

EDGE DOMINATION IN BOOLEAN FUNCTION GRAPH $B(G, L(G), NINC)$ OF A GRAPH

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ABSTRACT: For any graph G , let $V(G)$ and $E(G)$ denote the vertex set and edge set of G respectively. The Boolean function graph $B(G, L(G), NINC)$ of G is a graph with vertex set $V(G) \cup E(G)$ and two vertices in $B(G, L(G), NINC)$ are adjacent if and only if they correspond to two adjacent vertices of G , two adjacent edges of G or to a vertex and an edge not incident to it in G . For brevity, this graph is denoted by $B_1(G)$. In this paper, edge domination number of Boolean Function Graph $B(G, L(G), NINC)$ of some standard graphs and its bounds are obtained.

KEYWORDS: Boolean Function graph, Edge Domination Number

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I. INTRODUCTION

Graphs discussed in this paper are undirected and simple graphs. For a graph G , let $V(G)$ and $E(G)$ denote its vertex set and edge set respectively. The graph G is denoted by $G = (V, E)$. A subset $D \subseteq V$ is called a dominating set of G if every vertex not in D is adjacent to some vertex in S . The domination number $\gamma(G)$ of G is the minimum cardinality taken over all dominating sets of G . The open neighborhood $N(v)$ of v in V is the set of vertices adjacent to v and the set $N[v] = N(v) \cup \{v\}$ is the closed neighborhood of v . An edge e of a graph is said to be incident with the vertex v if v is an end vertex of e . In this case, we also say that v is incident with e .

A subset $F \subseteq E$ is called an edge dominating set of G if every edge not in F is adjacent to some edge in F . The edge domination number $\gamma'(G)$ of G is the minimum cardinality taken over all edge dominating sets of G . The maximum order of a partition of E into edge dominating sets of G is called the edge domatic number of G and is denoted by $d'(G)$. The concept of edge domination was introduced by Mitchell and Hedetniemi [8]. Jayaram [6] studied line (edge) dominating sets and obtained bounds for the line (edge) domination number and obtained Nordhaus-Gaddum results for the line domination number. Arumugam and Velammal [1] discussed edge domination number and edge domatic number. The complementary edge domination in graphs was studied by Kulli and Soner [7]. Vaidya and Pandit [9] determined edge domination number of middle graphs, total graphs and shadow graphs of Paths and Cycles. For graph theoretic notations and terminology, Harary [2] is followed. Janakiraman et al., introduced the concept of Boolean function graphs [3 - 5]. For a real x , $\lfloor x \rfloor$ denotes the greatest integer less than or equal to x .

Theorem 1.1. [6] For any (p, q) graph G , $\gamma' \leq \lfloor p/2 \rfloor$

Theorem 1.2. [6] For any (p, q) graph G , $\gamma' \leq q - \beta_1 + q_0$, where β_1 is the edge independence number and q_0 is the number of isolated edges in G .

Theorem 1.3. [6] For any (p, q) graph G , $\gamma' \leq q - \Delta'$, where Δ' denotes the maximum degree of an edge in G .

Observation [3]

1.4. G and $L(G)$ are induced subgraphs of $B_1(G)$.

1.5. Number of vertices in $B_1(G)$ is $p + q$ and if $d_i = \deg_G(v_i)$, $v_i \in V(G)$, then the number of edges in $B_1(G)$ is $q(p-2) + \frac{1}{2} \sum_{1 \leq i \leq p} d_i^2$.

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1.6. The degree of a vertex of G in $B_1(G)$ is q and the degree of a vertex e' of $L(G)$ in $B_1(G)$ is $\deg_{L(G)}(e') + p - 2$. Also if $d^*(e')$ is the degree of a vertex e' of $L(G)$ in $B_1(G)$, then $0 \leq d^*(e') \leq p + q - 3$. The lower bound is attained, if $G \cong K_2$ and the upper bound is attained, if $G \cong K_{1,n}$, for $n \geq 2$.

