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Inverse Domination Number and Inverse Total Domination of Sierpinski Star Graph

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ABSTRACT: *Given a graph* $\boldsymbol{G} = (\boldsymbol{V}(\boldsymbol{G}), \boldsymbol{E}(\boldsymbol{G}))$ *consisting of the set of vertices* $\boldsymbol{V}(\boldsymbol{G})$ *and the set of edges* $\boldsymbol{E}(\boldsymbol{G})$. *For example,* $\boldsymbol{D}(\boldsymbol{G})$ *is a domination set of graph* $\boldsymbol{G}$ *with minimum cardinality, if* $\boldsymbol{V}(\boldsymbol{G}) - \boldsymbol{D}(\boldsymbol{G})$ *contains a domination set* $\boldsymbol{D}^{-1}(\boldsymbol{G})$, *then* $\boldsymbol{D}^{-1}(\boldsymbol{G})$ *is called the inverse domination set of graph* $\boldsymbol{G}$. *The minimum cardinality of the inverse domination set of the graph* $\boldsymbol{G}$ *is called the inverse domination number, denoted by* $\boldsymbol{\gamma}^{-1}(\boldsymbol{G})$. *If* $\boldsymbol{D}_t(\boldsymbol{G})$ *is the total domination set of the graph* $\boldsymbol{G}$ *with minimal cardinality, and* $\boldsymbol{V}(\boldsymbol{G}) - \boldsymbol{D}_t(\boldsymbol{G})$ *contains the total domination set* $\boldsymbol{D}_t^{-1}(\boldsymbol{G})$, *then* $\boldsymbol{D}_t^{-1}(\boldsymbol{G})$ *is called the inverse total domination set of the graph* $\boldsymbol{G}$. *The minimum cardinality of the inverse total domination set of the graph* $\boldsymbol{G}$ *is called the inverse total domination number, denoted by* $\boldsymbol{\gamma}_t^{-1}(\boldsymbol{G})$. *This paper discusses the inverse domination and the inverse total domination on the Sierpinski Star graph* $\boldsymbol{SS_n}$, *obtained the inverse domination number* $\boldsymbol{\gamma}^{-1}(\boldsymbol{SS_n}) = \boldsymbol{0}$ *for* $\boldsymbol{n} < \boldsymbol{3}$ *and* $\boldsymbol{\gamma}^{-1}(\boldsymbol{SS_n}) = \boldsymbol{4 \cdot 3^{n-3}}$ *for* $\boldsymbol{n} \geq \boldsymbol{3}$ *and the inverse total domination number* $\boldsymbol{\gamma}_t^{-1}(\boldsymbol{SS_n}) = \boldsymbol{0}$ *for* $\boldsymbol{n} \geq \boldsymbol{1}$.

KEYWORDS: Sierpinski star graph, inverse domination, inverse total domination

INTRODUCTION

Graph theory was first introduced in 1736 by Leonhard Euler, a Swiss mathematician, in solving the Konigsberg bridge problem (J. Wilson, 2010). Domination is an essential topic in graph theory because of its broad scope and potential for solving real-life problems. For example, in a computer network, the domination set D represents a collection of core computers as servers to communicate directly with other computers.

Every server is connected with a minimum of one backup server as a place to store duplicate information. The backup computer will replace the core computer if an error occurs in the network or some D server computers cannot connect successfully to other computers. This leads to determining the inverse domination number, namely determining the optimal number of computers in a computer network (Kulli & Iyer, 2007).

