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CONNECTED TOTAL DOMINATING SETS AND ITS POLYNOMIAL OF $K_n \times P_r$

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ABSTRACT

In this paper, we are going to study the connected total domination polynomial of $K_n \times P_r$. The connected total domination polynomial of a graph G of order n is defined $D_{ct}(G,i) = \sum_{i=\gamma_{ct}(G)} d_{ct}(G,i)x^i$, where $d_{ct}(G,i)$ is the number of connected total dominating sets of G with size i and $\gamma_{ct}(G)$ is the connected total domination number of G.

Keywords: *Connected total dominating set, connected total domination number, connected total domination polynomial.*

1. INTRODUCTION

Let $G = (V,E)$ be a simple graph of order n. For any vertex $v \in V$, the open neighborhood of v is the set $N(v) = \{u \in V / uv \in E\}$ and the closed neighborhood of v is the set $N[v] = N(v) \cup \{v\}$. For a set $S \subseteq V$, the open neighborhood of S is N(S) = ∪ N(v) and the closed neighborhood of S is $N[S] = N(S) \cup S$. A set $S \subseteq V$ is a connected total dominating set of G if every vertex $v \in V$ is adjacent to atleast one element of S and the induced sub graph $< S >$ is connected. The connected total domination number γ_{ct}(G) is called a γ-set.

The polynomial, $D_{ct}(G, x) = \sum_{i=\gamma_{ct}(G)} d_{ct}(G,i)x^i$ is defined as connected total domination polynomial of G.

where $d_{ct}(G,i)$ is the number of connected total dominating sets with size i.

2. CONNECTED TOTAL DOMINATION POLYNOMIALS

Definition: 2.1 A graph G consists of a pair (V(G), E(G)), where $V(G)$ is a non empty finite set whose elements are called points (or) vertices and $E(G)$ is a set of unordered pairs of distinct elements of $V(G)$. The elements of $E(G)$ are called lines or edges of the graph G.

Definition: 2.2 If $e = \{u, v\}$ is an edge of a graph G, written $e = uv$, we say that e joins the vertices u and v. Also we say that u and v are adjacent vertices, u and v are incident with e. If two vertices or not joined, then we say that they are not-adjacent.

Definition: 2.3 The graph G is complete if every two distinct vertices of G are adjacent. A complete graph with n vertices is denoted by K_n.

Definition: 2.4 A walk of a graph G is an alternating sequence of points and lines $v_0, x_1, v_1, x_2, v_2, \ldots, v_{n-1}, x_n, v_n$ beginning and ending with points such that each line x_i is incident with v_{i-1} and v_i, A walk is called a path if all its points are distinct.

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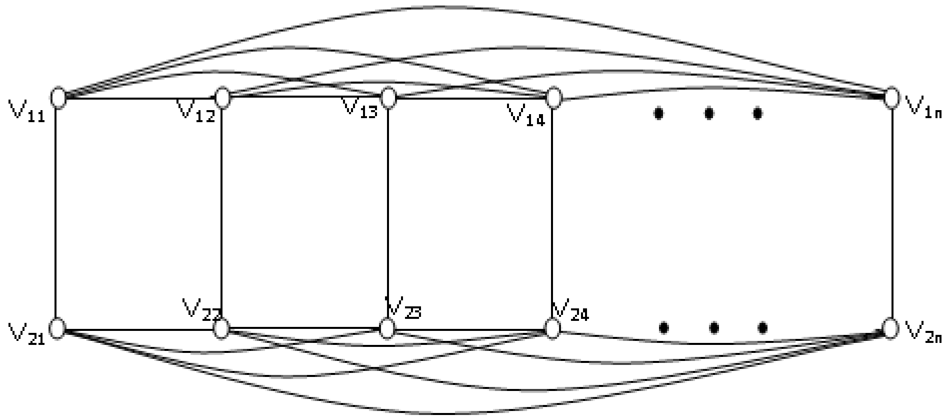
Definition: 2.5 A subset S of vertices in a graph G is said to be a dominating set, if every vertex $v \in V - S$ is adjacent to atleast one element of S. A dominating set of G is said to be a total dominating set, if every vertex $v \in V$ is adjacent to atleast one element of S.