Theorem 1.7. [3] $B_1(G)$ is disconnected if and only if G is one of the following graphs.
 $nK_1, K_2, 2K_2$ and $K_2 \cup nK_1$, for $n \geq 1$.

In this paper, edge domination number of Boolean Function Graph $B(G, L(G), NINC)$ of some standard graphs and its bounds are obtained.

II. MAIN RESULTS

In the following edge domination number of $B_1(P_n), B_1(C_n), B_1(K_p), B_1(K_{1,n})$ are found.

Theorem 2.1: For the Path P_n on n ($n \geq 3$) vertices, $\gamma'(B_1(P_n)) = n - 1$

Proof: Let $v_1, v_2, v_3, \dots, v_n$ be the vertices and $e_{12}, e_{23}, \dots, e_{n-1,n}$ be the edges in P_n , where $e_{i,i+1} = (v_i, v_{i+1}), i = 1, 2, \dots, n-1$. Then $v_1, v_2, \dots, v_n, e_{12}, e_{23}, \dots, e_{n-1,n} \in V(B_1(P_n))$. $B_1(P_n)$ has $2n - 1$ vertices and $n(n-1) - 1$ edges.

Let $f_i = (v_i, e_{i+1,i+2}) \in E(B_1(P_n))$, where $i = 1, 2, \dots, n - 2$ and $f_{n-1} = (v_{n-1}, e_{12})$. Let $D' = \{f_1, f_2, \dots, f_{n-1}\} \subseteq E(B_1(P_n))$. Since each edge in $E(B_1(P_n))$ is either in D' or is adjacent to an edge in D' , it follows that the set D' is an edge dominating set of $B_1(P_n)$. Therefore, $\gamma'(B_1(P_n)) \leq |D'| = n - 1$. Also D' is a minimum edge dominating set of $B_1(P_n)$, since for any edge $f_i \in D'$, the set $D' - \{f_i\}$ does not dominate the edge f_i . Any edge of the form (v_i, e_{jk}) ($j, k \neq i$), where e_{jk} is not incident with v_i , dominates $(n-1)$ edges. But $B_1(P_n)$ has $n^2 - n - 1 = n(n-1) - 1$ edges. To dominate all the edges of $B_1(P_n)$, an edge dominating set of $B_1(P_n)$ must contain at least $(n-1)$ edges. That is, any edge dominating set of $B_1(P_n)$ has at least $(n-1)$ edges. Therefore, $\gamma'(B_1(P_n)) \geq (n-1)$, Hence, $\gamma'(B_1(P_n)) = n - 1$.

Theorem 2.2: For the cycle C_n on n ($n \geq 4$) vertices, $\gamma'(B_1(C_n)) = n - 1$.

Proof: Let $v_1, v_2, v_3, \dots, v_n$ be the vertices and $e_{12}, e_{23}, \dots, e_{n-1,n}$ be the edges in C_n , where $e_{i,i+1} = (v_i, v_{i+1}), i = 1, 2, \dots, n - 1$. Then $v_1, v_2, \dots, v_n, e_{12}, e_{23}, \dots, e_{n-1,n} \in V(B_1(C_n))$. $B_1(C_n)$ has $2n$ vertices and n^2 edges. Let $f_i = (v_i, e_{i+1,i+2}) \in E(B_1(C_n))$ where $i = 1, 2, \dots, n-2, f_{n-1} = (v_{n-1}, e_{12})$. Let $D' = \{f_1, f_2, \dots, f_{n-1}\} \subseteq E(B_1(C_n))$. Since each edge in $E(B_1(C_n))$ is either in D' (or) is adjacent to an edge in D' , it follows that set D' is an edge dominating set of $B_1(C_n)$. Therefore, $\gamma'(B_1(C_n)) \leq |D'| = n - 1$. Also D' is a minimum edge dominating set of $B_1(C_n)$, since for any edge $f_i \in D'$, the set $D' - \{f_i\}$ does not dominate the edge f_i . Any edge of the form (v_i, e_{jk}) ($j, k \neq i$), where e_{jk} is not incident with v_i , dominates $(n-1)$ edges. But $B_1(C_n)$ has n^2 edges. To dominate all the edges of $B_1(C_n)$ an edge dominate set of $B_1(C_n)$ must contain at least $(n-1)$ edges. Therefore, $\gamma'(B_1(C_n)) \geq n - 1$ and hence $\gamma'(B_1(C_n)) = n - 1$.

