesn't contain a pendant vertex, therefore it is not a regular pendant dominating set. Therefore $\gamma_{Rpe}(G_1) =| S |= 2$.*

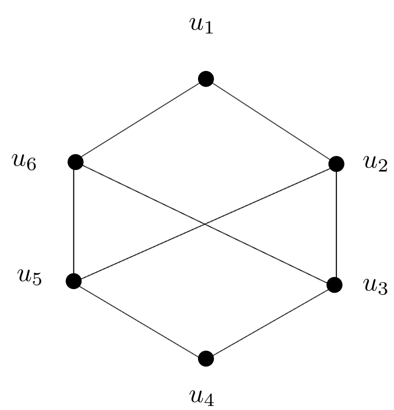

Figure 1. Graph G_1

Theorem 2.1 $\gamma_{Rpe}(K_n) = 2$ *for a complete graph K_n with $n \geq 2$ vertices.*

Proof 2.1 *Any two vertices can form the minimal regular pendant dominating set in a complete graph K_n since all the vertices have degree $n-1$. So, $\gamma_{Rpe}(K_n) = 2$.*

Theorem 2.2 *For $n \geq 4$,*

$$\gamma_{Rpe}(P_n) = \begin{cases} \frac{n}{3} + 1, & \text{if } n \equiv 0 \text{ (mod 3);} \\ \lceil \frac{n}{3} \rceil & \text{if } n \equiv 1 \text{ (mod 3);} \\ \lceil \frac{n}{3} \rceil + 1, & \text{if } n \equiv 2 \text{ (mod 3).} \end{cases}$$

Proof 2.2 *Let $V(P_n) = \{v_1, v_2, ..., v_n\}$ be a vertex set of path graph. Since we are aware that the path graph comprises n vertices, $n-1$ edges, two pendant vertices, and $n-2$ vertices of degree two. If S is a regular pendant dominating set, there are two alternatives for S. If $v_1, v_n \in S$, then v_1, v_n cannot dominate $n-4$ vertices of P_n and induced subgraph doesnot contain a pendant vertex, which is in conflict with the concept of regular pendant dominating set. Now if $v_2, v_3, ..., v_{n-1} \in S$ then this will be a regular pendant dominating set but not minimal. It is obvious that for a minimum regular pendant dominating set, v_2, v_3 and v_{n-1} must be a members of S. Now we construct the regular pendant dominating set S as*

follows:
Case 1: *Suppose* $n \equiv 0\,(mod\ 3)$. *Then* $n = 3k$, *for some integer* $k > 0$.
$S = \{v_2, v_{3i} : 0 < i \leq (k-1)\} \cup \{v_{n-1}\}$. *Then* $|\ S\ | = \frac{n}{3} + 1$. *There* $\frac{n}{3} + 1$ *vertices of* S *are of same degree, induced subgraph contains a pendant vertex and dominate all remaining vertices of* P_n. *Therefore* $\gamma_{Rpe}(P_n) = \frac{n}{3} + 1$ *if* $n = 3k$.
Case 2: *Suppose* $n \equiv 1\,(mod\ 3)$. *Then* $n = 3k+1$, *for some integer* $k > 0$. *The set* $S = \{v_2, v_{3i} : 0 < i \leq (k-1)\} \cup \{v_{n-1}\}$ *will be the regular pendant dominating set of* P_n. *Therefore* $\gamma_{Rpe}(P_n) = \lceil \frac{n}{3} \rceil$.
Case 3: *Proof of this case is similar to Case* 1.

Theorem 2.3 *For* $n \geq 4$, $\gamma_{Rpe}(C_n) = \gamma_{pe}(C_n)$.