Definition: 2.6 A total dominating set of G is said to be a connected total dominating set, if the induced sub graph $< S >$ of G is connected.

Theorem: 2.7 Let $G = K_n \times P_2$, then the total connected domination polynomial of G is,

$$D_{ct}(G,x) = nx^2[1+x]^{2(n-1)} - n\left[\overline{2(n-1)C}_1 - 2\right]x^{2n-1} - (n-1)x^{2n} + 2x^n[1+x]^n$$

Proof: $G_1 = K_n$ be the complete graph with n vertices, $G_2 = P_2$, its product $G = G_1 \times G_2$ is given in figure 1.1.



$G = K_n \times P_2$

Figure 1.1

The vertices of G are denoted by $\{v_{11}, v_{12}, \dots, v_{1n}, v_{21}, v_{22}, \dots, v_{2n}\}$

Let, $S_i = \{V_{ki} /\ k = 1,2;\ i = 1,2,\dots,n\}$ and
$T_j = \{V_{jk} /\ j = 1,2;\ k = 1,2,\dots,n\}$

The total connected dominating set with cardinality 2 are,

$$D_{ct}(G,2) = \{\{S_i\} / i = 1,2,\dots,n\}$$

Therefore, $d_{ct}(G,2) = n$

The total connected dominating set with cardinality 3 are,

$$D_{ct}(G,3) = \{S_i \cup \{x_j\} / i,j = 1,2,\dots,n; \quad i \neq j\}$$

Therefore, $d_{ct}(G,3) = n\left[\overline{2(n-1)C}_1\right]$

The total connected dominating set with cardinality 4 are,

$$D_{ct}(G,4) = \{S_i \cup \{x_j, x_k\} / i,j,k = 1,2,\dots,n; \quad i \neq j,k\}$$

Therefore, $d_{ct}(G,4) = n\left[\overline{2(n-1)C}_2\right]$

The total connected dominating set with cardinality 5 are,

$$D_{ct}(G,5) = \{S_i \cup \{x_j, x_k, x_l\} / i,j,k,l = 1,2,\dots,n; \quad i \neq j,k,l\}$$

Therefore, $d_{ct}(G,5) = n\left[\overline{2(n-1)C}_3\right]$

Proceeding in this way, we get

The total connected dominating set with cardinality n are,

$$D_{ct}(G,n) = \{S_i \cup \{x_j, x_k, \dots, x_t\} / i,j,k,\dots,t = 1,2,\dots,n; \quad i \neq j,k,\dots,t\} \cup \{\{T_j\} / j = 1,2\}$$

Therefore, $d_{ct}(G,n) = n\left[\overline{2(n-1)C}_{n-2}\right] + 2$

The total connected dominating set with cardinality $n+1$ are,

$$D_{ct}(G,n+1) = \{S_i \cup \{x_j, x_k, \dots, x_t, x_{t+1}\} / \ i,j,k,\dots,t+1 = 1,2,\dots,n; \quad i \neq j,k,\dots,t+1\}$$
$$\cup \left\{T_j \cup \{x_k\} / \ \{x_k\} \notin T_j, \ j = 1,2; \quad k = 1,2,\dots,n; \ \ j \neq k\right\}$$

Therefore, $d_{ct}(G,n+1) = n\left[\overline{2(n-1)C}_{n-1}\right] + 2(nC_1)$

The total connected dominating set with cardinality $n+2$ are,

$$D_{ct}(G,n+2) = \{S_i \cup \{x_j, x_k, \dots, x_{t+2}\} / \ i,j,k,\dots,t+2 = 1,2,\dots,n; \quad i \neq j,k,\dots,t+2\}$$
$$\cup \left\{T_j \cup \{x_k, x_l\} / \ \{x_k, x_l\} \notin T_j, \ j = 1,2; \quad k,l = 1,2,\dots,n; \ \ j \neq k,l\right\}$$

