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# LEAP GOURAVA INDICES OF CERTAIN WINDMILL 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 paper, we introduce some leap Gourava indices of a graph based on the second degrees of vertices. We also compute the first and second hyper leap Gourava indices, sum connectivity leap Gourava index, product connectivity leap Gourava index, general first and second leap Gourava indices of certain windmill graphs such as Dutch windmill graph, Kulli cycle windmill graph, Kulli path windmill graph and French windmill graph.*

***Keywords:*** *Leap Gourava indices, sum connectivity leap Gourava index, product connectivity leap Gourava index, windmill graphs.*

***Mathematics Subject Classification:*** *05C05, 05C07, 05C12, 05C76.*

## I. INTRODUCTION

Let $G$ be a finite, simple, connected graph with vertex set $V(G)$ and edge set $E(G)$. For a vertex $v$, the degree $d_G(v)$ is the number of vertices adjacent to $v$. The distance $d(u, v)$ between any two vertices $u$ and $v$ is the length of shortest path connecting $u$ and $v$. For a positive integer $k$, the open $k$-neighborhood $N_k(v)$ of a vertex $v$ in a graph $G$ is defined as $N_k(v/G) = \{u \in V(G): d(u, v)=k\}$. The $k$-distance degree $d_k(v)$ of a vertex $v$ in $G$ is defined as the number of $k$ neighbors of $v$ in $G$. We refer to [1] for undefined graph terminology and notation.

A graph index or a topological index is a numerical parameters mathematically derived from the graph structure [2]. It is a graph invariant. The graph indices have their applications in various disciplines of Science and Technology, see [3, 4].

Recently, some Gourava indices were introduced and studied such as hyper Gourava indices [5], sum connectivity Gourava index [6], product connectivity Gourava index [7], general first and second Gourava indices [8], multiplicative Gourava indices [9].

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

$$GO_1(G) = \sum_{uv \in E(G)} \left[ d_G(u) + d_G(v) + d_G(u) d_G(v) \right],$$

$$GO_2(G) = \sum_{uv \in E(G)} \left( d_G(u) + d_G(v) \right) \left( d_G(u) d_G(v) \right).$$

The first and second leap Gourava indices of a graph G are defined as [10]

$$LGO_1(G) = \sum_{uv \in E(G)} \left[ d_2(u) + d_2(v) + d_2(u) d_2(v) \right],$$

$$LGO_2(G) = \sum_{uv \in E(G)} \left( d_2(u) + d_2(v) \right) \left( d_2(u) d_2(v) \right).$$

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

$$HLGO_1(G) = \sum_{uv \in E(G)} \left[ d_2(u) + d_2(v) + d_2(u) d_2(v) \right]^2,$$

$$HLGO_2(G) = \sum_{uv \in E(G)} \left[ \left( d_2(u) + d_2(v) \right) d_2(u) d_2(v) \right]^2.$$

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Motivated by the definitions of the sum connectivity Gourava index [6] and product connectivity Gourava index [7] of a graph as follows:

The sum connectivity leap Gourava index of a graph $G$ is defined as

$$SLGO(G) = \sum_{uv \in E(G)} \frac{1}{\sqrt{d_2(u) + d_2(v) + d_2(u)d_2(v)}},$$

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

We continue this generalization and define the general first and second leap Gourava indices of a graph $G$ as

$$LGO_1^a(G) = \sum_{uv \in E(G)} \left[d_2(u) + d_2(v) + d_2(u)d_2(v)\right]^a, \tag{1}$$

$$LGO_2^a(G) = \sum_{uv \in E(G)} \left[(d_2(u) + d_2(v))d_2(u)d_2(v)\right]^a, \tag{2}$$

where $a$ is a real number.

Recently, some leap indices were studied, for example, in [11, 12, 13, 14, 15, 16, 17].

In this paper, we compute leap Gourava indices, hyper leap Gourava indices, sum connectivity leap Gourava index, product connectivity leap Gourava index, general leap Gourava indices of certain windmill graphs.