Some studies related to inverse domination include "Inverse Total Domination Number on Flower Graphs and Trampoline Graphs" by Febby Desy Lia in 2022, which obtained the inverse total domination number on flower graphs $\gamma_t^{-1}(Fl_n) = n$, for $n \geq 3$, $n \in \mathbb{N}$, and on trampoline graphs obtained $\gamma_t^{-1}\left(T(K_n)\right) = \frac{n}{2}$ (Lia et al., 2022). "Inverse Total and Inverse Numbers of Total Domination on Certain Graphs" by Shalini in 2021 received the total domination and inverse domination numbers on the lollipop graph, dragonfly graph, and jellyfish graph (Shalini & Rajasingh, 2021). "Inverse Domination and Inverse Total Domination on Undirected Graphs $G_{m,n}$" by Syeda Asma Kauser in 2020, the exact values of $\gamma^{-1}(G_{m,n})$ and $\gamma_t^{-1}(G_{m,n})$ are obtained for different values of m,n (Kauser et al., 2020). "Inverse Total Domination in the Corona and Join of Graphs" discussed in 2016 by V.R. Kulli, can determine the inverse total domination numbers of $G_1 \circ G_2$ and $G_1 \cup G_2$ (Kulli, 2016).

In this paper, the author analyzes the inverse domination and inverse total domination in Sierpinski Star graphs. The Sierpinski Star Graph has a unique structure because it is constructed from Sierpinski triangle (Khabibah & Munawwaroh, 2021).

DISCUSSION

Definition 2.1 (Kulli & Sigarkanti, 1991) *Given a graph $G = \left(V(G), E(G)\right)$ is formed from vertex set $V(G)$and edge set $E(G)$. Suppose $D(G)$ is the minimum domination set of graph G. If $V(G) - D(G)$ contains a domination set $D^{-1}(G)$ of graph G, then $D^{-1}(G)$ is called the inverse domination set of the graph G. The minimum cardinality of the inverse domination set of the graph G is called the inverse domination number denoted by $\gamma^{-1}(G)$.*

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Example 2.1 Given a graph G_1 .

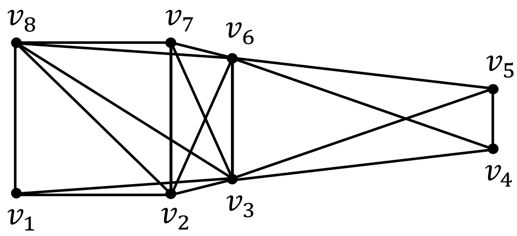

Figure 2.1 Graph G_1

From the graph G_1, a domina m cardinality one is obtained, $D(G_1) = \{v_3\}$. As a result, $V(G_1) - D(G_1) = \{v_1, v_2, v_4, v_5, v_6, v_7, v_8\}$, where all vertices are adjacent to vertex v_3. Therefore, $D(G_1)$ is the domination set of the graph G_1.

The set $V(G_1) - D(G_1)$ contains another dominance set, $D^{-1}(G_1) = \{v_1, v_6\}$, because vertex v_1 dominates vertex v_2, v_3, v_8 and vertex v_6 dominates vertex $v_2, v_3, v_4, v_5, v_7, v_8$, $D^{-1}(G_1)$ is the inverse domination set in graph G_1 with inverse domination number $\gamma^{-1}(G_1) = 2$.

Next, we discuss the definition of the Sierpinski Star Graph SS_n and its example.

Definition 2.2 (Khabibah & Munawwaroh, 2021) Sierpinski Star Graph SS_n, *defined as follows, for* SS_1 *consists of only one vertex, for* $n \geq 2$, *the vertex set of* SS_n *consists of* $(n-1)$*-tuples of numbers 0,1,2,3 that is* $V(SS_n) = \{0,1,2,3\}^{n-1}$. *Two vertex* $u = (u_1, u_2, \dots, u_{n-1})$ *with* $u_i \in \{0,1,2,3\}$ *and* $v = (v_1, v_2, \dots, v_{n-1})$ *with* $v_i \in \{1,2,3\}$ *are said to be adjacent if and only if there exists* $k \in \{1,2,\dots,n-1\}$ *such that*

i. $u_i = 0$ *for* $i = k, k+1, \dots, n-1$
ii. $u_i = v_i$ *for* $i = 1,2,\dots,k-1$
iii. $v_i \neq v_k$ *for* $i = k+1, k+2, \dots, n-1$
Furthermore, the vertex $(u_1, u_2, \dots, u_{n-1})$ *is written as* $\langle u_1 u_2 \dots u_{n-1} \rangle$.

