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# Strong Triple Connected Domination Number of a Graph

[1,]G. Mahadevan, [2,]V. G. Bhagavathi Ammal, [3,] Selvam Avadayappan, [4,]T. Subramanian

[1,4]Dept. of Mathematics, Anna University : Tirunelveli Region, Tirunelveli.
[2]PG. Dept. of Mathematics, Sree Ayyappa College for Women, Chunkankadai, Nagercoil.
[3]Dept.of Mathematics, VHNSN College, Virudhunagar.

**Abstract:** The concept of triple connected graphs with real life application was introduced in [14] by considering the existence of a path containing any three vertices of a graph G. In [3], G. Mahadevan et. al., introduced Smarandachely triple connected domination number of a graph. In this paper, we introduce a new domination parameter, called strong triple connected domination number of a graph. A subset *S* of *V* of a nontrivial graph *G* is said to be smarandachely triple connected dominating set, if *S* is a dominating set and the induced sub graph <*S*> is triple connected. The minimum cardinality taken over all triple connected dominating sets is called the triple connected domination number and is denoted by $\gamma_{tc}$. A set $D \subseteq V(G)$ is a strong dominating set of G, if for every vertex $x \in V(G) - D$ there is a vertex $y \in D$ with $xy \in E(G)$ and $d(x,G) \leq d(y,G)$. The strong domination number $\gamma_{st}(G)$ is defined as the minimum cardinality of a strong domination set. A subset *S* of *V* of a nontrivial graph *G* is said to be strong triple connected dominating set, if *S* is a strong dominating set and the induced sub graph <*S*> is triple connected. The minimum cardinality taken over all strong triple connected dominating sets is called the strong triple connected domination number and is denoted by $\gamma_{stc}$. We determine this number for some standard graphs and obtain bounds for general graph. Its relationship with other graph theoretical parameters are also investigated.

**Key Words**: Domination Number, Triple connected graph, Strong Triple connected domination number

AMS Subject Classification: *05C 69*

## 1 Introduction

By a graph we mean a finite, simple, connected and undirected graph G(V, E), where V denotes its vertex set and E its edge set. Unless otherwise stated, the graph G has p vertices and q edges. Degree of a vertex v is denoted by d(v), the maximum degree of a graph G is denoted by $\Delta(G)$. We denote a cycle on p vertices by $C_p$, a path on p vertices by $P_p$, and a complete graph on p vertices by $K_p$. A graph G is connected if any two vertices of G are connected by a path. A maximal connected subgraph of a graph G is called a component of G. The number of components of G is denoted by $\omega(G)$. The complement $\overline{G}$ of G is the graph with vertex set V in which two vertices are adjacent if and only if they are not adjacent in G. A tree is a connected acyclic graph. A bipartite graph (or bigraph) is a graph whose vertex set can be divided into two disjoint sets $V_1$ and $V_2$ such that every edge has one end in $V_1$ and another end in $V_2$. A complete bipartite graph is a bipartite graph where every vertex of $V_1$ is adjacent to every vertex in $V_2$. The complete bipartite graph with partitions of order $|V_1|=m$ and $|V_2|=n$, is denoted by $K_{m,n}$. A star, denoted by $K_{1,p-1}$ is a tree with one root vertex and p – 1 pendant vertices. A bistar, denoted by B(m, n) is the graph obtained by joining the root vertices of the stars $K_{1,m}$ and $K_{1,n}$. The friendship graph, denoted by $F_n$ can be constructed by identifying n copies of the cycle $C_3$ at a common vertex. A wheel graph, denoted by $W_p$ is a graph with p vertices, formed by connecting a single vertex to all vertices of $C_{p-1}$. A helm graph, denoted by $H_n$ is a graph obtained from the wheel $W_n$ by attaching a pendant vertex to each vertex in the outer cycle of $W_n$. Corona of two graphs $G_1$ and $G_2$, denoted by $G_1 \circ G_2$ is the graph obtained by taking one copy of $G_1$ and $|V_1|$ copies of $G_2$ ($|V_1|$ is the number of vertices in $G_1$) in which $i^{th}$ vertex of $G_1$ is joined to every vertex in the $i^{th}$ copy of $G_2$. If S is a subset of V, then <S> denotes the vertex induced subgraph of G induced by S. The open neighbourhood of a set S of vertices of a graph G, denoted by N(S) is the set of all vertices adjacent to some vertex in S and $N(S) \cup S$ is called the closed neighbourhood of S, denoted by N[S]. The diameter of a connected graph is the maximum distance between two vertices in G and is denoted by diam(G). A cut – vertex (cut edge) of a graph G is a vertex (edge) whose removal increases the number of components. A vertex cut, or separating set of a connected graph G is a set of vertices whose removal results in a disconnected. The connectivity or vertex connectivity of a graph G, denoted by $\kappa(G)$ (where G is not complete) is the size of a smallest vertex cut. A connected subgraph H of a connected graph G is called a H -cut if $\omega(G - H) \geq 2$. The chromatic number of a graph G, denoted by $\chi(G)$ is the smallest number of colors needed to colour all the vertices of a graph G in which adjacent vertices receive different colour. For any real number $x$, $\lfloor x \rfloor$ denotes the largest integer less than or equal to $x$. A Nordhaus -Gaddum-type result is a (tight) lower or upper bound on the sum or product of a parameter of a graph and its complement. Terms not defined here are used in the sense of [2]. A subset S of V is called a dominating set of G if every vertex in V − S is adjacent to at least one vertex in S. The domination number $\gamma(G)$ of G is the minimum cardinality taken over all dominating sets in G. A dominating set S of a connected graph G is said to be a *connected dominating set* of G if the induced sub graph <S> is connected. The minimum cardinality taken over all connected dominating sets is the **connected domination number** and is denoted by $\gamma_c$. A subset $S$ of $V$ is called a **strong dominating set** of G, if for every vertex $x \in V(G) - D$ there is a vertex $y \in D$ with $xy \in E(G)$ and $d(x,G) \le d(y,G)$. The **strong domination number** $\gamma_{st}(G)$ is defined as the minimum cardinality of a strong domination set. One can get a comprehensive survey of results on various types of domination number of a graph in [17, 18, 19]**.**Many authors have introduced different types of domination parameters by imposing conditions on the dominating set [15, 16]. Recently, the concept of triple connected graphs has been introduced by Paulraj Joseph J. et. al.,[14] by considering the existence of a path containing any three vertices of G. They have studied the properties of triple connected graphs and established many results on them. A graph G is said to be **triple connected** if any three vertices lie on a path in G. All paths, cycles, complete graphs and wheels are some standard examples of triple connected graphs. In [3] Mahadevan G. et. al., introduced triple connected domination number of a graph and found many results on them.

