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ON MULTIPLICATIVE LEAP GOURAVA INDICES OF GRAPHS

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ABSTRACT
Recently some leap Zagreb indices of a graph based on the second degrees of vertices were introduced. In this study, we introduce the multiplicative first and second leap Gourava indices, multiplicative first and second hyper leap Gourava indices, multiplicative sum and product connectivity, leap Gourava indices, general multiplicative first and second leap Gourava indices of a graph. We compute these multiplicative leap Gourava indices of wheel, gear, helm, flower and sunflower graphs.

KEYWORDS: *Multiplicative leap Gourava indices, multiplicative sum connectivity leap Gourava index, multiplicative product connectivity leap Gourava index, wheel, helm, flower graphs.*
Mathematics Subject Classification: *05C05, 05C07, 05C12.s*

1. INTRODUCTION
A graph index or a topological index is a numerical parameter mathematically derived from the graph structure [1]. It is a graph invariant. The graph indices have their applications in various disciplines of Science and Technology, see [2, 3].

By a graph, we mean a finite, undirected, connected without loops and multiple edges. Let G be a graph with vertex $V(G)$ and edge set $E(G)$. The degree $d_G(v)$ of a vertex v is the number of vertices adjacent to v. The distance $d(u, v)$ between any two vertices of a graph G is the number of edges in a shortest path connecting them. For a positive integer k, the open neighborhood of a vertex v in G is defined as $N_k(v\backslash G)=\{u\in V(G):d(u,v)=k\}$. The k-distance degree $d_k(v)$ of a vertex v in G is the number of k neighbors of v in G. For undefined graph terminology and notation, we refer [4].

In [5], Kulli introduced the multiplicative first and second Gourava indices of a graph G, defined as

$$GO_1II(G)=\prod_{uv\in E(G)}\left[d_G(u)+d_G(v)+d_G(u)d_G(v)\right].$$

$$GO_2II(G)=\prod_{uv\in E(G)}\left[\left(d_G(u)+d_G(v)\right)\left(d_G(u)d_G(v)\right)\right].$$

We introduce the multiplicative first and second leap Gourava indices of a graph G, defined as

$$LGO_1II(G)=\prod_{uv\in E(G)}\left[\left(d_2(u)+d_2(v)\right)+\left(d_2(u)d_2(v)\right)\right].$$

$$LGO_2II(G)=\prod_{uv\in E(G)}\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right).$$

We also introduce the multiplicative first and second hyper leap Gourava indices of a graph G, defined as

$$HLGO_1II(G)=\prod_{uv\in E(G)}\left[\left(d_2(u)+d_2(v)\right)+\left(d_2(u)d_2(v)\right)\right]^2.$$

$$HLGO_2II(G)=\sum_{uv\in E(G)}\left[\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right)\right]^2.$$

Furthermore, we introduce the multiplicative sum connectivity leap Gouava index and multiplicative product connectivity leap Gourava index of a graph and they are defined as

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$$SLGOII(G)=\prod_{uv\in E(G)}\frac{1}{\sqrt{d_2(u)+d_2(v)+d_2(u)d_2(v)}}.$$

$$PLGO(G)=\prod_{uv\in E(G)}\frac{1}{\sqrt{(d_2(u)+d_2(v))(d_2(u)d_2(v))}}.$$

We continue this generalization and introduce the general multiplicative first and second leap Gourava indices of a graph *G*, defined as

$$LGO_1^aII(G)=\prod_{uv\in E(G)}\left[d_2(u)+d_2(v)+d_2(u)d_2(v)\right]^a \quad (1)$$

$$LGO_2^aII(G)=\prod_{uv\in E(G)}\left[(d_2(u)+d_2(v))(d_2(u)d_2(v))\right]^2. \quad (2)$$

Recently, some Gourava indices were introduced and studied such as first and second Gourava indices [6], hyper Gourava indices [7], sum connectivity Gourava index [8], product connectivity index [9], general first and second Gourava indices [10], leap Gourava indices [11]. Recently, some different leap indices were studied, for example, in [12,13, 14, 15, 16, 17, 18].