Example 2.2 Given a Sierpinski Star Graph SS_3 with $|V(SS_3)| = 13$ and a Sierpinski Star Graph SS_4 with $|V(SS_4)| = 40$ as follows.

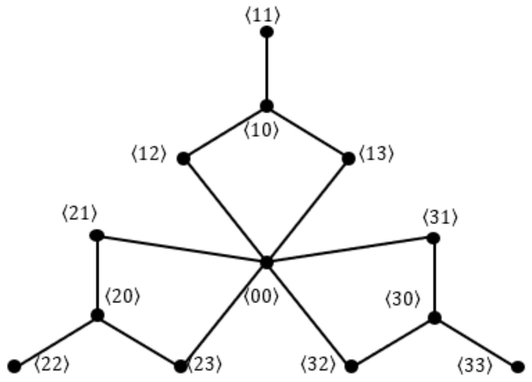

Figure 2.2 Sierpinski Star Graph SS_3

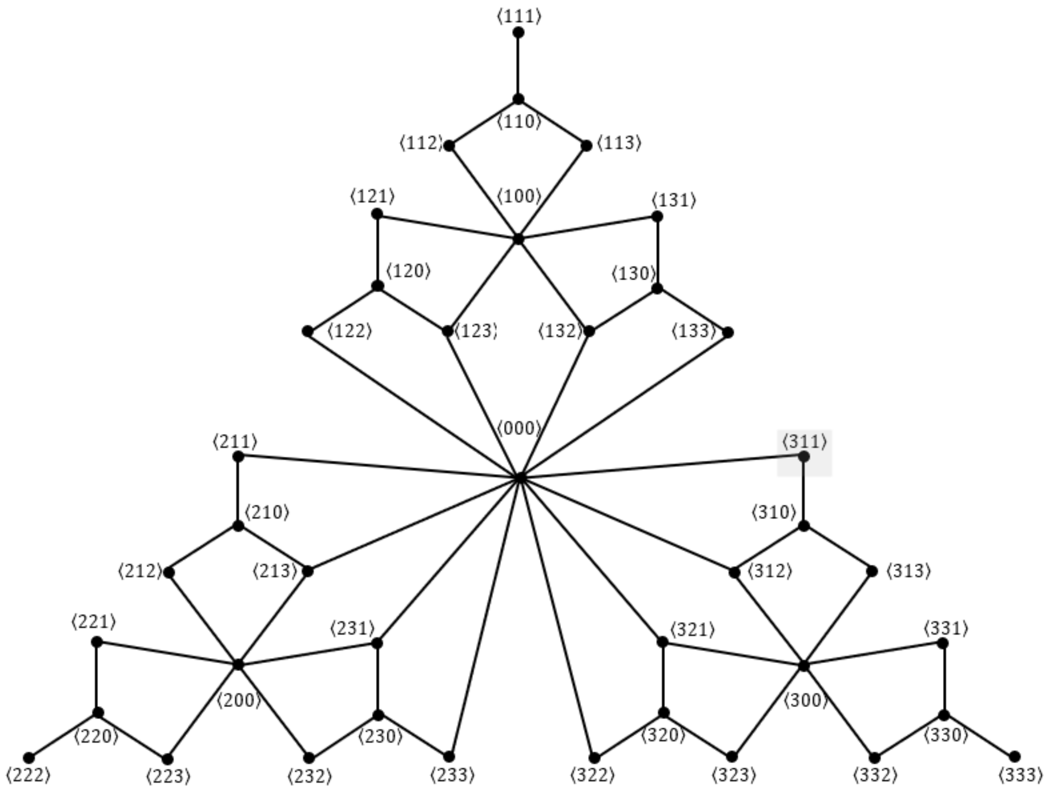

Figure 2.3 Sierpinski Star Graph SS_4

Theorem 2.1 *If SS_n is a Sierpinski Star Graph, then*

$$\gamma^{-1}(SS_n) = \begin{cases} 0, if \;\; n < 3 \\ 4 \cdot 3^{n-3}, if \;\; n \geq 3 \end{cases}, \text{ for } n \in \mathbb{N}.$$

Proof.