A subset S of V of a nontrivial connected graph G is said to be **triple connected dominating set**, if S is a dominating set and the induced sub graph <S> is triple connected. The minimum cardinality taken over all triple connected dominating sets is called the **triple connected domination number** of G and is denoted by $\gamma_{tc}$(G). In [4, 5, 6, 7, 8, 9] Mahadevan G. et. al., introduced complementary triple connected domination number, paried triple connected domination number, complementary perfect triple connected domination number, triple connected two domination number, restrained triple connected domination number, dom strong triple connected domination number of a graph. In [10], the authors also introduced weak triple connected domination of a graph and established many results.In this paper, we use this idea to develop the concept of strong triple connected dominating set and strong triple connected domination number of a graph.

**Theorem 1.1 [14]** A tree $T$ is triple connected if and only if $T \cong P_p$; $p \geq 3$.
**Theorem 1.2 [14]** A connected graph $G$ is not triple connected if and only if there exists a$H$ -cut with $\omega(G - H) \geq 3$ such that $|V(H) \cap N(C_i)| = 1$ for at least three components $C_1$, $C_2$, and $C_3$ of $G - H$.
**Theorem 1.3** Let G be any graph and D be any dominating set of G. then $|V - D| \leq \sum_{u \in V(D)} \deg(u)$ and equality hold in this relation if and only if D has the following properties.

i. D is independent
ii. For every $u \in V - D$, there exists a unique vertex $v \in D$ such that $N(u) \cap D = \{v\}$

**Notation 1.4** Let $G$ be a connected graph with $m$ vertices $v_1, v_2, \ldots, v_m$. The graph obtained from $G$ by attaching $n_1$ times a pendant vertex of $P_{l_1}$ on the vertex $v_1$, $n_2$ times a pendant vertex of $P_{l_2}$ on the vertex $v_2$ and so on, is denoted by $G(n_1P_{l_1}, n_2P_{l_2}, n_3P_{l_3}, \ldots, n_mP_{l_m})$ where $n_i, l_i \geq 0$ and $1 \leq i \leq m$.
**Example 1.5** Let $v_1, v_2, v_3, v_4$, be the vertices of $K_5$. The graph $K_5(P_2, 3P_2, P_3, 2P_4, P_2)$ is obtained from $K_5$ by attaching 1 time a pendant vertex of $P_2$ on $v_1$, 3 time a pendant vertex of $P_2$ on $v_2$, 1 time a pendant vertex of $P_3$ on $v_3$ and 2 times a pendant vertex of $P_4$ on $v_4$, 1 time a pendant vertex of $P_2$ and is shown in Figure 1.1.