In this paper, some multiplicative leap Gourava indices for wheel, gear, helm, flower and sunflower graphs are computed.

2. RESULTS FOR WHEELS

The wheel W_n is the join of C_n and K_1. Then W_n has n+1 vertices and 2n edges. A graph W_n is shown in Figure 1. The vertex K_1 is called apex and the vertices of C_n are called rim vertices.

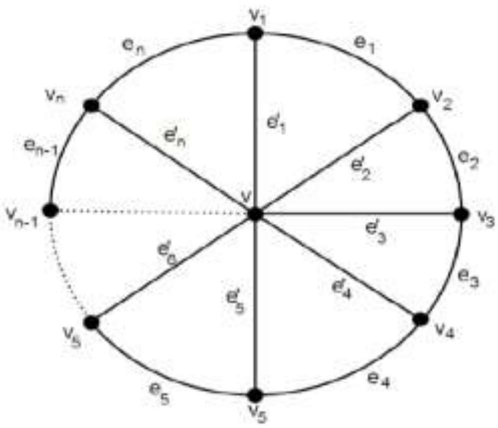

Figure 1. Wheel W_n

A graph W_n has two types of the 2-distance degree of edges as given in Table 1.

Table 1. Edge partition of W_n

$d_2(u), d_2(v) \setminus uv \in E(W_n)$	$(0, n-3)$	$(n-3, n-3)$
Number of edges	n	n

Theorem 1. The general multiplicative first leap Gourava index of W_n is

$$LGO_1^aII(W_n)=(n-3)^{2an}\times(n-1)^{an}. \quad (3)$$

Proof: By using equation (1) and Table 1, we deduce

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$$LGO_1^a(W_n) = \prod_{uv \in E(W_n)} \left[\left(d_2(u) + d_2(v) \right) + \left(d_2(u) d_2(v) \right) \right]^a$$
$$= [(0+n-3)+0(n-3)]^a \times [(n-3+n-3)+(n-3)(n-3)]^{an}$$
$$= (n-3)^{2an} \times (n-1)^{an}.$$

We establish the following results by using Theorem 1.

Corollary 1.1. The multiplicative first leap index of W_n is

$$LGO_1 II(W_n) = (n-3)^{2n} \times (n-1)^n.$$

Corollary 1.2. The multiplicative first hyper leap Gourava index of W_n is

$$HLGO_1 II(W_n) = (n-3)^{4n} \times (n-1)^{2n}.$$

Corollary 1.3. The multiplicative sum connectivity leap Gourava index of W_n is

$$SLGOII(W_n) = \left(\frac{1}{\sqrt{n-3}} \right)^{2n} \times \left(\frac{1}{\sqrt{n-1}} \right)^n.$$

Proof: Put a = 1, 2, –½ in equation (3), we get the desired results.

Theorem 2. The general multiplicative second leap Gourava index of a wheel W_n is

$$LGO_2^a II(W_n) = 2^{an}(n-3)^{3an}. \tag{4}$$

Proof: By using equation (2) and Table 1, we derive

$$LGO_2^a II(W_n) = \prod_{uv \in E(W_n)} \left[\left(d_2(u) + d_2(v) \right) \left(d_2(u) d_2(v) \right) \right]^a$$
$$= [(0+n-3) \times 0 \times (n-3)]^{an} \times [(n-3+n-3)(n-3)(n-3)]^{an}$$
$$= 2^{an}(n-3)^{3an}.$$

We establish the following results by using theorem 2.

Corollary 2.1. The multiplicative second leap Gourava index of W_n is

$$LGO_1 II(W_n) = 2^n (n-3)^{3n}.$$

Corollary 2.2. The multiplicative second hyper leap Gourava index of W_n is

$$HLGO_1 II(W_n) = 2^{2n}(n-3)^{6n}.$$

Corollary 2.3. The multiplicative product connectivity leap Gourava index of W_n is

$$PLGOII(W_n) = \left(\frac{1}{\sqrt{2}} \right)^n \times \left(\frac{1}{\sqrt{n-3}} \right)^{3n}.$$

Proof: Put a = 1, 2, –½ in equation (4), we obtain the desired results.