Definition 2.1 *The lollipop graph is represented by the symbol* $L_{m,n}$ *and consists of a bridge between a complete graph* K_n *and a path graph* P_m. *The lollipop graph for* $n = 3$ *and* $m = 6$ *is as follows:*

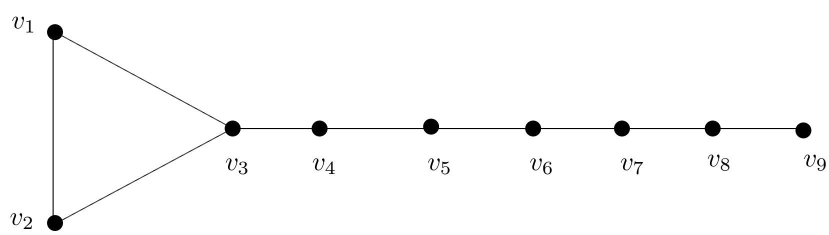

Figure 2. Lollipop graph $L_{3,6}$

Theorem 2.4 *For* $n \geq 3$, *the regular pendant domination number of the lollipop graph* $\gamma_{Rpe}(L_{3,n}) = \gamma_{Rpe}(P_n) + 1$.

Proof 2.3 *Assume that* $L_{3,n}$ *is a lollipop graph with* $n+3$ *vertices and edges. The vertex set of* $L_{3,n}$ *is defined as* $\{u_1, u_2, u_3, v_1, v_2, ..., v_n\}$. *Here* $deg(u_1) = deg(u_2) = 2$, $deg(u_3) = 3$, $deg(v_n) = 1$ *and* $deg(v_i) = 2\ \forall 1 \leq i \leq (n-1)$. *If* $L_{3,n}$ *has a regular pendant dominating set, then* S *must include the vertices whose degrees are equal. This suggest that neither the degree three nor the degree one vertices can belong to* S *because they cannot dominate the other vertices of* $L_{3,m}$. *We now construct the following set using vertices of degree 2:*
$S = S' \cup \{u_1\}$ *where the set* S' *is a regular pendant dominating set of path graph on* n *vertices. and the set* S *is a regular pendant dominating set of* $L_{3,n}$, *in accordance with the definition of regular pendant dominating set. Additionally the above set* S' *is the minimal regular pendant dominating set of* $L_{3,n}$. *Therefore* $\gamma_{Rpe}(L_{3,n}) = \gamma_{Rpe}(P_n) + 1$.

Corollary 2.1 *Lollipop graph* $L_{3,n}$ *has no* $\gamma_{Rpe}-$ *set for* $n = 1$

Proof 2.4 *In Figure* 2. $deg(v_1) = deg(v_2) = 2, deg(v_3) = 3$ *and* $deg(u_1) = 1$. *Given that the cardinality of the regular pendant dominating set is greater than 2, if we consider the set* $S = \{u_1, v_3\}$ *as a regular pendant dominating set, however, this would not be possible because both vertices have a different degree. Additionally if we consider the set* v_1, v_2 *we see that it is not a regular pendant dominating set since these vertices cannot dominate the vertex* u_1. *To construct a regular pendant dominating set all possible cases fail. As a result, it is implies that lollipop graph* $L_{3,1}$ *has no* $\gamma_{Rpe}-$ *set.*

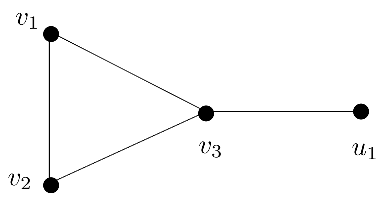

Figure 3: Lollipop graph $L_{3,1}$

Definition 2.2 *If we link an edge between two copies of complete graph K_n, then the resulting graph is called a barbell graph and it is represented by B_n. For $n = 4$, the barbell graph B_4 is shown below*