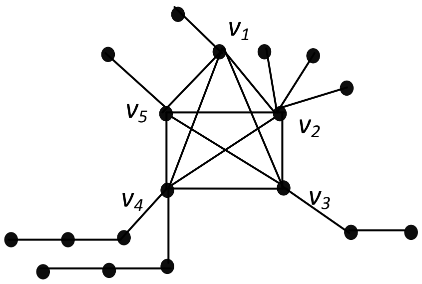


**Figure 1.1 : $K_5(P_2, 3P_2, P_3, 2P_4)$**

## 2 Strong Triple connected domination number

**Definition 2.1**

A subset $S$ of $V$ of a nontrivial graph $G$ is said to be a *strong triple connected dominating set*, if $S$ is a strong dominating set and the induced subgraph $<S>$ is triple connected. The minimum cardinality taken over all strong triple connected dominating sets is called the *strong triple connected domination number* of $G$ and is denoted by $\gamma_{stc}(G)$. Any strong triple connected dominating set with $\gamma_{stc}$ vertices is called a $\gamma_{stc}$ -set of $G$.
**Example 2.2** For the graph $H_1$ in Figure 2.1, $S = \{v_2, v_3, v_5\}$ forms a $\gamma_{stc}$ -set of $H_1$. Hence $\gamma_{stc}(H_1) = 3$

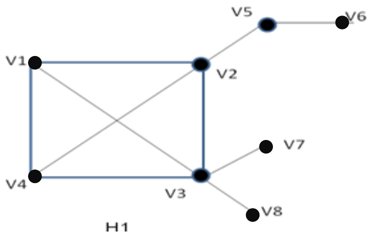


**Figure 2.1 : Graph with $\gamma_{stc}$ = 3.**

**Observation 2.3** Strong triple connected dominating set (stcd set) does not exists for all graphs and if exists, then $\gamma_{stc}(G) \geq 3$.

**Example 2.4** For the graph $G_1$ in Figure 2.2, any minimum dominating set must contain the supports and any connected subgraph containing these supports is not triple connected, which is a contradiction and hence $\gamma_{stc}$ does not exists.

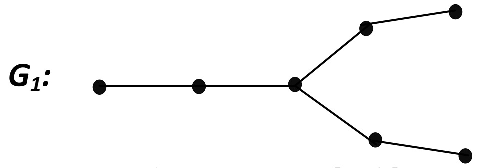


**Figure 2.2 : Graph with no stcd set**

Throughout this paper we consider only connected graphs for which strong triple connected dominating set exists.

**Preposition 2.5** Let D be any strong triple connected dominating set. Then $|V - D| < \sum_{u \in V(D)} d(u), \ \forall\ u \in D$.

**Proof** The proof follows directly from Theorem 1.3.

**Observation 2.6** Every strong triple connected dominating set is a dominating set but not conversely.

**Observation 2.7** Every strong triple connected dominating set is a triple connected dominating set but not conversely.

**Observation 2.8** The complement of the strong triple connected dominating set need not be a strong triple connected dominating set.

**Example 2.9** For the graph $H_1$ in Figure 2.3, $S = \{v_1, v_2, v_3\}$ forms a Strong triple connected dominating set of $H_1$. But the complement $V - S = \{v_4, v_5, v_6\}$ is not a strong triple connected dominating set.

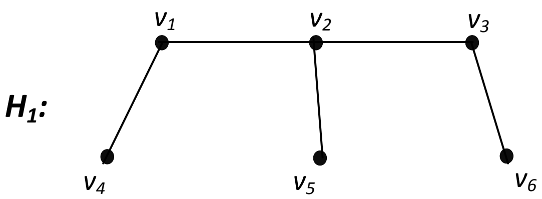


**Figure 2.3 : Graph in which V – S is not a stcd set**

**Observation 2.10** For any connected graph *G*, $\gamma(G) \leq \gamma_c(G) \leq \gamma_{tc}(G) \leq \gamma_{stc}(G)$ and the bounds are sharp for the graph $H_1$ in Figure 2.3.

