



# Domination polynomial of line graphs

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**Abstract**— This paper introduces a domination polynomial of a line graph. The domination polynomial of a line graph  $L(G)$  of order  $n$  is the polynomial  $D(L(G), x) = \sum_{i=\gamma(G)}^n d(L(G), i)x^i$  where  $\gamma(L(G), i)$  is the number of dominating sets of  $L(G)$  of size  $i$ , and  $\gamma(L(G))$  is the domination number of  $L(G)$ .

**Keywords**— domination number, dominating set, domination polynomial, graphs, line graphs.

## I. INTRODUCTION

Graph theory is an important branch of Discrete Mathematics that studies mathematical structures used to model pairwise relationships between objects. It has extensive applications in areas such as computer science, communication networks, chemistry, and operations research. A central concept within this field is the study of Graph Theory, where graphs are used to represent systems consisting of vertices (nodes) connected by edges (links). Understanding the structural and algebraic properties of graphs is essential for analysing complex networks and solving many practical problems. One of the important transformations in graph theory is the construction of a Line Graph. Given a graph  $G$ , its line graph  $L(G)$  is formed by representing each edge of  $G$  as a vertex in  $L(G)$ , and connecting two vertices in  $L(G)$  whenever the corresponding edges in  $G$  share a common endpoint. This transformation shifts the focus from vertex adjacency in the original graph to edge adjacency, providing a different perspective for studying the structural properties of graphs.

Graph polynomials play a significant role in capturing various characteristics of graphs through algebraic expressions. These polynomials encode combinatorial information about graphs and help in analysing properties such as connectivity, coloring, and matching structures. Examples include the Chromatic Polynomial, which counts the number of valid vertex colorings of a graph, and the

Matching Polynomial, which is related to the enumeration of matchings in a graph. The study of polynomials associated with line graphs combines the structural transformation of graphs with algebraic techniques. Investigating the polynomial properties of line graphs provides insights into how the edge structure of the original graph influences the algebraic characteristics of the derived graph. Such studies contribute to a deeper understanding of graph invariants and their relationships, and they also have applications in fields such as chemical graph theory, where molecular structures are often analyzed using graph transformations and associated polynomials. Therefore, examining the polynomials of line graphs is an important topic in graph theory research, as it connects combinatorial structures with algebraic representations and offers useful tools for analyzing complex graph-based systems. The concept of the domination polynomial was introduced by Alikhani and Peng [1], who studied the properties and coefficients of this polynomial and computed it for several classes of graphs. The domination parameters of the line graph of a sunlet graph were studied by Shobana and Logapriya [4], where various domination-related measures were analyzed for the corresponding line graph structure. The properties of dominating sets and domination polynomials for path graphs were investigated by Alikhani and Peng [5] in their study on domination polynomials of paths. In this paper, the domination polynomial of a linegraph.

## II. PRELIMINARIES

**Definition 1.** [2] A set  $D$  of vertices of the graph  $G$  is said to be a dominating set if every vertex in  $V-D$  is adjacent to a vertex in  $D$ . A dominating set  $D$  is said to be a minimal dominating set if no proper subset of  $D$  is a dominating set. The minimum cardinality of a dominating set of a graph  $G$  is called the domination number of  $G$  and is denoted by  $\gamma(G)$ .

**Definition 2.** [1] The domination polynomial of a graph  $G$  of order  $n$  is the polynomial  $D(G, x) = \sum_{i=\gamma(G)}^n d(G, i)x^i$  where  $\gamma(G, i)$  is the number of dominating sets of  $G$  of size  $i$ , and  $\gamma(G)$  is the domination number of  $G$ .

III. DOMINATION POLYNOMIAL OF LINE GRAPHS

**Theorem 1.** If line graph  $L(G)$  of a graph  $G$  consists of  $m$  components  $L(G_1), \dots, L(G_m)$ , then

$$D(L(G), x) = D(L(G_1), x) \dots D(L(G_m), x).$$

Proof. We prove the result for the case  $m = 2$ . The general case then follows by induction.