Therefore, $d_{ct}(G,n+2) = n\left[\overline{2(n-1)C}_{n}\right] + 2(nC_2)$

Proceeding in this way, we get

The total connected dominating set with cordinality $2n-2$ are,

$$D_{ct}(G,2n-2) = \{S_i \cup \{x_j, x_k, \dots, x_t, \dots, x_\alpha\} / \ i,j,\dots,\alpha = 1,2,\dots,n; \quad i \neq j,\dots,\alpha\}$$
$$\cup \left\{T_j \cup \{x_k, x_l, \dots, x_\alpha\} / \ \{x_k, x_l, \dots, x_\alpha\} \notin T_j, j = 1,2; \quad k,l,\dots,\alpha = 1,2,\dots,n; \ \ j \neq k,l,\dots,\alpha\right\}$$

Therefore, $d_{ct}(G,2n-2) = n\left[\overline{2(n-1)C}_{2(n-1)-2}\right] + 2(nC_{n-2})$

The total connected dominating set with cardinality $2n-1$ are,

$$D_{ct}(G,2n-1) = \{S_i - \{x_i\} / \ \{x_i\} \in S_i; \qquad i = 1,2,\dots,n\}$$

Therefore, $d_{ct}(G,2n-1) = 2n$

The total connected dominating set with cardinality $2n$ are,

$$D_{ct}(G,2n) = 1$$

Therefore, $d_{ct}(G,2n) = 1$

Hence, the total connected domination polynomial of G is,

$$D_{ct}(G,x) = nx^2 + n[\overline{2(n-1)C}_1]x^3 + n[\overline{2(n-1)C}_2]x^4$$
$$\dots + \left[n[\overline{2(n-1)C}_{(n-2)}] + 2\right]x^n + \left[n[\overline{2(n-1)C}_{(n-1)}] + 2(nC_1)\right]x^{n+1}$$
$$\dots + \left[n[\overline{2(n-1)C}_{2(n-1)-2}] + 2(nC_{n-2})\right]x^{2n-2} + 2nx^{2n-1} + x^{2n}$$

$$\Rightarrow D_{ct}(G,x) = \begin{bmatrix} nx^2 + n[\overline{2(n-1)C}_1]x^3 + n[\overline{2(n-1)C}_2]x^4 + \dots + n[\overline{2(n-1)C}_{(n-2)}]x^n \\ + n[\overline{2(n-1)C}_{(n-1)}]x^{n+1} + \dots + n[\overline{2(n-1)C}_{2(n-1)-2}]x^{2n-2} + 2nx^{2n-1} + x^{2n} \end{bmatrix}$$
$$+ [2x^n + 2(nC_1)x^{n+1} + \dots + 2(nC_{n-2})x^{2n-2}]$$