Theorem 2.3: For the complete graph K_p on p ($p \geq 4$) vertices, $\gamma'(B_1(K_p)) = (p(p-1))/2$.

Proof: Let $v_1, v_2, v_3, \dots, v_n$ be the vertices and $e_{12}, e_{23}, \dots, e_{n-1,n}$ be the edges in K_p , where $e_{i,i+1} = (v_i, v_{i+1}), i = 1, 2, \dots, n-1$. Then $v_1, v_2, \dots, v_n, e_{12}, e_{23}, \dots, e_{n-1,n} \in V(B_1(K_p))$. $B_1(K_p)$ has $(p(p+1))/2$ and $(p(p-1)(2p-3))/2$ edges. Let $f_i = (v_i, e_{i+1,i+2}) \in E(B_1(K_p))$, where $i = 1, 2, \dots, n - 2$ and $f_{n-1} = (v_{n-1}, e_{12})$. Let $D' = \{f_1, f_2, \dots, f_{n-1}\} \subseteq E(B_1(K_p))$. Since each edge in $E(B_1(K_p))$ is either in D' (or) is adjacent to an edge in D' , it follows that the set D' is an edge dominating set of $B_1(K_p)$. Therefore, $\gamma'(B_1(K_p)) \leq |D'| = (p(p-1))/2$. Also D' is a minimum edge dominating set of $B_1(K_p)$, since for any edge $f_i \in D'$ the set $D' - \{f_i\}$ does not dominate the edge f_i . Any edge of the form (v_i, e_{jk}) ($j, k \neq i$), where e_{jk} is not incident with v_i , dominates $(p(p-1))/2$ edges. But $B_1(K_p)$ has $(p(p-1)(2p-3))/2$ edges. To dominate all the edges of $B_1(K_p)$ an edge dominate set of $B_1(K_p)$ must contain atleast $(p(p-1))/2$ edges.

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Therefore, $\gamma'(B_1(K_p)) \geq (p(p-1))/2$ and hence $\gamma'(B_1(K_p)) = (p(p-1))/2$.

Theorem 2.4: For the star $K_{1,n}$ on $(n+1)$ vertices, $\gamma'(B_1(K_{1,n})) = (n+4)/3$, where $n \geq 2$.

Proof: Let $v_1, v_2, v_3, \dots, v_n$ be the vertices with v_1 as the central vertex and $e_{12}, e_{13}, \dots, e_{1n}$ be the edges in $K_{1,n}$, where $e_{1,i+1} = (v_1, v_{i+1})$, $i = 2, 3, \dots, n$ and. Then $v_1, v_2, \dots, v_n, e_{12}, e_{13}, \dots, e_{1n} \in V(B_1(K_{1,n}))$. $B_1(K_{1,n})$ has $2n+1$ vertices and $2n+1$ and $(n(3n-1))/2$ edges.

Let $f_i = (v_i, e_{1,i+1}) \in E(B_1(K_{1,n}))$, where $i = 1, 2, \dots, n$ and $f_{n-1} = (v_{n-1}, e_{12})$.

Let $D' = \{f_1, f_2, \dots, f_{n-1}\} \subseteq E(B_1(K_{1,n}))$. Since each edge in $E(B_1(K_{1,n}))$ is either in D' (or) is adjacent to an edge in D' , it follows that the set D' is an edge dominating set of $B_1(K_{1,n})$.

Therefore, $\gamma'(B_1(K_{1,n})) \leq |D'| = (n+4)/3$.