Let  $L(G) = L(G_1) \cup L(G_2)$  where  $L(G_1)$  and  $L(G_2)$  are the two connected components of the line graph  $L(G)$  of  $G$ . Then by the definition of domination, any dominating set of  $L(G)$  must contain a dominating set of  $L(G_1)$  and a dominating set of  $L(G_2)$ , since the components are disjoint and there are no edges between them. Let  $d(L(G), k)$  denote the number of dominating sets of size  $k$  in  $L(G)$ , and similarly for  $L(G_1)$  and  $L(G_2)$ . For each integer  $k \geq \gamma(L(G))$ , a dominating set of size  $k$  in  $L(G)$  can be formed by selecting a dominating set of size  $j$  in  $L(G_1)$  and a dominating set of size  $k - j$  in  $L(G_2)$ , for all possible values of  $j$ . Thus, we have  $d(L(G), k) = \sum_{j=\gamma(L(G_1))}^{\min(k, |V(L(G_1))|)} d(L(G_1), j) \cdot d(L(G_2), k - j)$ , where  $d(L(G_1), j) = 0$  if  $j < \gamma(L(G_1))$  or  $j > |V(L(G_1))|$ , and similarly for  $d(L(G_2), k - j)$ . Therefore, the coefficient of  $x^k$  in  $D(L(G_1), x) \cdot D(L(G_2), x)$  equals the coefficient of  $x^k$  in  $D(L(G), x)$  for all  $k$ , implying that

$$D(L(G), x) = D(L(G_1), x) \cdot D(L(G_2), x).$$

To complete the proof for the general case  $m > 2$ , we proceed by induction. Suppose that the result holds for  $m = r$ , i.e.  $D(L(G), x) = \prod_{i=1}^r D(L(G_i), x)$ .

Let  $L(G) = L(H) \cup L(G_{r+1})$ , where  $L(H) = \bigcup_{i=1}^r L(G_i)$ .

Then by case  $m = 2$ , we have

$D(L(G), x) = D(L(H), x) \cdot D(L(G_{r+1}), x)$ . By the induction hypothesis,  $D(L(H), x) = \prod_{i=1}^r D(L(G_i), x)$  and so,

$$\begin{aligned} D(L(G), x) &= \prod_{i=1}^r D(L(G_i), x) \cdot D(L(G_{r+1}), x) \\ &= \prod_{i=1}^{r+1} D(L(G_i), x) \end{aligned}$$

Hence, according to the principle of mathematical induction, the result holds for any integer  $m \geq 2$ .

**Corollary 1.** Let  $G$  be an empty graph with  $n$  vertices.

Then  $D(L(G), x) = 0$ .

Proof. The line graph of an empty graph with  $n$  vertices is also an empty graph, but with  $0$  vertices. Thus,  $\gamma(L(G)) = 0$ . Hence,  $D(L(G), x) = 0$ .

**Theorem 2.** For the line graph of star graph  $K_{1,n}$ , we have  $D(L(K_{1,n})) = (1 + x)^n - 1$ .

Proof. Let  $L(K_{1,n})$  be the line graph of the star graph  $K_{1,n}$ . Then we have  $L(K_{1,n}) = K_n$  and  $D(K_n, x) = (1 + x)^n - 1$ . Therefore,  $D(L(K_{1,n})) = (1 + x)^n - 1$ .

**Theorem 3.** If the line graph of a graph  $G$  is a disjoint union of  $n$  copies of  $K_2$ , then  $D(L(G), x) = (x^2 + 2x)^n$ .

Proof. Let  $L(G)$  be the line graph of a graph  $G$  with  $n$  vertices. Then we have the domination polynomial of  $K_2$  is  $D(K_2, x) = (1 + x)^2 - 1 = x^2 + 2x$ . Since  $L(G)$  is the disjoint union of  $n$  copies of  $K_2$  and the domination polynomial is multiplicative over components, it follows from Theorem 1 that  $D(L(G), x) = (D(K_2, x))^n = (x^2 + 2x)^n$ .

**Corollary 2.**

- I. For the spider graph  $K_{1,n,n}$ ,  $D(L(K_{1,n,n}), x) = (x^2 + 2x)^n$ .
- II. For the Sunlet graph  $S_n$ ,  $D(L(S_n), x) = (x^2 + 2x)^n$ .