Given a Sierpinski Star Graph SS_n. If $n < 3$, then the minimum number of members in SS_n that satisfy $d(v, D_1(SS_n)) \leq 1$ is one or $\gamma(SS_n) = 1$. However, the set $V(SS_n) - D_1(SS_n)$ contains the isolated vertex, so the minimum number of members in SS_n that satisfy $d(v, D_1^{-1}(SS_n)) \leq 1$ does not exist or $\gamma^{-1}(SS_n) = 0$.

Furthermore, the following is obtained by mathematical induction:

a. **Base Induction**

Based on Figure 2.2, if $n = 3$, it can be seen that the minimum number of members in the graph SS_3 that satisfy $d(v, D_1(SS_3)) \leq 1$ is four, that is $D_1(SS_3) = \{\langle 00\rangle, \langle 11\rangle, \langle 22\rangle, \langle 33\rangle\}$. Therefore, $D_1(SS_3)$ is a 1-distance domination set or domination set of graph SS_3 with a minimum cardinality of four, so the domination number of graph SS_3 is $\gamma(SS_3) = 4$.

Then, from the domination set, we get $V(SS_3) - D_1(SS_3) = \{\langle 10\rangle, \langle 12\rangle, \langle 13\rangle, \langle 20\rangle, \langle 21\rangle, \langle 23\rangle, \langle 30\rangle, \langle 31\rangle, \langle 32\rangle\}$. The set $V(SS_3) - D_1(SS_3)$ contains the 1-distance domination set or the other domination set, suppose $D_1^{-1}(SS_3)$. The minimum number of members that satisfy $d(v, D_1^{-1}(SS_3)) \leq 1$ is four, that is $D_1^{-1}(SS_3) = \{\langle 10\rangle, \langle 12\rangle, \langle 20\rangle, \langle 30\rangle\}$. Therefore, $D_1^{-1}(SS_3)$ is the inverse domination set of graph SS_3 with minimum cardinality four and the inverse domination number of graph SS_3 is $\gamma^{-1}(SS_3) = 4$. So, every inverse domination set in graph SS_3 has a minimum cardinality of four. Thus, based on Theorem 2.1, it is obtained that if $n = 3$, then $\gamma^{-1}(SS_n) = 4 \cdot 3^{n-3} = 4 \cdot 3^{3-3} = 4 \cdot 3^0 = 4 \cdot 1 = 4$. That is, the statement $\gamma^{-1}(SS_n) = 4 \cdot 3^{n-3}$ is true when $n = 3$.

b. **Inductive Induction**

The statement $\gamma^{-1}(SS_k) = 4 \cdot 3^{(k-3)}$ is assumed valid for $n = k$, where k is a certain natural number and $k > 3$. Then, it will be proved based on the induction assumption that this statement is also true for $n = k + 1$, that is $\gamma^{-1}\left(SS_{(k+1)}\right) = 4 \cdot 3^{(k+1-3)} = 4 \cdot 3^{(k-2)}$. Previously, based on manual calculation, the inverse domination number of the Sierpinski Star Graph, where $k \geq 3$, is obtained as follows:

$\gamma^{-1}(SS_3) = 4$

$\gamma^{-1}(SS_4) = 12 = \gamma^{-1}(SS_3) \cdot 3$

$\gamma^{-1}(SS_5) = 36 = \gamma^{-1}(SS_4) \cdot 3$

$\vdots$

$\gamma^{-1}(SS_n) = \gamma^{-1}\left(SS_{(n-1)}\right) \cdot 3$

$\gamma^{-1}(SS_{n+1}) = \gamma^{-1}\left(SS_{(n)}\right) \cdot 3$

so, because $n = k$, then $\gamma^{-1}(SS_{k+1}) = \gamma^{-1}\left(SS_{(k)}\right) \cdot 3$.