3. RESULTS FOR GEAR GRAPHS

The gear graph G_n is a graph obtained from a wheel W_n by adding a vertex between each pair of adjacent rim vertices. Clearly G_n has $2n$+1 vertices and $3n$ edges. A gear graph G_n is shown in Figure 2.

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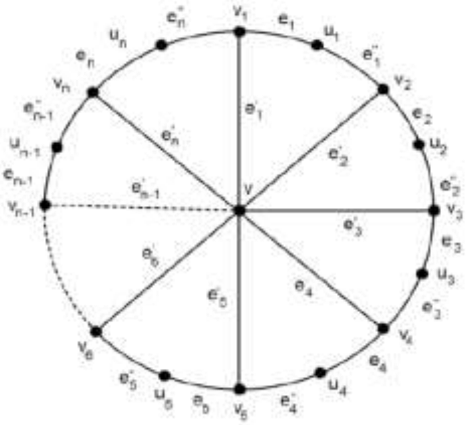

Figure 2. Gear graph G_n

Let G_n be a gear graph with $2n+1$ vertices and $3n$ edges. Then G_n has two types of the 2-distance degree of edges as given in Table 2.

Table 2. Edge partition of G_n.

$d_2(u), d_2(v) \setminus uv \in E(G_n)$	$(n, n-1)$	$(3, n-1)$
Number of edges	n	$2n$

Theorem 3. The general multiplicative first leap Gourava index of G_n is

$$LGO_1^a II(G_n) = (n^2+n-1)^{an} \times (4n-1)^{2an}. \quad (5)$$

Proof: From equation (1) and by using Table 2, we obtain

$$LGO_1^a II(G_n) = \prod_{uv \in E(G_n)} \left[(d_2(u)+d_2(v)) + d_2(u)d_2(v) \right]^a$$

$$= [(n+n-1)+n(n-1)]^{an} \times [(3+n-1)+3(n-1)]^{2an}$$

$$= (n^2+n-1)^{an} \times (4n-1)^{2an}.$$

We obtain the following results by using Theorem 3.

Corollary 3.1. The multiplicative first leap Gourava index of G_n is given by

$$LGO_1 II(G_n) = (n^2+n-1)^n \times (4n-1)^{2n}.$$

Corollary 3.2. The multiplicative first hyper leap Gourava index of G_n is

$$HLGO_1 II(G_n) = (n^2+n-1)^{2n} + (4n-1)^{4n}.$$

Corollary 3.3. The multiplicative sum connectivity leap Gourava index of G_n is

$$SLGO(G_n) = \left(\frac{1}{\sqrt{n^2+n-1}} \right)^n \times \left(\frac{1}{\sqrt{4n-1}} \right)^{2n}.$$

Proof: Put a = 1, 2, –½ in equation (5), we obtain the desired results.

Theorem 4. The general multiplicative second leap Gourava index of a gear graph G_n is given by

$$LGO_2^a II(G_n) = [n(n-1)(2n-1)]^{an} \times [3(n-1)(n+2)]^{2an}. \quad (6)$$

Proof: By using equation (2) and Table 2, we derive

$$LGO_2^a II(G_n) = \prod_{uv \in E(G_n)} \left[(d_2(u)+d_2(v))(d_2(u)d_2(v)) \right]^a$$

$$= [(n+n-1)n(n-1)]^{an} \times [(3+n-1)3(n-1)]^{2an}$$

$$= [n(n-1)(2n-1)]^{an} \times [3(n-1)(n+2)]^{2an}.$$

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We obtain the following results by using Theorem 4.