Proof. (i) Let  $L(K_{1,n,n})$  be the line graph of the spider graph  $K_{1,n,n}$ . Let  $v$  be the central vertex of  $K_{1,n,n}$  and  $v_1, v_2, \dots, v_n$  be the nodes adjacent to  $v$  with  $u_1, u_2, \dots, u_n$  be the nodes adjacent to  $v_1, v_2, \dots, v_n$ , respectively. Then denote the edge  $vv_n$  as  $e_n$  and  $v_n u_n$  as  $e'_n$ . It is clear that  $e_1, e_2, \dots, e_n$  is cycle of  $n$  vertices and  $e'_1, e'_2, \dots, e'_n$  connected to  $e_1, e_2, \dots, e_n$  respectively in  $L(K_{1,n,n})$ . Also, we have  $L(K_{1,n,n})$  is the disjoint union of  $n$  copies of  $K_2$ . Hence it follows from Theorem 3 that  $D(L(K_{1,n,n}), x) = (D(K_2, x))^n = (x^2 + 2x)^n$ .

(ii) The  $n$ -sunlet graph  $S_n$  is obtained by attaching  $n$  pendant edges to the cycle  $C_n$ . Let  $v_1, v_2, \dots, v_n$  be the vertices of the outer cycle of  $S_n$  and  $u_1, u_2, \dots, u_n$  be the vertices connected to  $v_1, v_2, \dots, v_n$  respectively. Then denote the edges of outer cycle as  $S_n$  by  $e_1, e_2, \dots, e_n$  and  $v_n u_n$  as  $e'_n$ . Also, we have  $L(S_n)$  is the disjoint union of  $n$  copies of  $K_2$ . Hence it follows from Theorem 3 that  $D(L(S_n), x) = (D(K_2, x))^n = (x^2 + 2x)^n$ .

IV. DOMINATION POLYNOMIAL OF LINE GRAPHS OF A PATH

Remark:  $L(P_{n+1}) = P_n$

j	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
n	
1	0
2	1
3	2 1
4	1 3 1
5	0 4 4 1
6	0 3 8 5 1
7	0 1 10 13 6 1
8	0 0 8 22 19 7 1
9	0 0 4 26 40 26 8 1
10	0 0 1 22 61 65 34 9 1
11	0 0 0 13 70 120 98 43 10 1
12	0 0 0 5 61 171 211 140 53 11 1
12	0 0 0 1 40 192 356 343 192 64 12 1
14	0 0 0 0 19 171 483 665 526 255 76 13 1
15	0 0 0 0 6 120 534 1050 1148 771 330 89 14 1

Table 1:  $d(L(P_n), j)$ , the number of dominating set of  $L(P_n)$  with cardinality  $j$

**Remark:**

- $d(L(P_{n+1}), j) = d(L(P_n), j - 1) + d(L(P_{n-1}), j - 1) + d(L(P_{n-2}), j - 1)$ .
- $d(L(P_{3(n+1)}), n + 1) = d(L(P_{3n}), n) + d(L(P_{3n+1}), n)$ .
- $d(L(P_{3(n+2)}), n) = 0$ .

**Theorem 5.** The following properties hold for the coefficients of  $D(L(P_n), x)$ ,

- $d(L(P_{3n}), n) = n + 1, \forall n \in \mathbb{N}$
- $d(L(P_{3n+1}), n) = 1, \forall n \in \mathbb{N}$
- $d(L(P_{3(n+1)}), n + 1) = n + 2, \forall n \in \mathbb{N}$
- $d(L(P_{3n+2}), n + 1) = \frac{(n+2)(n+3)}{2} - 2, \forall n \in \mathbb{N}$
- $d(L(P_{3n+1}), n + 1) = \frac{n(n+1)(n+8)}{6}, \forall n \in \mathbb{N}$
- $d(L(P_{n+1}), n) = 1, \forall n \in \mathbb{N}$
- $d(L(P_{n+1}), n - 1) = n, \forall n \geq 2$
- $d(L(P_{n+1}), n - 2) = \frac{n(n-1)}{2} - 2, \forall n \geq 3$
- $d(L(P_{n+1}), n - 3) = \frac{(n-4)(n-3)(n+4)}{6}, \forall n \geq 2$
- $d(L(P_{n+1}), n - 4) = \frac{(n-5)(n^3 - n^2 - 42n + 96)}{24}, \forall n \in \mathbb{N}$
- For every  $n \in \mathbb{N}$ , and  $k = 0, 1, 2, \dots, 2n - 1$ ,  $d(L(P_{2n+1-k}), n) = d(L(P_{2n+1+k}), n)$ .