$\gamma^{-1}(SS_{k+1}) = \gamma^{-1}\left(SS_{(k)}\right) \cdot 3$

$\gamma^{-1}\left(SS_{(k+1)}\right) = \left(4 \cdot 3^{(k-3)}\right) \cdot 3$

$\gamma^{-1}\left(SS_{(k+1)}\right) = 4 \cdot 3^{(k-3)+1}$

$\gamma^{-1}\left(SS_{(k+1)}\right) = 4 \cdot 3^{(k-2)}$

Therefore, it has been proved that $\gamma^{-1}\left(SS_{(k+1)}\right) = 4 \cdot 3^{(k+1-3)} = 4 \cdot 3^{(k-2)}$, where $k \geq 3$. So, this statement is also true for $n = k + 1$.

Based on the mathematical induction above, it is proved that for every Sierpinski Star Graph SS_n, $\gamma^{-1}(SS_n) = 0$ for $n < 3$ and $\gamma^{-1}(SS_n) = 4 \cdot 3^{n-3}$ for $n \geq 3$. ■

Example 2.3 Given a Sierpinski Star Graph SS_4 as in Figure 2.3 with vertex set as follows:

$V(SS_4) = \{\langle 000\rangle, \langle 100\rangle, \langle 110\rangle, \langle 111\rangle, \langle 112\rangle, \langle 113\rangle, \langle 120\rangle, \langle 121\rangle, \langle 122\rangle, \langle 123\rangle,$
$\langle 130\rangle, \langle 131\rangle, \langle 132\rangle, \langle 133\rangle, \langle 200\rangle, \langle 210\rangle, \langle 211\rangle, \langle 212\rangle, \langle 213\rangle, \langle 220\rangle,$
$\langle 221\rangle, \langle 222\rangle, \langle 223\rangle, \langle 230\rangle, \langle 231\rangle, \langle 232\rangle, \langle 233\rangle, \langle 300\rangle, \langle 310\rangle, \langle 311\rangle,$
$\langle 312\rangle, \langle 313\rangle, \langle 320\rangle, \langle 321\rangle, \langle 322\rangle, \langle 323\rangle, \langle 330\rangle, \langle 331\rangle, \langle 332\rangle, \langle 333\rangle\},$

obtained domination set with minimum cardinality

$D(SS_4) = \{\langle 100\rangle, \langle 111\rangle, \langle 122\rangle, \langle 133\rangle, \langle 200\rangle, \langle 211\rangle, \langle 222\rangle, \langle 233\rangle, \langle 300\rangle, \langle 311\rangle,$
$\langle 322\rangle, \langle 333\rangle\},$

hence the domination number of the graph SS_4 is $\gamma(SS_4) = 12$.

Then, from the domination set obtained

$V(SS_4) - D(SS_4) = \{\langle 000\rangle, \langle 110\rangle, \langle 112\rangle, \langle 113\rangle, \langle 120\rangle, \langle 121\rangle, \langle 123\rangle, \langle 130\rangle, \langle 131\rangle,$
$\langle 132\rangle, \langle 210\rangle, \langle 212\rangle, \langle 213\rangle, \langle 220\rangle, \langle 221\rangle, \langle 223\rangle, \langle 230\rangle, \langle 231\rangle,$

$\langle 232\rangle, \langle 310\rangle, \langle 312\rangle, \langle 313\rangle, \langle 320\rangle, \langle 321\rangle, \langle 323\rangle, \langle 330\rangle, \langle 331\rangle,$
$\langle 332\rangle\}$.

From Figure 2.3, it can be seen that the vertices contained in $V(SS_4) - D(SS_4)$ are adjacent, and there is no isolated vertex, so $V(SS_4) - D(SS_4)$ contains another domination set, let $D^{-1}(SS_4)$, that is $D^{-1}(SS_4) = \{\langle 110\rangle, \langle 120\rangle, \langle 130\rangle, \langle 132\rangle, \langle 210\rangle, \langle 213\rangle, \langle 220\rangle, \langle 230\rangle, \langle 310\rangle, \langle 312\rangle, \langle 320\rangle, \langle 330\rangle\}$. Thus, $D^{-1}(SS_4)$ is the inverse domination set on graph SS_4 with inverse domination number $\gamma^{-1}(SS_4) = 12$.