Corollary 4.1. The multiplicative second leap Gourava index of G_n is

$$LGO_2II(G_n) = [n(n-1)(2n-1)]^n \times [3(n-1)(n+2)]^{2n}.$$

Corollary 4.2. The multiplicative second hyper leap Gourava index of G_n is

$$HLGO_2II(G_n) = [n(n-1)(2n-1)]^{2n} \times [3(n-1)(n+2)]^{4n}.$$

Corollary 4.3. The multiplicative second hyper leap Gourava index of G_n is

$$PLGOII(G_n) = \left(\frac{1}{n(n-1)(2n-1)}\right)^{n/2} \times \left(\frac{1}{\sqrt{3(n-1)(n+2)}}\right)^{2n}.$$

Proof: Put a = 1, 2, –½ in equation (6), we obtain the desired results.

4. RESULTS FOR HELM GRAPHS

Let W_n be a wheel with n+1 vertices and 2n edges. A helm graph H_n is a graph obtained from W_n attaching an edge to each rim vertex of W_n. Clearly, H_n has 2n+1 vertices and 3n edges. A graph H_n is shown in Figure 3.

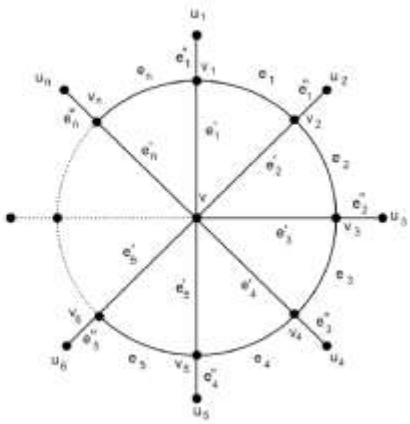

Figure 3. Helm graph H_n

In H_n, there are three types of the 2-distance degree of edges as given in Table 3.

` ***Table 3. Edge partition of H_n***

$d_2(u), d_2(v) \setminus uv \in E(H_n)$	$(n, n-1)$	$(3, n-1)$	$(n-1, n-1)$
Number of edges	n	n	n

Theorem 5. The general multiplicative first leap Gourava index of H_n is

$$LGO_1^a(H_n) = (n^2+n-1)^{an} \times (4n-1)^{an} \times (n^2-1)^{an}. \qquad (7)$$

Proof: By using equation (1) and Table 3, we deduce

$$LGO_1^a(H_n) = \sum_{uv \in E(H_n)} [d_2(u)+d_2(v)+d_2(u)d_2(v)]^a$$

$$= [n+n-1+n(n-1)]^{an} \times [3+n-1+3(n-1)]^{an} \times [n-1+n-1+(n-1)(n-1)]^{an}$$

$$= (n^2+n-1)^{an} \times (4n-1)^{an} \times (n^2-1)^{an}.$$

The following results are obtained by using Theorem 5.

Corollary 5.1. The multiplicative first leap Gourava index of H_n is

$$LGO_1(H_n) = (n^2+n-1)^n \times (4n-1)^n \times (n^2-1)^n.$$

Corollary 5.2. The multiplicative first hyper leap Gourava index of H_n is

$$HLGO_1(H_n) = (n^2+n-1)^{2n} \times (4n-1)^{2n} \times (n^2-1)^{2n}.$$

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Corollary 5.3. The multiplicative sum connectivity leap Gourava index of H_n is

$$SLGO(H_n)=\left(\frac{1}{\sqrt{n^2+n-1}}\right)^n\times\left(\frac{1}{\sqrt{4n-1}}\right)^n\times\left(\frac{1}{\sqrt{n^2-1}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (7), we get the desired results.

Theorem 6. The general multiplicative second leap Gourava index of a helm graph H_n is

$$LGO_2^a(H_n)=(2n^3-3n^2+n)^{an}\times(3n^2+3n-6)^{an}\times(2n^3-6n^2+6n-2)^{an}. \quad (8)$$

Proof: From equation (2) and by using Table 3, we have

$$LGO_2^a(H_n)=\prod_{uv\in E(H_n)}\left[\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right)\right]^a$$

$$=[(n+n-1)n(n-1)]^{an}\times[(3+n-1)3(n-1)]^{an}\times[(n-1+n-1)(n-1)(n-1)]^{an}$$

$$=(2n^3-3n^2+n)^{an}\times(3n^2+3n-6)^{an}\times(2n^3-6n^2+6n-2)^{an}.$$

We obtain the following results by using Theorem 6.