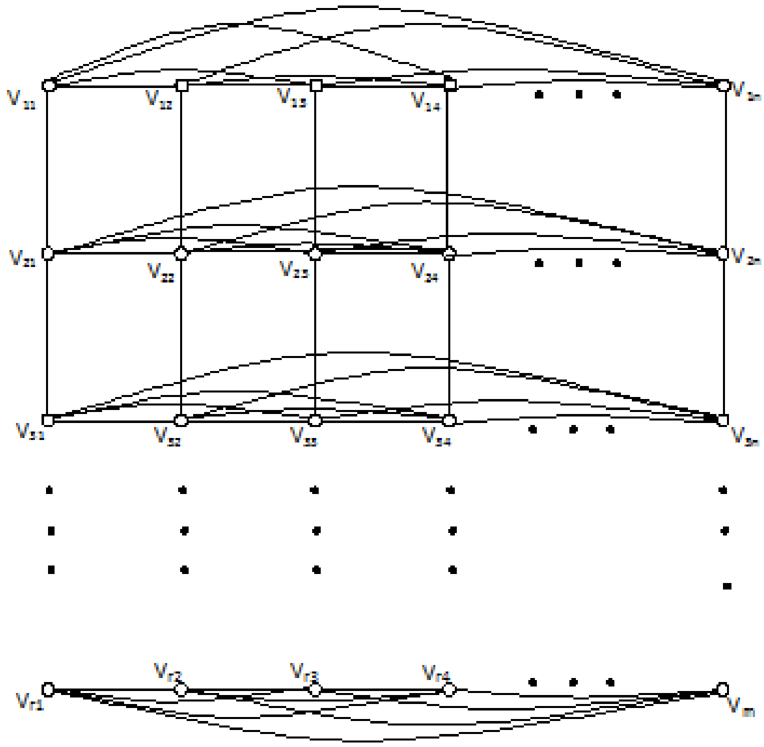
$$\Rightarrow D_{ct}(G,x) = \Big[nx^2 + n[\overline{2(n-1)C}_1]x^3 + n[\overline{2(n-1)C}_2]x^4 + \dots + n[\overline{2(n-1)C}_{(n-2)}]x^n$$
$$+ n[\overline{2(n-1)C}_{(n-1)}]x^{n+1} + \dots + n[\overline{2(n-1)C}_{2(n-1)-2}]x^{2n-2} + n[\overline{2(n-1)C}_{2(n-1)-1}]x^{2n-1}$$
$$+ n[\overline{2(n-1)C}_{2(n-1)}]x^{2n} - n[\overline{2(n-1)C}_1 - 2]x^{2n-1} - (n-1)x^{2n}\Big]$$
$$+ [2x^n + 2(nC_1)x^{n+1} + \dots + 2(nC_{n-2})x^{2n-2}]$$

$$\Rightarrow D_{ct}(G,x) = nx^2[1+x]^{2(n-1)} - n[\overline{2(n-1)C}_1 - 2]x^{2n-1} - (n-1)x^{2n} + 2x^n[1+x]^n$$

Theorem: 2.8 Let $G = K_n \times P_r$, then the total connected domination polynomial of G is,

$$D_{ct}(G,x) = nx^r[1+x]^{r(n-1)} - n[\overline{r(n-1)C}_1 - r]\,x^{rn-1} - (n-1)x^{rn} + (r-2)[n(n-1)]x^{r+1}[1+x]^{(n-2)r} + x^{(r-2)n}[1+x]^{2n}$$ for some $r > 2$.

Proof: K_n be the complete graph with n vertices, P_r is a path of length r. Then its product $G = K_n \times P_r$ is given in figure 1.2



$G = K_n \times P_r$

Figure: 1.2

The vertices of G is denoted by $\{V_{ij} /\ i = 1,2,\ldots,r;\ j = 1,2,\ldots,n\}$

Let, $S_i = \{V_{ki} /\ k = 1,2,\ldots,r;\ i = 1,2,\ldots,n\}$ and
$T_j = \{V_{jk} / j = 1,2,\ldots,r;\ k = 1,2,\ldots,n\}$

The total connected dominating set with cardinality r are,
$D_{ct}(G,r) = \{\{S_i\} / i = 1,2,\ldots,n\}$

Therefore, $d_{ct}(G,r) = n$

The total connected dominating set with cardinality $r+1$ are,
$D_{ct}(G,r+1) = \{S_i \cup \{x_j\} /\ i,j = 1,2,\ldots,n;\quad i \neq j\} \cup \{S_i - \{v_{ki}\} \cup \{v_{kj}\} / k = 1,2,\ldots,r;\ \ i,j = 1,2,\ldots,n;\ \ i \neq j\}$

Therefore, $d_{ct}(G,r+1) = n\left[\overline{r(n-1)C}_1\right] + (r-2)[n(n-1)]$

The total connected dominating set with cardinality $r+2$ are,
$D_{ct}(G,r+2) = \{S_i \cup \{x_j, x_k\} /\ i,j,k = 1,2,\ldots,n;\quad i \neq j,k\} \cup$
$\{S_i \cup S_j - \{v_{ki}, v_{kj}\} \cup \{x_i\} /\ k = 1,2,\ldots,r;\ \ i,j = 1,2,\ldots,n;\quad i \neq j\}$