**Theorem 2.11** If the induced subgraph of each connected dominating set of *G* has more than two pendant vertices, then *G* does not contain a strong triple connected dominating set.

**Proof** The proof follows from *Theorem 1.2*.

**Exact value for some standard graphs:**

1) For any path of order $p \geq 3$, $\gamma_{stc}(P_p) = \begin{cases} 3 & \text{if } p < 5 \\ p-2 & \text{if } p \geq 5. \end{cases}$

2) For any cycle of order $p \geq 3$, $\gamma_{stc}(C_p) = \begin{cases} 3 & \text{if } p < 5 \\ p-2 & \text{if } p \geq 5. \end{cases}$

3) For any complete bipartite graph of order $p \geq 4$, $\gamma_{stc}(K_{m,n}) = \begin{cases} 3 & \text{if } m = n \\ 2m-1 & \text{if } m < n. \end{cases}$

(where $m, n \geq 2$ and $m + n = p$ ).

4) For any star of order $p \geq 3$ , $\gamma_{stc}(K_{1,\, p-1}) = 3$.

5) For any complete graph of order $p \geq 3$, $\gamma_{stc}(K_p) = 3$.

6) For any wheel of order $p \geq 4$, $\gamma_{stc}(W_p) = 3$.

7) For any helm graph of order $p \geq 7$, $\gamma_{stc}(H_n) = \frac{p+1}{2}$ (where $2n - 1 = p$).

8) For any bistar of order $p \geq 4$, $\gamma_{stc}(B(m, n)) = 3$ (where $m, n \geq 1$ and $m + n + 2 = p$).

9) For the friendship graph, , $\gamma_{stc}(F_n) = 3$.

**Observation 2.12** For any connected graph $G$ with $p$ vertices, $\gamma_{stc}(G) = p$ if and only if $G \cong P_3$ or $C_3$..

**Theorem 2.13** For any connected graph $G$ with $p > 3$, we have $3 \leq \gamma_{stc}(G) \leq p - 1$ and the bounds are sharp.

**Proof** The lower bound follows from *Definition 2.1* and the upper bound follows from *Observation 2.12*. The lower bound is attained for $C_5$ and the upper bound is attained for $K_{1,3}$.

**Theorem 2.14** For a connected graph $G$ with 5 vertices, $\gamma_{stc}(G) = p - 2$ if and only if $G$ is isomorphic to $P_5$, $C_5$, $W_5$, $K_5$, $K_{2,3}$, $F_2$, $K_5 - \{e\}$, $K_4(P_2)$, $C_4(P_2)$, $C_3(P_3)$, $C_3(2P_2)$, $C_3(P_2, P_2, 0)$, $P_4(0, P_2, 0, 0)$ or any one of the graphs shown in Figure 2.4.