## 2. RESULTS FOR DUTCH WINDMILL GRAPHS

The Dutch windmill graph $D_n^m$, $m \geq 2$, $n \geq 5$ is the graph obtained by taking $m$ copies of the cycle $C_n$ with a vertex in common [18]. The graph $D_n^m$ is shown in Figure 1. The Dutch windmill graph $D_3^m$ is called a friendship graph.

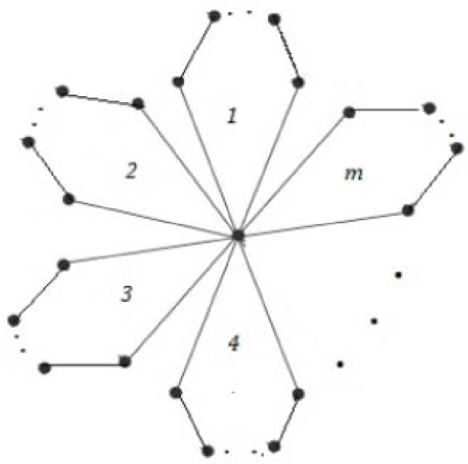


**Figure-1:** Dutch windmill graph $D_n^m$

Let $G$ be a Dutch windmill graph $D_n^m$ with $1 + m(n-1)$ vertices and $mn$ edges, $m \geq 2$, $n \geq 2$. Then $G$ has three types of 2-distance degree of edges as given in Table 1.

| $d_2(u), d_2(v) \setminus uv \in E(D)$ | $(2m, 2m)$ | $(2m, 2)$ | $(2, 2)$ |
|---|---|---|---|
| Number of edges | $2m$ | $2m$ | $m(n-4)$ |

**Table-1:** 2-distance degree edge partition of $D_n^m$

**Theorem 1:** Let $D$ *be the graph* of a Dutch windmill graph $D_n^m$. Then

$$LGO_1^a(D_n^m) = (4m + 4m^2)2m + (6m+2)^a 2m + 8^a m(n-4). \tag{3}$$

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

$$LGO_1^a(D_n^m) = \sum_{uv \in E(D)} \left[d_2(u) + d_2(v) + d_2(u)d_2(v)\right]^a$$

$$= (2m + 2m + 2m \times 2m)^a 2m + (2m + 2 + 2m \times 2)^a 2m + (2 + 2 + 2 \times 2)^a m(n-4)$$

$$= (4m + 4m^2)^a 2m + (6m+2)^a 2m + 8^a m(n-4).$$

We establish the following results by using Theorem 1.

**Corollary 1.1:** The first leap Gourava index of $D_n^m$ is given by

$$LGO_1\left(D_n^m\right) = 8mn + 8m^3 + 20m^2 - 28m.$$

**Corollary 1.2:** The first hyper leap Gourava index of $D_n^m$ is given by

$$HLGO_1\left(D_n^m\right) = 64mn + 32m^5 + 64m^4 + 104m^3 + 48m^2 - 248m.$$

**Corollary 1.3:** The sum connectivity leap Gourava index of $D_n^m$ is given by

$$SLGO\left(D_n^m\right) = \frac{m}{\sqrt{m+m^2}} + \frac{2m}{\sqrt{6m+2}} + \frac{m(m-4)}{\sqrt{8}}$$

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

**Theorem 2:** Let $D$ be the graph of a Dutch windmill graph $D_n^m$. Then

$$LGO_2^a\left(D_n^m\right) = \left(16m^3\right)^a 2m + \left[8m(m+1)\right]^a 2m + 16^a m(n-4). \qquad (4)$$

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

$$LGO_2^a\left(D_n^m\right) = \sum_{uv\in E(D)} \left[\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right)\right]^a$$

$$= \left[(2m+2m)(2m\times 2m)\right]^a 2m + \left[(2m+2)(2m\times 2)\right]^a 2m + \left[(2+2)(2\times 2)\right]^a m(n-4)$$

$$= \left(16m^3\right)^a 2m + \left[8m(m+1)\right]^a 2m + 16^a m(n-4).$$

We obtain the following results by using Theorem 2.