Therefore, $d_{ct}(G,r+2) = n[\overline{r(n-1)C}_2] + (r-2)[n(n-1)][(n-2)rC_1]$

Proceeding in this way, we get

The total connected dominating set with cardinality $(r-2)n$ are,

$$D_{ct}(G,(r-2)n) = \{S_i \cup \{x_j, x_k, \dots, x_t\} / \ i,j,k,\dots,t = 1,2,\dots,n; \quad i \neq j,k,\dots,t\}$$
$$\cup \{S_i \cup S_j - \{v_{ki}, v_{kj}\} \cup \{x_i,\dots,x_t\} / \ k = 1,2,\dots,r; \ i,j,\dots,t = 1,2,\dots,n; \ i \neq j,\dots,t\}$$
$$\cup \ \{\{T_j\} / \ j = 1,2,\dots,r\}$$

Therefore, $d_{ct}(G,(r-2)n) = n[\overline{r(n-1)C}_{(r-2)(n-r)}] + (r-2)[n(n-1)] \ [\overline{(n-2)rC}_{(r-2)(n-r-1)}] + 1$

The total connected dominating set with cardinality $\overline{(r-2)n} + 1$ are,

$$D_{ct}(G,\overline{(r-2)n}+1) = \{S_i \cup \{x_j, x_k, \dots, x_t, x_{t+1}\} / \ i,j,k,\dots,t+1 = 1,2,\dots,n; \ i \neq j,k,\dots,t+1\}$$
$$\cup \ \{S_i \cup S_j - \{v_{ki}, v_{kj}\} \cup \{x_i,\dots,x_{t+1}\} / \ k = 1,2,\dots,r; \ i,j,\dots,t+1 = 1,2,\dots,n; \ i \neq j,\dots,t+1\}$$
$$\cup \{T_j \cup \{x_k\} / \{x_k\} \notin T_j; \ j = 1,2,\dots,r; k = 1,2,\dots,n; j \neq k\}$$

Therefore,

$$d_{ct}(G,\overline{(r-2)n}+1) = n[\overline{r(n-1)C}_{(r-2)(n+1-r)}]$$
$$+(r-2)[n(n-1)] \overline{(n-2)rC}_{(r-2)(n-r)}] + (2n)C_1$$

The total connected dominating set with cardinality $\overline{(r-2)n} + 2$ are,

$$D_{ct}(G,\overline{(r-2)n}+2) = \{S_i \cup \{x_j,\dots,x_{t+2}\} / \ i,j,k,\dots,t+2 = 1,2,\dots,n; \ i \neq j,k,\dots,t+2\} \cup$$
$$\{S_i \cup S_j - \{v_{ki}, v_{kj}\} \cup \{x_i,\dots,x_{t+2}\} / \ k = 1,2,\dots,r; \ i,j,\dots,t+2 = 1,2,\dots,n; \ i \neq j,\dots,t+2\}$$
$$\cup \{T_j \cup \{x_k, x_l\} / \{x_k, x_l\} \in T_j; \ j = 1,2,\dots,r; k,l = 1,2,\dots,n; j \neq k,l\}$$

Therefore, $d_{ct}G,\overline{(r-2)n}+2) = n[\overline{r(n-1)C}_{(r-2)(n+2-r)}]$

$$+(r-2)[n(n-1)] \overline{(n-2)rC}_{(r-2)(n-r+1)}] + (2n)C_2$$

Proceeding in this way, we get

The total connected dominating set with cardinality $rn-2$ are,

$$D_{ct}(G,rn-2) = \{S_i \cup \{x_j, x_k, \dots, x_t, \dots, x_\alpha\} / \ i,j,k,\dots,\alpha = 1,2,\dots,n; \ i \neq j,k,\dots,\alpha\} \cup$$
$$\{S_i \cup S_j - \{v_{ki}, v_{kj}\} \cup \{x_i, x_j, \dots, x_\alpha\} / \ k = 1,2,\dots,r; \ i,j,\dots,\alpha = 1,2,\dots,n; \ i \neq j,\dots,\alpha\} \cup$$
$$\{T_j \cup \{x_k, x_l, \dots, x_\alpha\} / \{x_k, x_l, \dots, x_\alpha\} \notin T_j; \quad j = 1,2,\dots,r; \quad k,l = 1,2,\dots,n; \quad j \neq k,l,\dots,\alpha\}$$