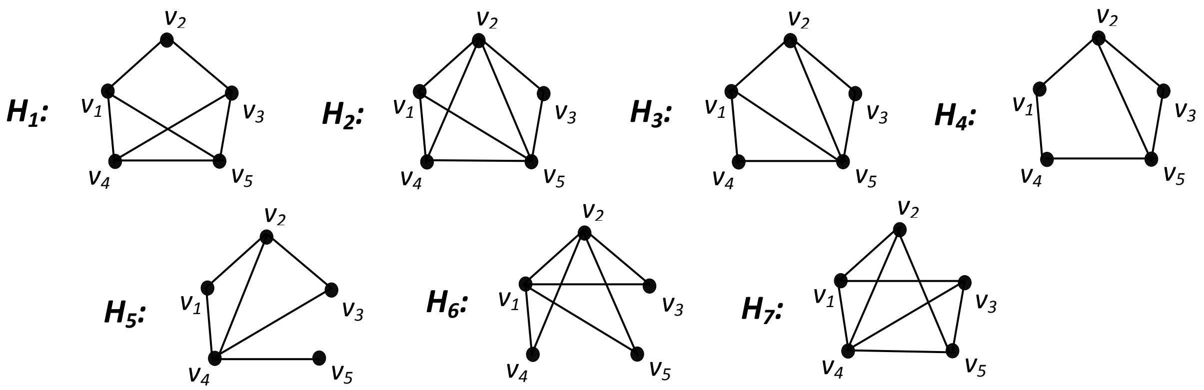


**Figure 2.4 : Graphs with $\gamma_{stc} = p - 2$.**

**Proof** Suppose $G$ is isomorphic to $P_5$, $C_5$, $W_5$, $K_5$, $K_{2,3}$, $F_2$, $K_5 - \{e\}$, $K_4(P_2)$, $C_4(P_2)$, $C_3(P_3)$, $C_3(2P_2)$, $C_3(P_2, P_2, 0)$, $P_4(0, P_2, 0, 0)$ or any one of the graphs $H_1$ to $H_7$ given in Figure 2.4., then clearly $\gamma_{stc}(G) = p - 2$. Conversely, let $G$ be a connected graph with 5 vertices and $\gamma_{stc}(G) = 3$. Let $S = \{v_1, v_2, v_3\}$ be a $\gamma_{stc}$ -set, then clearly $\langle S \rangle = P_3$ or $C_3$. Let $V - S = V(G) - V(S) = \{v_4, v_5\}$, then $\langle V - S \rangle = K_2$ or $\overline{K}_2$.

**Case (i)** $\langle S \rangle = P_3 = v_1v_2v_3$.

**Subcase (i)** $\langle V - S \rangle = K_2 = v_4v_5$.

Since $G$ is connected, there exists a vertex say $v_1$ (or $v_3$) in $P_3$ which is adjacent to $v_4$ (or $v_5$) in $K_2$. Then $S = \{v_1, v_2, v_4\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. If $v_4$ is adjacent to $v_1$, if $d(v_1) = d(V_2) = 2$, $d(v_3) = 1$, then $G \cong P_5$. Since $G$ is connected, there exists a vertex say $v_2$ in $P_3$ is adjacent to $v_4$ (or $v_5$) in $K_2$. Then $S = \{v_2, v_4, v_5\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. If $d(v_1) = d(v_3) = 1$, $d(v_2) = 3$, then $G \cong P_4(0, P_2, 0, 0)$. Now by increasing the degrees of the vertices, by the above arguments, we have $G \cong C_5$, $W_5$, $K_5$, $K_{2,3}$, $K_5 - \{e\}$, $K_4(P_2)$, $C_4(P_2)$, $C_3(P_3)$, $C_3(2P_2)$, $C_3(P_2, P_2, 0)$ and $H_1$ to $H_5$ and $H_7$ in Figure 2.4. In all the other cases, no new graph exists.

**Subcase (ii)** $\langle V - S \rangle = \overline{K}_2$.

Since $G$ is connected, there exists a vertex say $v_1$ (or $v_3$) in $P_3$ is adjacent to $v_4$ and $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. Since $G$ is connected, there exists a vertex say $v_2$ in $P_3$ which is adjacent to $v_4$ and $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. Since $G$ is connected, there exists a vertex say $v_1$ in $P_3$ which is adjacent to $v_4$ in $\overline{K}_2$ and $v_2$ in $P_3$ is adjacent to $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. Since $G$ is connected, there exists a vertex say $v_1$ in $P_3$ which is adjacent to $v_4$ in $\overline{K}_2$ and $v_3$ in $P_3$ which is adjacent to $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. In all the above cases, no new graph exists.

**Case (ii)** $<S> = C_3 = v_1v_2v_3v_1$.

**Subcase (i)** $<V - S> = K_2 = v_4v_5$.

Since $G$ is connected, there exists a vertex say $v_1$ (or $v_2$, $v_3$) in $C_3$ is adjacent to $v_4$ (or $v_5$) in $K_2$. Then $S = \{v_1, v_2, v_4\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. If $d(v_1) = 4$, $d(v_2) = d(v_3) = 2$, then $G \cong F_2$. In all the other cases, no new graph exists.

**Subcase (ii)** $<V - S> = \overline{K}_2$.

Since $G$ is connected, there exists a vertex say $v_1$ (or $v_2$, $v_3$) in $C_3$ is adjacent to $v_4$ and $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. If $d(v_1) = d(v_2) = 4$, $d(v_3) = 2$, then $G \cong H_6$. In all the other cases, no new graph exists. Since $G$ is connected, there exists a vertex say $v_1$(or $v_2$, $v_3$) in $C_3$ is adjacent to $v_4$ in $\overline{K}_2$ and $v_2$ (or $v_3$) in $C_3$ is adjacent to $v_5$ in $\overline{K}_2$. Then $S = \{v_1, v_2, v_3\}$ forms a $\gamma_{stc}$ -set of $G$ so that $\gamma_{stc}(G) = p - 2$. In this case, no new graph exists.