Proof.

- We prove by induction on  $n \in \mathbb{N}$  that  $d(L(P_{3n}), n) = n + 1$ . When  $n=1$ , the line graph of the path  $P_3$  consists of the set of vertex  $\{e_1, e_2\}$ . Thus,  $\{e_1\}$  and  $\{e_2\}$  are the possible dominating sets of size 1. Hence  $d(L(P_3), 1) = 2$ . Therefore, the result is true for  $n=1$ . Now suppose that the result is true for all  $k \in \mathbb{N}$ , that is,  $d(L(P_{3k}), k) = k + 1$  and there exists a  $k + 1$  dominating set of size  $k$ . We prove the result for  $n=k+1$  as follows. Consider the line graph  $L(P_{3(k+1)})$  with the vertex set  $\{e_1, e_2, e_3, \dots, e_{3k+2}\}$ . We partition this line graph into the sub path  $L(P_{3k})$  and the final 3-vertex segment  $\{e_{3k}, e_{3k+1}, e_{3k+2}\}$ . By the induction hypothesis, the subpath  $L(P_{3k})$  have  $k + 1$  dominating set of size  $k$ . To dominate the remaining segment, it suffices to include the central vertex  $e_{3k+1}$ , which dominates  $\{e_{3k}, e_{3k+1}, e_{3k+2}\}$ . Thus, the dominating set for  $L(P_{3(k+1)})$  of size  $k + 1$  is  $k + 1 + 1 = k + 2$ . Hence,  $d(L(P_{3(k+1)}), k + 1) = k + 2$ . By the principle of mathematical induction, the result holds  $d(L(P_{3n}), n) = n + 1, \forall n \in \mathbb{N}$ .
- We prove by induction on  $n \in \mathbb{N}$  that  $d(L(P_{3n+1}), n) = 1$ . When  $n=1$ , the line graph of the path  $P_4$  consists of the set of vertices  $\{e_1, e_2, e_3\}$ . Thus,  $\{e_2\}$  is the only dominant set of size 1. Hence  $d(L(P_4), 1) = 1$ . Therefore, the result is true for  $n=1$ . Now suppose that the result is true for all  $k \in \mathbb{N}$ , that is,  $d(L(P_{3k+1}), k) = 1$  and there exists a unique dominating set of size  $k$  as  $\{e_2, e_5, e_8, \dots, e_{3k-1}\}$  of  $L(P_{3k+1})$ . We prove the result for  $n=k+1$  as follows. Consider the line graph  $L(P_{3(k+1)+1})$  with the vertex set  $\{e_1, e_2, e_3, \dots, e_{3k+3}\}$ . We partition this line graph into the sub path  $L(P_{3k+1})$  and the final 3-vertex segment  $\{e_{3k+1}, e_{3k+2}, e_{3k+3}\}$ . By the induction hypothesis, the sub path  $L(P_{3k+1})$  is uniquely dominated by  $\{e_2, e_5, e_8, \dots, e_{3k-1}\}$ . To dominate the remaining segment, it suffices to include the central vertex  $e_{3k+2}$ , which dominates  $\{e_{3k+1}, e_{3k+2}, e_{3k+3}\}$ . Thus, the dominating set for  $L(P_{3(k+1)+1})$  of size  $k + 1$  is  $\{e_2, e_5, e_8, \dots, e_{3k-1}, e_{3k+2}\}$ . This set dominates all the vertices in  $L(P_{3(k+1)+1})$ , and by construction, no other dominating set of size  $k + 1$  exists, as any deviation would leave at least one vertex undominated or require more than  $k + 1$  vertices. Hence,  $d(L(P_{3(k+1)+1}), k + 1) = 1$ . By the principle of mathematical induction, the result holds  $d(L(P_{3n+1}), n) = 1, \forall n \in \mathbb{N}$ .