**Corollary 2.1:** The second leap Gourava index of $D_n^m$ is given by

$$LGO_2\left(D_n^m\right) = 16mn + 32m^4 + 16m^3 + 16m^2 - 64m.$$

**Corollary 2.2:** The second hyper leap Gourava index of $D_n^m$ is given by

$$HLGO_2\left(D_n^m\right) = 256mn + 512m^7 + 128m^5 + 256m^4 + 128m^3 - 1024m.$$

**Corollary 2.3:** The product connectivity leap Gourava index of $D_n^m$ is given by

$$PLGO\left(D_n^m\right) = \frac{1}{2\sqrt{m}} + \frac{m}{\sqrt{2m(m+1)}} + \frac{m(n-4)}{4}$$

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

## 3. RESULTS FOR KULLI CYCLE WINDMILL GRAPHS

The Kulli cycle windmill graph [19] is the graph obtained by taking $m$ copies of the graph $K_1 + C_n$ for $n \geq 3$ with a vertex $K_1$ in common and it is denoted by $C_{n+1}^m$. This graph is presented in Figure 2.

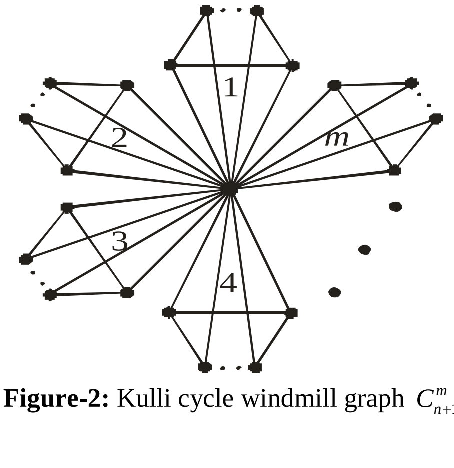


**Figure-2:** Kulli cycle windmill graph $C_{n+1}^m$

Let C= $C_{n+1}^{m}$ be a Kulli cycle windmill graph with *mn*+1 vertices and 2*mn* edges, *m*≥2, *m*≥5. Then *C* has two types of 2-distance degree of edges as given in Table 2.

| $d_2(u), d_2(v) \setminus uv \in E(C)$ | $(0, mn-2)$ | $(mn-2, mn-2)$ |
|---|---|---|
| Number of edges | $mn$ | $mn$ |

**Table-2:** 2-distance degree edge partition of $C_{n+1}^{m}$

**Theorem 3:** The general first leap Gourava index of $C_{n+1}^{m}$ is given by

$$LGO_1^a\left(C_n^m\right) = (mn-2)^a\ mn\left(1+m^a n^a\right). \tag{5}$$

**Proof:** Let $C = C_{n+1}^{m}.$ By using equation (1) and Table 2, we obtain

$$LGO_1^a\left(C_n^m\right) = \sum_{uv\in E(C)} \left[d_2(u)+d_2(v)+d_2(u)d_2(v)\right]^a$$

$$= \left[0+nm-2+0\times(mn-2)\right]^a mn + \left[(mn-2)+(nm-2)+(mn-2)(mn-2)\right]^a mn$$

$$= (mn-2)^a\ mn + \left[2(mn-2)+(mn-2)^2\right]^a mn$$

$$= (mn-2)^a\ mn\left(1+m^a n^a\right)$$

We obtain the following results by using Theorem 3.

**Corollary 3.1:** The first leap Gourava index of $C_{n+1}^{m}$ is

$$LGO_1\left(C_{n+1}^m\right) = (mn-2)(1+mn)\,mn.$$

**Corollary 3.2:** the first hyper leap Gourava index of $C_{n+1}^{m}$ is

$$HLGO_1\left(C_{n+1}^m\right) = (mn-2)^2\left(1+m^2n^2\right)mn.$$

**Corollary 3.3:** The sum connectivity leap Gourava index of $C_{n+1}^{m}$ is

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

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

**Theorem 4:** The general second leap Gourava index of $C_{n+1}^{m}$ is given by

$$LGO_2^a\left(C_n^m\right) = \left[2(mn-2)^3\right]^a mn. \tag{6}$$

**Proof:** Let $C = C_{n+1}^{m}.$ By using equation (2) and Table 2, we deduce

$$LGO_2^a\left(C_{n+1}^m\right) = \sum_{uv\in E(C)} \left[(d_2(u)+d_2(v))\left(d_2(u)d_2(v)\right)\right]^a$$

$$= \left[(0+mn-2)0\times(mn-2)\right]^a mn + \left[(mn-2+mn-2)(2m-2)(mn-2)\right]^a mn$$

$$= \left[2(mn-2)^3\right]^a mn.$$

The following results are obtained by using Theorem 4.