Also D' is a minimum edge dominating set of $B_1(K_{1,n})$, since for any edge $f_i \in D'$ the set $D' - \{f_i\}$ does not dominate the edge f_i . Any edge of the form (v_i, e_{jk}) ($j, k \neq i$), where e_{jk} is not incident with v_i , dominates $n+4$ edges. But $B_1(K_{1,n})$ has $(n(3n-1))/2$ edges. To dominate all the edges of $B_1(K_{1,n})$ an edge dominating set of $B_1(K_{1,n})$ must contain atleast $(n+4)/3$ edges.

Therefore, $\gamma'(B_1(K_{1,n})) \geq (n+4)/3$ and hence $\gamma'(B_1(K_{1,n})) = (n+4)/3$.

A Wheel W_n on n vertices is defined as $W_n = C_{n-1} + K_1$, where $n \geq 4$.

In the following, edge domination number of $B_1(W_n)$ is found.

Theorem 2.5: For the Wheel W_n on n ($n \geq 7$) vertices, $\gamma'(B_1(W_n)) = n-1$.

Proof: Let $v_1, v_2, v_3, \dots, v_n$ be the vertices with v_1 as the central vertex and $e_{12}, e_{13}, \dots, e_{1n}$ be the edges in W_n , where $e_{1,i+1} = (v_1, v_{i+1})$, $i = 2, 3, \dots, n$. Then $v_1, v_2, \dots, v_n, e_{12}, e_{13}, \dots, e_{1n} \in V(B_1(W_n))$.

$B_1(W_n)$ has $2n-1$ vertices and $((n-1)(3n-4))/2$.

Let $f_i = (v_i, e_{1,i+1}) \in E(B_1(W_n))$, where $i = 1, 2, \dots, n$ and $f_{n-1} = (v_{n-1}, e_{12})$.

Let $D' = \{f_1, f_2, \dots, f_{n-1}\} \subseteq E(B_1(W_n))$

Since each edge in $E(B_1(W_n))$ is either in D' (or) is adjacent to an edge in D' , it follows that the set D' is an edge dominating set of $B_1(W_n)$. Therefore $\gamma'(B_1(W_n)) \leq |D'| = n-1$.

Also D' is an minimum edge dominating set of $B_1(W_n)$, since for any edge $f_i \in D'$ the set $D' - \{f_i\}$ does not dominate the edge f_i . Any edge of the form (v_i, e_{jk}) ($j, k \neq i$), where e_{jk} is not incident with v_i , dominates $n-1$ edges. But $B_1(W_n)$ has $((n-1)(3n-4))/2$ edges.

To dominate all the edges of $B_1(W_n)$, an edge dominating set of $B_1(W_n)$ must contain atleast $(n-1)$ edges.

Therefore, $\gamma'(B_1(W_n)) \geq n-1$ and hence $\gamma'(B_1(W_n)) = n-1$.

Theorem 2.6: If $G \cong nK_2$, $n \geq 2$, then $\gamma'(B_1(nK_2)) = n$.

Proof: Let D' be a minimum edge dominating set of nK_2 . Then $|D'| = n$. Since $L(nK_2)$ is totally disconnected, D' is also an edge dominating set of $B_1(G)$. Also any edge dominating set of $B_1(G)$ having less than n edges of $B_1(G)$ is not an edge dominating set of $B_1(G)$. Therefore, $\gamma'(B_1(nK_2)) = n$.

Remark 2.1: Since G and $L(G)$ are induced subgraphs of $B_1(G)$, $\gamma'(B_1(G)) \geq \gamma'(G)$ and $\gamma'(B_1(G)) \geq \gamma'(L(G))$. But any edge dominating set of G or $L(G)$ is not an edge dominating set of $B_1(G)$, $\gamma'(B_1(G)) > \gamma'(G)$ and $\gamma'(B_1(G)) > \gamma'(L(G))$.

In the following, upper bounds of $\gamma'(B_1(G))$ are obtained.

Theorem 2.7: For any graph G , $\gamma'(B_1(G)) \leq \gamma'(G) + \gamma'(L(G))$, where $L(G)$ is the line graph of G .

Proof: Let D be a dominating set of G and let D' be a dominating set of $L(G)$. Then the set $D \cup D'$ is an edge dominating set of $B_1(G)$. Hence $\gamma'(B_1(G)) \leq \gamma'(G) + \gamma'(L(G))$.