III. We have  $d(L(P_{3(n+1)}), n + 1) = d(L(P_{3n}), n) + d(L(P_{3n+1}), n)$  and from parts (i) and (ii) we get  $d(L(P_{3(n+1)}), n + 1) = n + 2, \forall n \in \mathbb{N}$ .

IV. Proof by induction on  $n$ . The result is true for  $n = 1$ , because  $d(L(P_5), 2) = 4$ . Now suppose that the result is true for  $n-1$ , that is,

$$\begin{aligned} d(L(P_{3(n-1)+2}), n - 1 + 1) &= \frac{(n - 1 + 2)(n - 1 + 3)}{2} - 2 \\ &= \frac{(n + 1)(n + 2)}{2} - 2, \forall n \in \mathbb{N}. \end{aligned}$$

We prove it for  $n$  as follows. By parts (i), (ii), and the induction hypothesis we have

$$\begin{aligned} d(L(P_{3n+2}), n + 1 &= d(L(P_{3n+1}), n) + d(L(P_{3n}), n) \\ &\quad + d(L(P_{3n-1}), n) \\ &= 1 + n + 1 + \frac{(n + 1)(n + 2)}{2} - 2 \\ &= \frac{(n + 2)(n + 3)}{2} - 2 \end{aligned}$$

V. Proof by induction on  $n$ . The result is true for  $n = 1$ , because  $d(L(P_4), 2) = 3$ . Now suppose that the result is true for  $n-1$ , that is,

$$\begin{aligned} d(L(P_{3(n-1)+1}), n) &= \frac{(n - 1)(n - 1 + 1)(n - 1 + 8)}{6} \\ &= \frac{n(n - 1)(n + 7)}{6}, \forall n \in \mathbb{N}. \end{aligned}$$

We prove it for  $n$  as follows. By parts (ii), (iii), and the induction hypothesis we have

$$\begin{aligned} d(L(P_{3n+1}), n + 1) &= d(L(P_{3n}), n) + d(L(P_{3n-1}), n) + \\ &\quad d(L(P_{3n-2}), n) \\ &= n + 1 + \frac{(n + 1)(n + 2)}{2} - 2 + \frac{n(n - 1)(n + 7)}{6} \\ &= \frac{n(n + 1)(n + 8)}{6} \end{aligned}$$

VI. Let  $L(P_{n+1})$  be the line graph of path  $P_{n+1}$  on  $n$  vertices. We aim to determine the number of dominating sets of size  $n$ , i.e.,  $d(L(P_{n+1}), n)$ . Then we have the only subset of size  $n$  of the vertex set  $L(P_{n+1})$  is the entire set  $V(L(P_{n+1}))$  itself. Since

every vertex in a graph dominates itself and possibly its neighbors, the full vertex set trivially forms a dominating set. Hence,  $d(L(P_{n+1}), n) = 1, \forall n \in \mathbb{N}$ .

VII. Let  $L(P_{n+1})$  be the line graph of path  $P_{n+1}$  with vertex set  $\{e_1, e_2, \dots, e_n\}$ . Then there are exactly  $n$  subsets of size  $n - 1$ , each obtained by removing one vertex  $e_i$  from the full vertex set. In each case, the excluded vertex  $e_i$  is adjacent to at least one of its neighbors, which remain in the set, ensuring it is dominated. Hence, all such  $n$  subsets are dominating sets and so,  $d(L(P_{n+1}), n - 1) = n, \forall n \geq 2$ .

VIII. Proof by induction on  $n$ . The result is true for  $n = 3$ , because  $d(L(P_4), 1) = 1$ . Now suppose that the result is true for  $n-1$ , that is,

$$d(L(P_n), n - 3) = \frac{(n-1)(n-2)}{2} - 2.$$

We prove it for  $n$  as follows. By parts (vi), (vii), and the induction hypothesis we have,

$$\begin{aligned} d(L(P_{n+1}), n - 2) &= d(L(P_n), n - 3) + d(L(P_{n-1}), n - 3) + d(L(P_{n-2}), n - 3) \\ &= \frac{(n - 1)(n - 2)}{2} - 2 + n - 2 + 1 \\ &= \frac{n(n - 1)}{2} - 2. \end{aligned}$$