**Corollary 4.1:** The second leap Gourava index of $C_{n+1}^{m}$ is

$$LGO_2\left(C_{n+1}^m\right) = 2(mn-2)^3\ mn.$$

**Corollary 4.2:** The second hyper leap Gourava index of $C_{n+1}^{m}$ is

$$HLGO_2\left(C_{n+1}^m\right) = 4(mn-2)^6\ mn.$$

**Corollary 4.3:** The product connectivity leap Gourava index of $C_{n+1}^{m}$ is

$$PLGO\left(C_{n+1}^m\right) = \frac{mn}{(mn-2)\sqrt{2(mn-2)}}.$$

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

## 4. RESULTS FOR KULLI PATH WINDMILL GRAPHS

The Kulli path windmill graph [20] is the graph obtained by taking *m* copies of the graph $K_1+P_n$ with a vertex $K_1$ in common and it is denoted by $P_{n+1}^m$. This graph is shown in Figure 3. The Kulli path windmill graph $P_3^m$ is a friendship graph.

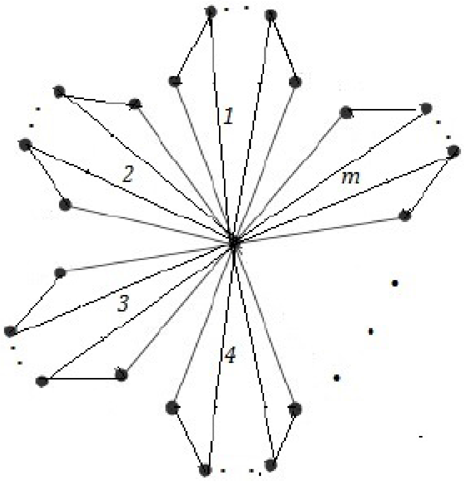


**Figure-3:** Kulli path windmill graph $P_{n+1}^m$

Let $P = P_{n+1}^m$, $m \geq 2$, $n \geq 5$. Then *P* has $mn+1$ vertices and $2mn - m$ edges. The graph *P* has four types of 2-distance degree of edges as given Table 3.

| $d_2(u), d_2(v) \setminus uv \in E(G)$ | $(0, mn-2)$ | $(0, mn-3)$ | $(mn-2, mn-3)$ | $(mn-3, mn-3)$ |
|---|---|---|---|---|
| Number of edges | $2m$ | $mn-2m$ | $2m$ | $mn-3m$ |

**Table-3:** 2-distance degree edge partition of $P_{n+1}^m$

**Theorem 5:** The general first leap Gourava index of $P_{n+1}^m$ is

$$LGO_1^a\left(P_{n+1}^m\right) = (mn-2)^2\, 2m + (mn-3)^a (mn-2m) + \left(m^2n^2 - 3mn + 1\right)^a 2m + \left(m^2n^2 - 4mn + 3\right)^a (mn-3m). \quad (7)$$

**Proof:** Let $P = P_{n+1}^m$, By using equation (1) and Table 3, we deduce

$$LGO_1^a\left(P_{n+1}^m\right) = \sum_{uv \in E(P)} \left[d_2(u) + d_2(v) + d_2(u)d_2(v)\right]^a$$

$$= \left[0 + mn - 2 + 0(mn-2)\right]^a 2m + \left[0 + mn - 3 + 0(mn-3)\right]^a (mn-2m)$$

$$+ \left[mn - 2 + mn - 3 + (mn-2)(mn-3)\right]^a 2m + \left[mn - 3 + mn - 3(mn-3)(mn-3)\right]^a (mn-3m)$$

$$= (mn-2)^a\, 2m + (mn-3)^a (mn-2m) + \left(m^2n^2 - 3mn + 1\right)^a 2m + \left(m^2n^2 - 4mn + 3\right)^a (mn-2m)$$

We obtain the following results by using Theorem 5.