**Theorem 2.15** Let $G$ be a connected graph with $p \geq 3$ vertices and has exactly one full vertex. Then $\gamma_{stc} = 3$.

For, let $v$ be the full vertex in $G$. Then $S = \{v, v_i, v_j\}$ is a minimum strong triple connected dominating set of $G$, where $v_i$ and $v_j$ are in $N(v)$. Hence $\gamma_{stc}(G) = 3$.

**Theorem 2.16** For any connected graph $G$ with $p \geq 3$ vertices and exactly one vertex has $\Delta(G) = p - 2$, $\gamma_{stc}(G) = 3$.

**Proof** Let $G$ be a connected graph with $p \geq 3$ vertices and exactly one vertex has maximum degree $\Delta(G) = p - 2$. Let $v$ be the vertex of maximum degree $\Delta(G) = p - 2$. Let $v_1, v_2, \ldots$ and $v_{p-2}$ be the vertices which are adjacent to $v$, and let $v_{p-1}$ be the vertex which is not adjacent to $v$. Since $G$ is connected, $v_{p-1}$ is adjacent to a vertex $v_i$ for some $i$. Then $S = \{v, v_i, v_{p-1}\}$ forms a minimum strong triple connected dominating set of $G$. Hence $\gamma_{stc}(G) = 3$.

The Nordhaus – Gaddum type result is given below:

**Theorem 2.18** Let $G$ be a graph such that $G$ and $\bar{G}$ have no isolates of order $p > 3$. Then $\gamma_{stc}(G) + \gamma_{stc}(\bar{G}) \leq 2(p - 1)$ and $\gamma_{stc}(G) . \gamma_{stc}(\bar{G}) \leq (p - 1)^2$ and the bound is sharp.

**Proof** The bounds directly follows from *Theorem 2.13*. For the path $P_4$, the bounds are sharp.

## 3 Relation With Other Graph Theoretical Parameters

**Theorem 3.1** For any connected graph $G$ with $p > 3$ vertices, $\gamma_{stc}(G) + \kappa(G) \leq 2p - 2$ and the bound is sharp if and only if $G \cong K_4$.

**Proof** Let $G$ be a connected graph with $p > 3$ vertices. We know that $\kappa(G) \leq p - 1$ and by *Theorem 2.13*, $\gamma_{stc}(G) \leq p - 1$. Hence $\gamma_{stc}(G) + \kappa(G) \leq 2p - 2$. Suppose $G$ is isomorphic to $K_4$. Then clearly $\gamma_{stc}(G) + \kappa(G) = 2p - 2$. Conversely, Let $\gamma_{stc}(G) + \kappa(G) = 2p - 2$. This is possible only if $\gamma_{stc}(G) = p - 1$ and $\kappa(G) = p - 1$. But $\kappa(G) = p - 1$, and so $G \cong K_p$ for which $\gamma_{stc}(G) = 3 = p - 1$ so that $p = 4$. Hence $G \cong K_4$.

**Theorem 3.2** For any connected graph $G$ with $p > 3$ vertices, $\gamma_{stc}(G) + \chi(G) \leq 2p - 1$ and the bound is sharp if and only if $G \cong K_4$.

**Proof** Let $G$ be a connected graph with $p > 3$ vertices. We know that $\chi(G) \leq p$ and by *Theorem 2.13*, $\gamma_{stc}(G) \leq p - 1$. Hence $\gamma_{stc}(G) + \chi(G) \leq 2p - 1$. Suppose $G$ is isomorphic to $K_4$. Then clearly $\gamma_{stc}(G) + \chi(G) = 2p - 1$. Conversely, let $\gamma_{stc}(G) + \chi(G) = 2p - 1$. This is possible only if $\gamma_{stc}(G) = p - 1$ and $\chi(G) = p$. Since $\chi(G) = p$, $G$ is isomorphic to $K_p$ for which $\gamma_{stc}(G) = 3 = p - 1$ so that $p = 4$. Hence $G \cong K_4$.

**Theorem 3.3** For any connected graph $G$ with $p > 3$ vertices, $\gamma_{stc}(G) + \Delta(G) \leq 2p - 2$ and the bound is sharp.

**Proof** Let $G$ be a connected graph with $p > 3$ vertices. We know that $\Delta(G) \leq p - 1$ and by *Theorem 2.13*, $\gamma_{stc}(G) \leq p - 1$. Hence $\gamma_{stc}(G) + \Delta(G) \leq 2p - 2$. The bound is sharp for $K_4$.

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