Corollary 6.1. The multiplicative second leap Gourava index of H_n is

$$LGO_1(H_n)=(2n^3-3n^2+n)^n\times(3n^2+3n-6)^n\times(2n^3-6n^2+6n-2)^n.$$

Corollary 6.2. The multiplicative second hyper leap Gourava index of H_n is

$$HLGO_2(H_n)=(2n^3-3n^2+n)^{2n}\times(3n^2+3n-6)^{2n}\times(2n^3-6n^2+6n-2)^{2n}.$$

Corollary 6.3. The multiplicative product connectivity leap Gourava index of H_n is

$$PLGO(H_n)=\left(\frac{1}{\sqrt{2n^3-3n^2+n}}\right)^n\times\left(\frac{1}{\sqrt{3n^2+3n-6}}\right)^n\times\left(\frac{1}{\sqrt{2n^3-6n^2+6n-2}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (8), we obtain the desired results.

5. RESULTS FOR FLOWER GRAPHS

A graph is a flower graph, denoted by Fl_n, which is obtained from a helm graph H_n by joining an end vertex to the apex of the helm graph. A flower graph Fl_n has $2n$+1 vertices and $4n$ edges. A flower graph Fl_n is shown in Figure 4.

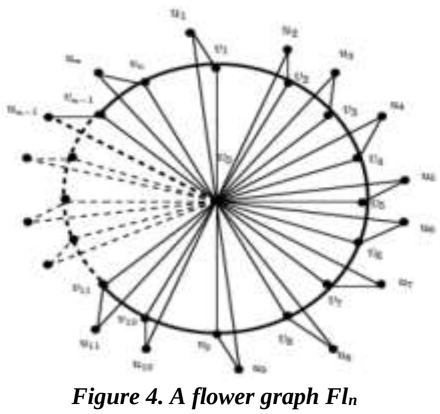

Figure 4. A flower graph Fl_n

In Fl_n, there are four types of the 2-distance degree of edges as given Table 4.

Table 4. Edge partition of Fl_n

$d_2(u), d_2(v) \setminus uv \in E(Fl_n)$	(0, n – 5)	(0, n – 2)	(n – 5, n – 2)	(n – 5, n – 5)
Number of edges	n	n	n	n

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Theorem 7. The general multiplicative first leap Gourava index of a flower graph Fl_n is

$$LGO_1^a(Fl_n)=(n-5)^{an}\times(n-2)^{an}\times(n^2-5n+3)^{an}\times(n^2-8n+15)^{an}. \quad (9)$$

Proof: From equation (1) and by using Table 4, we obtain

$$LGO_1^a(Fl_n)=\prod_{uv\in E(Fl_n)}\left[d_2(u)+d_2(v)+d_2(u)d_2(v)\right]^a$$

$$=[0+n-5+0(n-5)]^{an}\times[0+n-2+0(n-2)]^{an}\times[n-5+n-2+(n-5)(n-2)]^{an}$$

$$+[n-5+n-5+(n-5)(n-5)]^{an}$$

$$=(n-5)^{an}\times(n-2)^{an}\times(n^2-5n+3)^{an}\times(n^2-8n+15)^{an}.$$

We establish the following results by using Theorem 7.