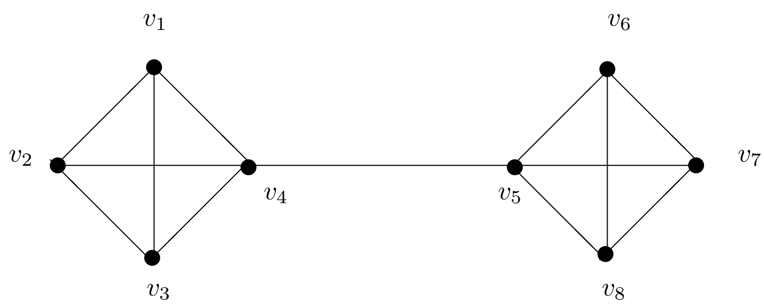

Figure 4: Barbell Graph B_4

Theorem 2.5 *Barbel graph B_n has a regular pendant dominating set with $\gamma_{Rpe}(B_n) = 2$ for any n.*

Proof 2.5 *The barbell graph B_n contains $2n$ vertices, $2(n-1)$ of them have degree $n-1$, while remaining two have degree n. Let S indicates the regular pendant dominating set. There are two choices for S here: First, we need to choose two vertex of degree $n-1$ from each copy of complete graph K_n and these two vertices in K_n are must be adjacent to a vertex of degree n if S has vertices of degree $n-1$ and induced subgraph contains a pendant vertex. This is necessary for the regular pendant dominating set. But the set S is not a minimal regular pendant dominating set. Additionally, it is evident from fig 1 that vertices of degree n dominate all other vertices and induced subgraph contains a pendant vertex. This one is minimal regular pendant dominating set of cardinality two. As a result we can say that $\gamma_{Rpe}(B_n) = 2$ for any n.*

Definition 2.3 *A graph is said to be a complete bipartite graph in which the vertices can be divided into two subsets, say V_1 and V_2, so that no edge has both ends in the same subset and every vertex in V_1 set is connected to every vertex in V_2. It is represented by $K_{m,n}$*

Theorem 2.6 *For a complete bipartite graph $K_{m,n}$, $\gamma_{Rpe}(K_{m,n}) = 2$ if $m = n$.*

Proof 2.6 *Let $V_1 = \{u_1, u_2, ..., u_m\}$ and $V_2 = \{v_1, v_2, ..., v_n\}$ be two partite sets of the complete bipartite graph $K_{m,n}$, which has m and n vertices respectively. If $m = n$, then construct regular pendant dominating* *set, we choose one vertex from vertex set V_1 and another from set V_2. Additionally, this a regular pendant dominating set with minimum cardinality. Therefore, $\gamma_{Rpe}(K_{m,n}) = 2$ for $m = n$.*

Definition 2.4 *Bistar $B_{n,n}$ is the graph obtained by joining the center (apex) vertices of two copies of $K_{1,n}$ by an edge. The vertex set of $B_{n,n}$ is $B_{n,n} = \{u, v, u_i, v_i\ 1 \leq i \leq n\}$, where u, v are apex vertices and u_i, v_i are pendant vertices.*

Theorem 2.7 *If $G \cong B_{n,n}$ is a bistar graph then $\gamma_{Rpe}(G) = 2$.*

Proof 2.7 *There are $2n$ pendant vertices and two apex vertices of degree $n + 1$ in a bistar graph. Two vertices of the same degree are required for a regular pendant dominating set. As a result, the vertex the pendant vertices cannot create a regular pendant dominating set, so we must select two apex vertices to make a regular pendant dominating set that is the least minimal regular pendant dominating set. Therefore $\gamma_{Rpe}(B_{n,n}) = 2$.*

Theorem 2.8 *For a Petersen graph G, $\gamma_{Rpe}(G) = \gamma_{pe}(G)$.*

Theorem 2.9 *For any fan graph $F_{m,n}$ with $m \geq 2$ and $n \geq 4$ vertices, then $\gamma_{Rpe}(F_{m,n}) = \gamma_{pe}(P_n)$.*