IX. Proof by induction on  $n$ . The result is true for  $n = 4$ , because  $d(L(P_5), 1) = 0$ . Now suppose that the result is true for  $n-1$ , that is,

$$d(L(P_n), n - 4) = \frac{(n - 5)(n - 4)(n + 3)}{6}.$$

We prove it for  $n$  as follows. By parts (vii), (viii), and the induction hypothesis. We have,

$$\begin{aligned} d(L(P_{n+1}), n - 3) &= d(L(P_n), n - 4) + d(L(P_{n-1}), n - 4) + d(L(P_{n-2}), n - 4) \\ &= \frac{(n - 5)(n - 4)(n + 3)}{6} + \frac{(n - 2)(n - 3)}{2} - 2 + n - 3 \\ &= \frac{n^3 - 3n^2 - 16n + 48}{6} \\ &= \frac{(n - 4)(n - 3)(n + 4)}{6}. \end{aligned}$$

X. Proof by induction on  $n$ . The result is true for  $n = 4$ , because  $d(L(P_5), 1) = 0$ . Now suppose that the result is true for  $n-1$ , that is,

$$d(L(P_n), n - 5) = \frac{(n - 6)((n - 1)^3 - (n - 1)^2 - 42(n - 1) + 96)}{24}.$$

We prove it for  $n$  as follows. By parts (viii), (ix), and the induction hypothesis we have

$$d(L(P_{n+1}), n - 4) = d(L(P_n), n - 5) + d(L(P_{n-1}), n - 5) + d(L(P_{n-2}), n - 5)$$

$$= \frac{(n-6)((n-1)^3 - (n-1)^2 - 42(n-1) + 96)}{6} + \frac{(n-6)(n-5)(n+2)}{6} + \frac{(n-3)(n-4)}{2} - 2$$

$$= \frac{(n-5)(n^3 - n^2 - 42n + 96)}{24}$$

- XI. Proof by induction on  $n$ . The result is true for  $n = 1$  and  $k=1$ , because  $d(L(P_2), 1) = d(L(P_4), 1) = 1$ . Now suppose that the result is true for  $n-1$ , that is  $d(L(P_{2n+3-k}), n) = 8$   
 $d(L(P_{2n+3+k}), n)$ . We prove it for  $n$  as follows.  
 $d(L(P_{2n+1-k}), n) = d(L(P_{2n-k}), n - 1) + d(L(P_{2n-1-k}), n - 1) + d(L(P_{2n-2-k}), n - 1)$   
 $= d(P_{2n-1-k}, n - 1) + d(P_{2n-2-k}, n - 1) + d(P_{2n-3-k}, n - 1)$   
 $= d(P_{2(n-1)+1-k}, n - 1) + d(P_{2(n-1)-k}, n - 1) + d(P_{2(n-1)-1-k}, n - 1)$   
 $= d(P_{2(n-1)-1+k}, n - 1) + d(P_{2(n-1)+k}, n - 1) + d(P_{2(n-1)+1+k}, n - 1)$   
 $= d(P_{2n+k-3}, n - 1) + d(P_{2n+k-2}, n - 1) + d(P_{2n+k-1}, n - 1)$   
 $= d(P_{2n+k}, n) = d(L(P_{2n+1+k}), n)$ .

**Conclusion**

In this work, the domination polynomial of line graphs was studied to understand how domination properties behave under the line graph transformation. The domination polynomial serves as a useful algebraic tool that encodes the number of dominating sets of different cardinalities in a graph. By analyzing the domination polynomial of line graphs, we explored the relationship between the structural properties of an original graph and those of its corresponding line graph. The study shows that the domination polynomial of a line graph reflects the edge domination characteristics of the original graph. Several results demonstrate how dominating sets in line graphs correspond to edge-based structures in the original graph, providing insights into the combinatorial behavior of domination under graph transformations. For particular classes of graphs, explicit forms or patterns of the

domination polynomial of their line graphs were identified and discussed. Overall, this research contributes to the broader understanding of domination theory and graph polynomials. The results highlight connections between edge domination, line graph structures, and domination polynomials. Future research may focus on deriving closed forms for wider classes of graphs, investigating roots of domination polynomials of line graphs, and exploring applications in network analysis and combinatorial optimization.

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