Corollary 7.1. The multiplicative first leap Gourava index of Fl_n is

$$LGO_1(Fl_n)=(n-5)^n\times(n-2)^n\times(n^2-5n+3)^n\times(n^2-8n+15)^n.$$

Corollary 7.2. The multiplicative first hyper leap Gourava index of Fl_n is

$$HLGO_1(Fl_n)=(n-5)^{2n}\times(n-2)^{2n}\times(n^2-5n+3)^{2n}\times(n^2-8n+15)^{2n}.$$

Corollary 7.3. The multiplicative sum connectivity leap Gourava index of Fl_n is

$$SLGO(Fl_n)=\left(\frac{1}{\sqrt{n-5}}\right)^n\times\left(\frac{1}{\sqrt{n-2}}\right)^n\times\left(\frac{1}{\sqrt{n^2-5n+3}}\right)^n\times\left(\frac{1}{\sqrt{n^2-8n+15}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (9), we get the desired results.

Theorem 8. The general multiplicative second leap Gourava index of a flower graph Fl_n is

$$LGO_2^a(Fl_n)=[(2n-7)(n-5)(n-2)]^{an}\times\left[2(n-5)^3\right]^{an}. \quad (10)$$

Proof: By using equation (2) and Table 4, we deduce

$$LGO_2^a(Fl_n)=\prod_{uv\in E(Fl_n)}\left(d_2(u)+d_2(v)\right)+\left(d_2(u)d_2(v)\right)$$

$$=[(0+n-5)0(n-5)]^{an}\times[(0+n-2)0(n-2)]^{an}\times[(n-5+n-2)(n-5)(n-2)]^{an}$$

$$+[(n-5+n-5)(n-5)(n-5)]^{an}$$

$$=[(2n-7)(n-5)(n-2)]^{an}\times\left[2(n-5)^3\right]^{an}.$$

We obtain the following results by using Theorem 8.

Corollary 8.1. The multiplicative second leap Gourava index of Fl_n is

$$LGO_2(Fl_n)=[(2n-7)(n-5)(n-2)]^n\times\left[2(n-5)^3\right]^n.$$

Corollary 8.2. The multiplicative second leap Gourava index of Fl_n is

$$HLGO_2(Fl_n)=[(2n-7)(n-5)(n-2)]^{2n}\times\left[2(n-5)^3\right]^{2n}.$$

Corollary 8.3. The multiplicative product connectivity leap Gourava index of Fl_n is

$$PLGO(Fl_n)=\left(\frac{1}{\sqrt{(2n-7)(n-5)(n-2)}}\right)^n\times\left(\frac{1}{(n-5)\sqrt{2(n-5)}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (10), we get the desired results.

6. RESULTS FOR SUNFLOWER GRAPHS

A graph is a sunflower graph Sf_n which is obtained from a flower graph Fl_n by attaching n end edges to the apex vertex. A sunflower graph Sf_n has $3n$+1 vertices and $5n$ edges. A graph Sf_n is presented in Figure 5.

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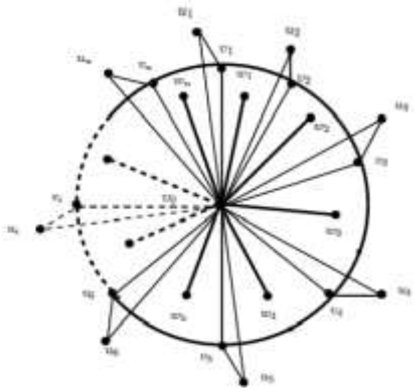

Figure 5. A sunflower graph Sf_n

In Sf_n, there are five types of the 2-distance degree of edges as given in Table 5.

Table 5. Edge partition of Sf_n

$d_2(u), d_2(v) \setminus uv \in E(Sf_n)$	(0, 3n – 4)	(0, 3n – 2)	(0, 3n – 1)	(3n – 4, 3n – 4)	(3n – 4, 3n – 2)
Number of edges	n	n	n	n	n

Theorem 9. The general multiplicative first leap Gourava index of a sunflower graph Sf_n is

$$LGO_1^a(Sf_n) = (3n-4)^{an} \times (3n-2)^{an} \times (3n-1)^{an} \times (9n^2-18n+8)^{an} \times (9n^2-12n+2)^{an}. \qquad (11)$$