This bound is attained if $G \cong P_3, C_3$ or C_4 .

Theorem 2.8.: For any graph G with p vertices, $\gamma'(B_1(G)) \leq p + \gamma'(L(G))$

Proof: Let D' be a dominating set of $L(G)$. Then $V(G) \cup D'$ is an edge dominating set of $B_1(G)$ and hence $\gamma'(B_1(G)) \leq |V(G) \cup D'| = p + \gamma'(L(G))$.

Theorem 2.9: For any graph G with q edges, $\gamma'(B_1(G)) \leq q + \gamma'(G)$

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Proof: Let D be a dominating set of G . Then $V(L(G)) \cup D$ is an edge dominating set of $B_1(G)$ and hence $\gamma'(B_1(G)) \leq |V(L(G)) \cup D| = q + \gamma'(G)$.

Theorem 2.10: For any graph G , $\gamma'(B_1(G)) > \gamma'(G)$, if P_3 is a subgraph of G .

Proof: Assume P_3 is a subgraph of G . Then $L(G)$ has atleast one edge. Let D' be a minimum edge dominating set of G . Since G is an induced subgraph of $B_1(G)$, D' dominates edges of $B_1(G)$ corresponding to the edges in G . To dominate the edges in $E(L(G)) \cap E(B_1(G))$, atleast one edge in $B_1(G)$ is to be included with D' . Hence $\gamma'(B_1(G)) > \gamma'(G)$, if P_3 is a subgraph of G .

Theorem 2.11: $\gamma'(B_1(G)) = 1$ if and only if $G \cong K_2$

Proof: Let D' be a dominating set of $B_1(G)$ such that $|D'| = 1$. Let $D' = (x_1, x_2) \in E(B_1(G))$

Case i: Let $e_1 = (x_1, x_2)$. Then $e_1 \in E(G)$ and if there exists an $e_2 \in E(G)$ such that e_2 is adjacent to e_1 , then the edge $(e_1, e_2) \in E(B_1(G))$ is adjacent e_1 in $B_1(G)$.

Case ii: $x_1 \in V(G)$, $x_2 \in E(G)$.

Let $x_2 = (u_2, v_2)$ where $u_2, v_2 \in V(B_1(G))$ and the edge

$(x_1, x_2) \in E(B_1(G))$ and the edge $x_2 \in E(G)$ is not incident with x_1 in G .

That is $u_2, v_2 \neq x_1$ in G . Then the edge $(u_2, v_2) \in E(B_1(G))$ is not adjacent to both x_1 and x_2 .

Case iii: $x_1, x_2 \in E(G)$.

Let $x_1 = (u_1, v_1)$, $x_2 = (u_2, v_2)$ where $u_1, v_1, u_2, v_2 \in V(G)$. Then x_1, x_2 are adjacent edges in G . Let $v_1 = u_2$. Then the edge $(u_1, v_1) \in E(B_1(G))$ is not adjacent to the edge (x_1, x_2) in $B_1(G)$. Therefore, G has exactly one edge $G \cong K_2$.

Conversely, if $G \cong K_2$, then $\gamma'(B_1(G)) = 1$.

Theorem 2.12: Let e_1 and e_2 be two edges in G . Then $\{e_1, e_2\}$ is a edge dominating set of $B_1(G)$ if and only if $G \cong 2K_2$.

Proof: Let $e_1 = (x_1, x_2)$ and $e_2 = (x_3, x_4)$ where $x_1, x_2, x_3, x_4 \in V(G)$.

Case i: $D' = \{e_1, e_2\} \subseteq E(B_1(G))$.

Then they are adjacent in $B_1(G)$. Let $e_1 = (x_1, x_2)$ and $e_2 = (x_2, x_4)$. Then the edge $(e_1, e_2) \in E(B_1(G))$ is not adjacent to both e_1 and e_2 .

Case ii: e_1 and e_2 are nonadjacent edges in G .