Therefore,

$$d_{ct}G,(rn-2) = n \ [\overline{r(n-1)C}_{r\,(n-1)-2}] + (r-2)[n(n-1)] \overline{(n-2)rC}_{(n-2)-(n-2)}] + (2n)C_{2n-2}$$

The total connected dominating set with cardinality $r\,n-1$ are,

$$D_{ct}G,(rn-1) = \{S_i - \{x_i\} \ / \ \{x_i\} \in S_i, i = 1,2,\dots,n\}$$

Therefore, $d_{ct}(G,rn-1) = rn$

The total connected dominating set with cArdinality $r\,n$ are,

$$D_{ct}(G,rn) = 1$$

Therefore, $d_{ct}(G,rn) = 1$

Hence the total connected domination polynomial of G is

$$D_{ct}(G,x) = nx^r + \left[\mathrm{n}\,[\overline{\mathrm{r(n-1)C}}_1] + (\mathrm{r}-2)\,[\mathrm{n(n-1)}]\right] x^{\mathrm{r+1}}$$
$$+\left[\mathrm{n}[\overline{\mathrm{r(n-1)C}}_2] + (\mathrm{r}-2)[\mathrm{n(n-1)}][(\mathrm{n}-2)\mathrm{rC}_1\right] x^{\mathrm{r+2}} +$$
$$\dots + \left[\mathrm{n}\,[\overline{\mathrm{r(n-1)C}}_{\text{(r-2)(n-r)}}] + (\mathrm{r}-2)\,[\mathrm{n(n-1)}][\overline{(\mathrm{n}-2)\mathrm{rC}}_{\text{(r-2)(n-r-1)}}] + 1\right] x^{(r-2)n}$$
$$+\left[\mathrm{n}[\overline{\mathrm{r(n-1)C}}_{\text{(r-2)(n+1-r)}}] + (\mathrm{r}-2)[\mathrm{n(n-1)}][\overline{(\mathrm{n}-2)\mathrm{rC}}_{\text{(r-2)(n-r)}}] + 2nC_1\right] x^{\overline{\text{(r+2)n}}+1}$$
$$+\dots + \left[\mathrm{n}\,[\overline{\mathrm{r(n-1)C}}_{\text{r(n-1)-2}}] + (\mathrm{r}-2)\,[\mathrm{n(n-1)}][\overline{(\mathrm{n}-2)\mathrm{rC}}_{\text{(n-2)-(n-2)}}] + 2nC_{2n-2}\right] x^{rn-2} + rnx^{rn-1} + x^{rn}$$

$$\begin{aligned}\Rightarrow D_{ct}(G,x) = [\ & nx^{r} + n[\overline{\mathrm{r(n-1)C}_1}]x^{r+1} + \mathrm{n}[\overline{\mathrm{r(n-1)C}_2}]x^{r+2} + \ldots. + \mathrm{n}\ [\overline{\mathrm{r(n-1)C}}_{\mathrm{(r\text{-}2)(n\text{-}r)}}]x^{(r-2)n} \\ & + \mathrm{n}\ [\overline{\mathrm{r(n-1)C}}_{\mathrm{(r\text{-}2)(n+1\text{-}r)}}]x^{\overline{(r-2)n}+1} + \ldots. + n[\overline{\mathrm{r(n-1)C}}_{\mathrm{r(n\text{-}1)\text{-}2}}]x^{rn-2} + rnx^{rn-1} + x^{rn}\ \ ] \\ & + [\ (r-2)[n(n-1)]x^{r+1} + (r-2)[n(n-1)][(\overline{n-2)rC_1}]x^{r+2} \\ & + \ldots. + (r-2)[n(n-1)][(\overline{n-2)rC}_{(r-2)(n-r-1)}]x^{(r-2)n} \\ & + (r-2)[n(n-1)][(\overline{n-2)rC}_{(r-2)(n-r)}]x^{\overline{(r-2)n}+1} \\ & + \ldots. + (r-2)[n(n-1)][(\overline{n-2)rC}_{(n-2)-(n-2)}]x^{rn-(r-1)}\ \ ] \\ & + \left[x^{(r-2)n} + 2nC_1 x^{\overline{(r-2)n}+1} + \ldots\ldots + 2nC_{2n-2}x^{rn-2} \right]\end{aligned}$$