Definition 2.5 *A cone graph, $C_{m,n}$, is produced when a cycle graph C_m on n vertices and an empty graph K_n on n vertices are joined. For m = 6 and n = 2, the cone graph is as shown in the figure 5:*

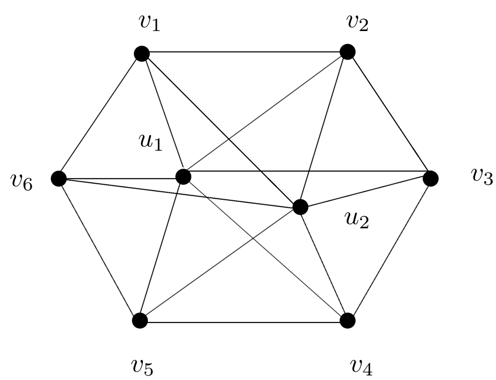

Figure 5: Cone graph $C_{6,2}$

Theorem 2.10 *For a cone graph $C_{m,n}$ with $m \geq 3$ and $n \geq 2$ vertices*

$$\gamma_{Rpe}(C_{m,n}) = \begin{cases} \frac{m}{3} + 1, & \text{if } m \equiv 0 \text{ (mod 3)}; \\ \lceil \frac{m}{3} \rceil & \text{if } m \equiv 1 \text{ (mod 3)}; \\ \lceil \frac{m}{3} \rceil + 1, & \text{if } m \equiv 2 \text{ (mod 3)}. \end{cases}$$

Proof 2.8 *As we know, a cone graph $C_{m,n}$ is formed by joining a cycle graph C_m and empty graph $\overline{K_n}$ on n vertices, i.e., $C_{m,n} = C_m + \overline{K_n}$. According to the notion of joining two graphs, every vertex of $\overline{K_n}$ is connected to every vertex of C_m in the cycle, which has vertex of degree of two. The degree of each vertex in C_m and $\overline{K_n}$ are $n+2$ and m respectively. Now we construct the regular pendant dominating set of cone graph as follows:*

Case 1: *Suppose $m \equiv 0\,(mod\ 3)$. Then $m = 3k$, for some integer $k > 0$.*

$S = \{v_1, v_2, v_{3i-1} : 1 < i \leq k\}$ is a regular pendant dominating set of $C_{m,n}$. Hence $\gamma_{Rpe}(C_{m,n}) \leq\mid S \mid$.

i.e., $\gamma_{Rpe}(C_{m,n}) \leq \frac{m}{3} + 1$. *There* $\frac{n}{3} + 1$ *vertices of* S *are of same degree, induced subgraph contains a pendant vertex and dominate all remaining vertices of* $C_{m,n}$. *Therefore* $\gamma_{Rpe}(C_{m,n}) = \frac{m}{3} + 1$ *if* $m = 3k$
Case 2: *Suppose* $m \equiv 1\,(mod\ 3)$. *Then* $m = 3k+1$, *for some integer* $k > 0$. *The set* $S = \{v_1, v_2, v_{3i-1} : 1 < i \leq k\}$ *will be the regular pendant dominating set of* $C_{m,n}$. *Therefore* $\gamma_{Rpe}(C_{m,n}) = \lceil \frac{n}{3} \rceil$
Case 3: *Proof of this case is similar to Case* 1.

Theorem 2.11 *Let* P_n *and* P_m *be two path graphs on* $n \geq 4$ *and* $m \geq 4$ *vertices. Then*

$$\gamma_{Rsp}(P_n + P_m) = \begin{cases} 2, & if\ m = n, \\ \gamma_{Rpe}(P_k), & \text{if } m \neq n. \end{cases}$$

Where k is min (m, n).