Proof: By using equation (1) and Table 5, we derive

$$LGO_1^a(Sf_n) = \prod_{uv\in E(Sf_n)} \left[d_2(u)+d_2(v)+d_2(u)d_2(v)\right]^a$$
$$= [0+3n-4+0(3n-4)]^{an} \times [0+3n-2+0(3n-2)]^{an} \times [0+3n-1+0(3n-1)]^{an}$$
$$\times [3n-4+3n-4+(3n-4)(3n-4)]^{an} \times [3n-4+3n-2+(3n-4)(3n-2)]^{an}$$
$$= (3n-4)^{an} \times (3n-2)^{an} \times (3n-1)^{an} \times (9n^2-18n+8)^{an} \times (9n^2-12n+2)^{an}.$$

We obtain the following results by using Theorem 9.

Corollary 9.1. The multiplicative first leap Gourava index of Sf_n is

$$LGO_1^a(Sf_n) = (3n-4)^n \times (3n-2)^n \times (3n-1)^n \times (9n^2-18n+8)^n \times (9n^2-12n+2)^n.$$

Corollary 9.2. The multiplicative first hyper leaf Grourava index of Sf_n is

$$HLGO_1^a(Sf_n) = (3n-4)^{2n} \times (3n-2)^{2n} \times (3n-1)^{2n} \times (9n^2-18n+8)^{2n} \times (9n^2-12n+2)^{2n}.$$

Corollary 9.3. The multiplicative sum connectivity leap Gourava index of Sf_n is

$$SLGO(Sf_n) = \left(\frac{1}{\sqrt{3n-4}}\right)^n \times \left(\frac{1}{\sqrt{3n-2}}\right)^n \times \left(\frac{1}{\sqrt{3n-1}}\right)^n \times \left(\frac{1}{\sqrt{9n^2-18n+8}}\right)^n \times \left(\frac{1}{\sqrt{9n^2-12n+2}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (11), we get the desired results.

Theorem 10. The general multiplicative second leap Gourava index of a sunflower graph Sf_n is

$$LGO_2^a(Sf_n) = \left[2(3n-4)^3\right]^{an} \times [(6n-6)\times(3n-4)\times(3n-2)]^{an}. \qquad (12)$$

Proof: From equation (1) and by using Table 5, we deduce

$$LGO_2^a(Sf_n) = \prod_{uv\in E(Sf_n)} \left[(d_2(u)+d_2(v))d_2(u)d_2(v)\right]^a$$
$$= [(0+3n-4)\times 0(3n-4)]^{an} \times [(0+3n-2)\times 0(3n-2)]^{an} \times [(0+3n-1)\times 0(3n-1)]^{an}$$
$$\times [(3n-4+3n-4)(3n-4)(3n-4)]^{an} \times [(3n-4+3n-2)+(3n-4)(3n-2)]^{an}$$
$$= \left[2(3n-4)^3\right]^{an} \times [(6n-6)\times(3n-4)\times(3n-2)]^{an}.$$

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We establish the following results by using Theorem 10.

Corollary 10.1. The multiplicative second leap Gourava index of Sf_n is

$$LGO_2^a\left(Sf_n\right)=2^n\left(3n-4\right)^{3n}\times\left[\left(6n-6\right)\times\left(3n-4\right)\times\left(3n-2\right)\right]^n.$$

Corollary 10.2. The multiplicative second hyper leap Gourava index of Sf_n is

$$HLGO_2\left(Sf_n\right)=2^{2n}\left(3n-4\right)^{6n}\times\left[\left(6n-6\right)\times\left(3n-4\right)\times\left(3n-2\right)\right]^{2n}.$$

Corollary 10.3. The multiplicative product connectivity leap Gourava index of Sf_n is

$$PLGO\left(Sf_n\right)=\left(\frac{1}{\left(3n-4\right)\sqrt{2\left(3n-4\right)}}\right)^n\times\left(\frac{1}{\sqrt{\left(6n-6\right)\left(3n-4\right)\left(3n-2\right)}}\right)^n.$$

Proof: Put a = 1, 2, –½ in equation (12), we obtain the desired results

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