$$\begin{aligned}\Rightarrow D_{ct}(G,x) = [\ & nx^{r} + n[\overline{\mathrm{r(n-1)C}_1}]x^{r+1} + \mathrm{n}[\overline{\mathrm{r(n-1)C}_2}]x^{r+2} + \ldots. + \mathrm{n}\ [\overline{\mathrm{r(n-1)C}}_{\mathrm{(r\text{-}2)(n\text{-}r)}}]x^{(r-2)n} \\ & + \mathrm{n}\ [\overline{\mathrm{r(n-1)C}}_{\mathrm{(r\text{-}2)(n+1\text{-}r)}}]x^{\overline{(r-2)n}+1} + \ldots. + n[\overline{\mathrm{r(n-1)C}}_{\mathrm{r(n\text{-}1)\text{-}2}}]x^{rn-2} + n[\overline{\mathrm{r(n-1)C}}_{\mathrm{r(n\text{-}1)\text{-}1}}]x^{rn-1} \\ & + n[\overline{\mathrm{r(n-1)C}}_{\mathrm{r(n\text{-}1)}}]x^{rn} - n[\overline{\mathrm{r(n-1)C}_1}\ \text{-}\ \mathrm{r}]x^{rn-1} - (n-1)x^{rn}\ \ ] \\ & + [\ (r-2)[n(n-1)]x^{r+1} + (r-2)[n(n-1)][(\overline{n-2)rC_1}]x^{r+2} \\ & + \ldots. + (r-2)[n(n-1)][(\overline{n-2)rC}_{(r-2)(n-r-1)}]x^{(r-2)n} \\ & + (r-2)[n(n-1)][(\overline{n-2)rC}_{(r-2)(n-r)}]x^{\overline{(r-2)n}+1} \\ & + \ldots. + (r-2)[n(n-1)][(\overline{n-2)rC}_{(n-2)-(n-2)}]x^{rn-(r-1)}\ \ ] \\ & + \left[x^{(r-2)n} + 2nC_1 x^{\overline{(r-2)n}+1} + \ldots\ldots + 2nC_{2n-2}x^{rn-2} \right]\end{aligned}$$

$D_{ct}(G,x) = nx^{r}[1+x]^{r(n-1)} - n[r(\overline{n-1)C_1} - r]x^{rn-1} - (n-1)x^{rn} + (r-2)[n(n-1)]x^{r+1}[1+x]^{(n-2)r} + x^{(r-2)n}[1+x]^{2n}$ for some $r > 2$.

Hence the Proof.

The following Table represents the coefficients of the total domination polynomial of $G = K_n \times P_2$ for all $n < 8$.

$d_{ct}(G,i)$ / G	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9	x^{10}	x^{11}	x^{12}	x^{13}	x^{14}	x^{15}	x^{16}
$K_3 \times P_2$	3	14	24	6	1										
$K_4 \times P_2$	4	24	62	88	72	8	1								
$K_5 \times P_2$	5	40	140	282	360	300	160	10	1						
$K_6 \times P_2$	6	60	270	720	1262	1524	1290	760	300	12	1				
$K_7 \times P_2$	7	84	462	1540	3465	5546	6482	5586	3535	1610	504	14	1		
$K_8 \times P_2$	8	112	728	2912	8008	16016	24026	27472	24080	16128	8148	3024	784	16	1

Table: 2.1

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