Proof 2.9 *Let* $V(P_n) = \{v_1, v_2, ..., v_n\}$ *and* $V(P_m) = \{v_1, v_2, ..., v_m\}$ *be the vertex sets of* P_n *and* P_m *respectively. Now according to the definition of join of graphs every vertex of* P_n *is adjacent to every vertex of* P_m, *therefore* $deg(v_1) = deg(v_n) = m + 1$. *and* $deg(v_i) = m + 2$ *for all* $2 \leq i \leq n - 1$. *Similarly,* $deg(u_1) = deg(u_n) = n + 1$ *and* $deg(u_j) = n + 2$, *for all* $2 \leq j \leq m - 1$. *Here we consider three cases as follows:*
Case 1: *If* $m = n$
To construct a regular pendant dominating set, we require minimum two vertices of the same degree that can dominate all other vertices of $V(P_n + P_m)$. *In this case any two vertices in the graph form a regular pendant dominating set also* S *must be a minimum because any regular pendant dominating set cannot be a singleton set. Therefore* $\gamma_{Rsp}(P_n + P_m) = 2$
Case 2: *If* $n \leq m$
In this case we create Table 1 to determine the regular pendant domination number as follows Consequently, using the values from the above table as a generalisation, we have $\gamma_{Rsp}(P_n + P_m) = \gamma_{Rpe}(P_k)$ *Where* k *is min* (m, n).
Case 3: *If* $n > m$

Table 1: Regular pendant domination of $P_n + P_m$

S.No.	Values of n	Values of m	$\gamma_{Rsp}(P_n + P_m)$
1	n=4	m=5,6,7,...	2
2	n=5	m=6,7,8,...	3
3	n=6	m=7,8,9...	3
4	n=7	m=8,9,10,...	3
5	n=8	m= 9,10,11,...	4
6	n=9	m=10,11,12,...	4
7	n=10	m=11,12,13,...	4
8	n=11	m=12,13,14,...	5
9	n=12	m= 13,14,15,...	5
10	n=13	m=14,15,16,...	5
11	n=14	m=15,16,17,...	6
12	n=15	m=16,17,18,...	6

The proof is the same as in Case 2.
From the above two cases, we conclude that $\gamma_{Rsp}(P_n + P_m) = \gamma_{Rpe}(P_k)$

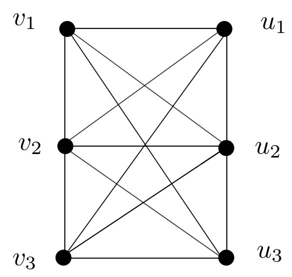

Figure 6: Join of two graphs $P_3 + P_3$

Corollary 2.2 *For $m = 3$ or $n = 3$ then $\gamma_{Rpe}(P_n + P_m) = 2$*

Proof 2.10 *From figure it is obvious that $deg(v_1) = deg(v_3) = deg(u_1) = deg(u_3) = 4$ and $deg(v_2) = deg(u_2) = 5$. A regular pendant dominating set of least cardinality can be formed here by taking the vertices v_2 and u_2. Hence $\gamma_{Rpe}(P_3 + P_3) = 2$.*

Definition 2.6 *Windmill graph $W_{m,n}$ is an undirected graph constructed by joining m copies of complete graph K_n with a common vertex K_1. The figure of windmill graph for $m = 3$ and $n = 4$ is as below:*

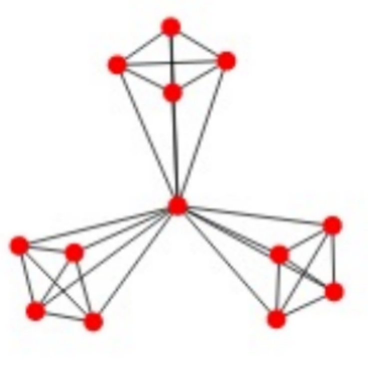

Figure 7. Windmill graph: $W_{3,4}$

Theorem 2.12 *For any windmill graph $W_{m,n}$ with $m \geq 2$ and $n \geq 3$, $\gamma_{Rpe}(W_{m,n}) = n$.*