Then they are nonadjacent in $B_1(G)$. Let $e_1 = (x_1, x_2)$ and $e_2 = (x_3, x_4)$ then the edge $(e_1, e_2) \in E(B_1(G))$ and D' is a edge dominating set of $B_1(G)$ if $G \cong 2K_2$.

Conversely, if $G \cong 2K_2$, then the vertices in $B_1(G)$ corresponding to two edges in $2K_2$ forms a minimum edge dominating set of $B_1(G)$.

Remark 2.2: Let $v_1, v_2 \in V(G)$ and $e_i \in E(G)$ ($i = 1, 2$) be the edges in G not incident with v_i and let $e_{11} = (v_1, e_1)$, $e_{12} = (v_2, e_2)$. Then $\{e_{11}, e_{12}\} \subseteq E(B_1(G))$ is an edge dominating set of $B_1(G)$ if and only if $G \cong P_3$.

Remark 2.3: For any connected graph G , let D' be an edge dominating set of G and let v be a vertex in G not incident with any of the edges in D' . Let D'' be the set of edges in G corresponding to the saturated vertices of maximum matching in $L(G)$. If the edges of G not incident with v are elements of D'' , then $D' \cup D''$ is an edge dominating set of $B_1(G)$ and hence $\gamma'(B_1(G)) \leq \gamma'(G) + \beta_1'(L(G))$, where β_1' is the independence number of $L(G)$.

Theorem 2.13: Let G be a graph having P_3 as an induced subgraph and let H be the set of all edges joining vertices of the subgraph $G - P_3$ of G and P_3 . Then $\gamma'(B_1(G)) \leq \gamma'(\langle H \rangle) + 3$.

Proof: Let $V(P_3) = (v_1, v_2, v_3)$ and $E(P_3) = \{e_{12}, e_{23}\}$, where $e_{12} = (v_1, v_2)$, $e_{23} = (v_2, v_3)$.

Then $(v_1, v_2), (v_2, v_3), (e_{12}, e_{23}) \in E(B_1(G))$. Let D be a minimum edge dominating set of $\langle H \rangle$. Therefore, $|D| = \gamma'(\langle H \rangle)$

Then the set $D' = \{(v_1, v_2), (v_2, v_3), (e_{12}, e_{23})\} \cup D \subseteq E(B_1(G))$ is an edge dominating set of $B_1(G)$ and hence

$\gamma'(B_1(G)) \leq |D'| = 3 + \gamma'(\langle H \rangle)$.

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Remark 2.3: (1) In general, if P_n is an induced subgraph of G and if H be the set of edges joining vertices of the subgraph $G - P_n$ of G to vertices of P_n , then $\gamma'(B_1(G)) \leq |E(P_n)| + |E(L(P_{n-1}))| + \gamma'(\langle H \rangle)$

$$= n - 1 = n - 2 + \gamma'(\langle H \rangle) = 2n - 3 + \gamma'(\langle H \rangle)$$

(2) If C_n ($n \geq 3$) is the smallest cycle in G and if H is the set of all edges joining vertices of the subgraph $G - C_n$ of G to vertices of C_n , then $\gamma'(B_1(G)) \leq 2n + \gamma'(\langle H \rangle)$.

Theorem 2.14: Let G be a unicyclic graph with p vertices. Then $\gamma'(B_1(G)) \leq p$, $p \geq 3$.

Proof: Since G is unicyclic, the number of edges in G is p . Let v_1, v_2, \dots, v_p be the vertices of G and let $\deg_G(v_i) = d_i$. Then there are $t_i = p - d_i$ edges in G not incident with v_i . For each v_i in G , choose an edge e_i not incident v_i , such that e_i are distinct. Let $D = \{(v_i, e_i) : i = 1, 2, \dots, p\}$. Then D is an edge dominating set of $B_1(G)$.

Hence $\gamma'(B_1(G)) \leq |D| = p$.

III. CONCLUSION

In this paper, edge domination numbers of Boolean Function Graph $B(G, L(G), NINC)$ of paths, cycles, complete graphs, stars, wheels and union of K_2 are found and bounds are obtained.

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