Definition 2.3 (Kulli & Iyer, 2007) *Given a graph $G = (V(G), E(G))$ is formed from the set of edges $V(G)$ and vertices $E(G)$. Suppose $D_t(G) \subseteq V(G)$, the minimum total domination set on graph G. If $V(G) - D_t(G)$ contains a total domination set $D_t^{-1}(G)$, then $D_t^{-1}(G)$ is the inverse total domination set of graph G. The minimum cardinality of the inverse total domination set of the graph G is called the inverse total domination number denoted by $\gamma_t^{-1}(G)$.*

Example 2.4 Based on Figure 2.1, in Example 2.2, the total domination set with minimum cardinality two can be obtained, that is $D_t(G_1) = \{v_2, v_3\}$, because $N(v_2) = \{v_1, v_3, v_6, v_7, v_8\}$ and $N(v_3) = \{v_1, v_2, v_4, v_5, v_6, v_7, v_8\}$, so that it satisfies $N(D_t) = N(v_2) \cup N(v_3) = V(G_1)$.
From the total domination set, we get $V(G_1) - D_t(G_1) = \{v_1, v_4, v_5, v_6, v_7, v_8\}$, where all vertices are connected and there are no isolated vertices. Therefore, the set $V(G_1) - D_t(G_1)$ contains another total domination set, that is $D_t^{-1}(G_1) = \{v_6, v_8\}$, since $N(v_6) = \{v_2, v_3, v_4, v_5, v_7, v_8\}$ and $N(v_8) = \{v_1, v_2, v_3, v_6, v_7\}$, so that $N(D_t^{-1}) = N(v_6) \cup N(v_8) = V(G_1)$. Therefore, $D_t^{-1}(G_1)$ is the inverse total domination set on graph G_1, with the inverse total domination number being $\gamma_t^{-1}(G_1) = 2$.

Theorem 2.2 *If SS_n is a Sierpinski Star Graph, then*

$$\gamma_t^{-1}(SS_n) = 0, if\ n \geq 1 \text{ for } n \in \mathbb{N}.$$

Proof.

Given a Sierpinski Star Graph SS_n. If $n \geq 1$, then the minimum number of members in SS_n satisfying $d(v, D_t(SS_n)) \leq 1$ can be divided into two cases, as follows:

Case 1: If $n < 3$, then $\gamma_t(SS_n) = n$ and $\gamma_t^{-1}(SS_n) = 0$

Given a Sierpinski Star Graph SS_n. If $n < 3$, then the minimum number of members in $SS_{n<3}$ satisfying $d(v, D_t(SS_{n<3})) \leq 1$ is n or $\gamma_t(SS_{n<3}) = n$. Furthermore, the set $V(SS_{n<3}) - D_t(SS_{n<3})$ contains the isolated vertex, so it does not contain any other total domination set. Thus, every total domination set in graph $SS_{n<3}$ does not have an inverse total domination set because the minimum number of members in $SS_{n<3}$ that satisfy $d(v, D_t^{-1}(SS_{n<3})) \leq 1$ does not exist or $\gamma_t^{-1}(SS_{n<3}) = 0$.

Case 2: If $n \geq 3$, then $\gamma_t(SS_n) = 6.3^{n-3}$ and $\gamma_t^{-1}(SS_n) = 0$

Given a Sierpinski Star Graph SS_n. If $n \geq 3$, then the minimum number of members in $SS_{n<3}$ satisfying $d(v, D_t(SS_{n\geq3})) \leq 1$ is 6.3^{n-3} or $\gamma_t(SS_{n\geq3}) = 6.3^{n-3}$. Furthermore, the set $V(SS_{n\geq3}) - D_t(SS_{n\geq3})$ contains the isolated vertex, so it does not contain any other total domination set. Thus, every total domination set in graph $SS_{n\geq3}$ does not have an inverse total domination set because the minimum number of members in $SS_{n\geq3}$ that satisfy $d(v, D_t^{-1}(SS_{n\geq3})) \leq 1$ does not exist or $\gamma_t^{-1}(SS_{n\geq3}) = 0$.