Proof 2.11 *A windmill graph is formed by joining m copies of the complete graph K_n at a single common vertex, and is denoted by the notation $mK_n + K_1$. It is clear that a regular pendant dominating set cannot be formed using the common vertex v, as a regular pendant dominating set must include at least two vertices. Every vertex in the m copies of the complete graph has a degree of n. Now, we must choose two vertices from any one of the complete graph and at least one vertex from $m - 1$ copies of complete graph in order to build a regular pendant dominating set. Therefore $\gamma_{Rpe}(W_{m,n}) = n$*

Theorem 2.13 *Let G be a non-regular graph G of order n and H ba a complete graph K_m on m vertices, then $\gamma_{Rpe}(G \circ H) = n + 1$.*

Proof 2.12 *Let G be a non-regular graph and $\{v_1, v_2, ..., v_n\}$ be its vertex set. According to the definition of corona, there are n- copies of K_m attached to each vertex G. Since G is a non regular graph, its vertex does not form an regular pendant dominating set. Now, to construct the minimum regular pendant dominating set of $G \circ K_m$, select two vertices from any one copy of complete graph and one vertex from $n-1$ copies of K_m. Therefore, $\gamma_{Rpe}(G \circ H) = n + 1$.*

Theorem 2.14 *Let P_n and P_m be two path graphs on n and m vertices respectively, then $\gamma_{Rpe}(P_n \circ P_m) = n \times \gamma_{Rpe}(P_m)$*

Proof 2.13 *As we know that path graph on n vertices not a regular graph and $deg(v_1) = deg(v_n) = m+1$ and $deg(v_i) = m + 2$ for $2 \leq I \leq n-1$. Its clear that either vertices of degree $m+1$ or $m+2$ are not sufficient to form a regular pendant dominating set of $P_n \circ P_m$. Now we another choice to form a regular pendant dominating set with vertices of n copies of P_m. As we already prove that regular pendant domination number of path graph so that we have to select regular pendant domination number of n copies of P_m. Thus $\gamma_{Rpe}(P_n \circ P_m) = n \times \gamma_{Rpe}(P_m)$.*

Corollary 2.3

1. $\gamma_{Rpe}(P_n \circ P_m) = 2$ *for* $n = 2$ *and* $m \in Z^+$.
2. $\gamma_{Rpe}(P_n \circ \overline{K_m}) = 2$ *for* $n = 2$ *and* $m \in Z^+$.

Theorem 2.15 *Let G be a non- regular graph of order n and H be a complete graph K_m on m vertices, then $\gamma_{Rpe}(G \circ H) = n + 1$.*

Proof 2.14 *Let G be a non-regular graph and $\{v_1, v_2, v_3, ..., v_n\}$ be its vertex set. According to the definition of corona, there are n-copies of K_m attached to each vertex G. Since G is a non-regular graph, its vertex does not form an regular pendant dominating set. Now, to construct the regular pendant dominating set of $G \circ K_m$ of minimum cardinaltiy, select at least edge from any one of the complete graph and select one vertex from $n-1$ copies of K_m. Therefore, $\gamma_{Rpe}(G \circ H) = n + 1$.*

3. Application of Regular Pendant Domination

The concept of domination has its application in identifying minimum number of security guards to guard a city. Also the pendant domination is about keeping at least one security guard assigned as a back up. Identifying the minimum number of security guards needed to protect a city while assigning each guard an equal amount of responsibilities (by allocating each guard an equal number of positions) with at least one security guard assigned as a back up is the application of regular pendant domination.

4. Conclusion

Motivated by the concept of regular domination in fuzzy graph and regular domination in some special graph described by Prabakaran et al. and Jyoti Rani etal. [14] we introduced concept of regular pendant domination for simple graphs. Here, we determined the regular pendant domination number of several graphs like complete graph, path graph, cycle graph. Further regular pendant domination number can also be determined for specific graph operations such as join and corona of two graphs.

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