Based on the above explanation, it is proven that for every Sierpinski Star Graph SS_n, it holds that $\gamma_t^{-1}(SS_n) = 0$ for $n \geq 1$. ■

Example 2.5 Given a Sierpinski Star Graph SS_4 as in Figure 2.3 with vertex set as follows:

$$V(SS_4) = \{\langle 000\rangle, \langle 100\rangle, \langle 110\rangle, \langle 111\rangle, \langle 112\rangle, \langle 113\rangle, \langle 120\rangle, \langle 121\rangle, \langle 122\rangle, \langle 123\rangle, \langle 132\rangle, \langle 133\rangle, \langle 200\rangle, \langle 210\rangle, \langle 211\rangle, \langle 212\rangle, \langle 213\rangle, \langle 220\rangle, \langle 221\rangle, \langle 222\rangle, \langle 223\rangle, \langle 230\rangle, \langle 231\rangle, \langle 232\rangle, \langle 233\rangle, \langle 300\rangle, \langle 310\rangle, \langle 311\rangle, \langle 312\rangle, \langle 313\rangle, \langle 320\rangle, \langle 321\rangle, \langle 322\rangle, \langle 323\rangle, \langle 330\rangle, \langle 331\rangle, \langle 332\rangle, \langle 333\rangle\}.$$

Suppose the open neighborhood set of each vertex in the Sierpinski Star Graph SS_4 is:

$$N(\langle 000\rangle) = \{\langle 122\rangle, \langle 123\rangle, \langle 132\rangle, \langle 133\rangle, \langle 211\rangle, \langle 213\rangle, \langle 231\rangle, \langle 233\rangle, \langle 311\rangle, \langle 312\rangle, \langle 321\rangle, \langle 322\rangle\};$$

$$N(\langle 100\rangle) = \{\langle 112\rangle, \langle 113\rangle, \langle 121\rangle, \langle 123\rangle, \langle 131\rangle, \langle 132\rangle\};$$

$N(\langle 110\rangle) = \{\langle 111\rangle, \langle 112\rangle, \langle 113\rangle\}$

$\vdots$

$N(\langle 333\rangle) = \{\langle 330\rangle\}$.

Based on the open neighborhood of each vertex in the graph SS_4 obtained

$$D_t(SS_4) = \{\langle 110\rangle, \langle 112\rangle, \langle 120\rangle, \langle 121\rangle, \langle 130\rangle, \langle 131\rangle, \langle 210\rangle, \langle 212\rangle, \langle 220\rangle, \langle 221\rangle, \langle 230\rangle, \langle 231\rangle, \langle 310\rangle, \langle 312\rangle, \langle 320\rangle, \langle 321\rangle, \langle 330\rangle, \langle 331\rangle\}.$$

It is a total domination set with minimum cardinality, so the total domination number of the graph SS_4 is $\gamma_t(SS_4) = 18$. However, the set $V(SS_4) - D_t(SS_4)$ contains the isolated vertices $\langle 111\rangle, \langle 222\rangle, \langle 333\rangle$. Thus, the graph SS_4 has no inverse total domination, so the inverse total domination number of the SS_4 is $\gamma_t^{-1}(SS_4) = 0$.

CONCLUSION

Based on the discussion of inverse domination and inverse total domination in Sierpinski Star Graph SS_n, it can be obtained that the inverse domination number in the Sierpinski Star Graph SS_n, $\gamma^{-1}(SS_n) = 0$ for $n < 3$ and $\gamma^{-1}(SS_n) = 4 \cdot 3^{n-3}$ for $n \geq 3$. The inverse total domination number on the Sierpinski Star Graph SS_n is $\gamma_t^{-1}(SS_n) = 0$ for $n \geq 1$.

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