**Corollary 5.1:** The first leap Gourava index of $P_{n+1}^m$ is

$$LGO_1\left(P_{n+1}^m\right) = m^3n^3 - m^3n^2 - 3m^2n^2 + 6m^2n - 5m.$$

**Corollary 5.2:** The first hyper Gourava index of $P_{n+1}^m$ is

$$HLGO_1\left(P_{n+1}^m\right) = (mn-2)^2\, 2m + (mn-3)^2 (mn-2m) + \left(m^2n^2 - 3mn + 1\right)^2 2m + \left(m^2n^2 - 4mn + 3\right)^2 (mn-3m).$$

**Corollary 5.3:** The sum connectivity leap Gourava index of $P_{n+1}^m$

$$SLGO\left(P_{n+1}^m\right) = \frac{2m}{\sqrt{mn-2}} + \frac{mn-2m}{\sqrt{mn-3}} + \frac{2m}{\sqrt{m^2n^2 - 3mn + 1}} + \frac{mn-3m}{\sqrt{m^2n^2 - 4mn + 3}}.$$

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

**Theorem 6:** The general second leap Gourava index of $P_{n+1}^m$ is

$$LGO_2^a\left(P_{n+1}^m\right)=\left[(2mn-5)(mn-2)(mn-3)\right]^a 2m+\left[2(mn-3)^3\right]^a (mn-3m). \quad (8)$$

**Proof:** Let $P= P_{n+1}^m$. From equation (2) and by using Table 3, we obtain

$$LGO_2^a\left(P_{n+1}^m\right)=\sum_{uv\in E(P)}\left[\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right)\right]^a$$

$$=\left[(0+mn-2)0(mn-2)\right]^a 2m+\left[(0+mn-3)0(mn-3)\right]^a(mn-2m)$$

$$+\left[(mn-2+mn-3)(mn-2)(mn-3)\right]^a 2m+\left[(mn-3+mn-3)(mn-3)(mn-3)\right]^a(mn-3m)$$

$$=\left[(2mn-5)(mn-2)(mn-3)\right]^a 2m+\left[2(mn-3)^3\right]^a(mn-3m).$$

**Corollary 6.1:** The second leap Gourava index of $P_{n+1}^m$ is

$$LGO_2\left(P_{n+1}^m\right)=(2mn-5)(mn-2)(mn-3)2m+2(mn-3)^3(mn-3)$$

**Corollary 6.2:** The second hyper leap Gourava index of $P_{n+1}^m$ is

$$HLGO_2\left(P_{n+1}^m\right)=(2mn-5)^2(mn-2)^2(mn-3)^2 2m+4(mn-3)^6(mn-3m).$$

**Corollary 6.3:** The product connectivity leap Gourava index of $P_{n+1}^m$ is

$$PLGO\left(P_{n+1}^m\right)=\frac{2m}{\sqrt{(2mn-5)(mn-2)(mn-3)}}+\frac{mn-3m}{(mn-3)\sqrt{2(mn-3)}}.$$

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

## 5. RESULTS FOR FRENCH WINDMILL GRAPHS

The French windmill graph $F_n^m$ is the graph obtained by taking $m \geq 3$ copies of $K_n$, $n \geq 3$ with a vertex in common [18]. The graph $F_n^m$ is presented in Figure 4. The French windmill graph $F_3^m$ is called a friendship graph.

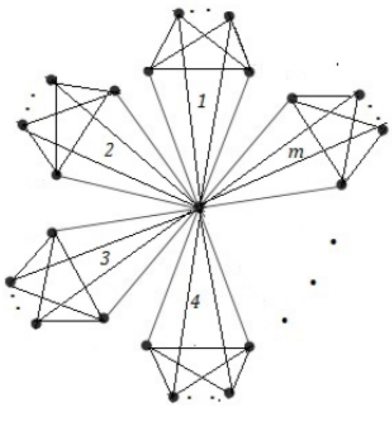


**Figure-4:** French windmill graph $F_n^m$

Let $F$ be a French windmill graph $F_n^m$. Then $F$ has 1+ $m(n-1)$ vertices and ½$mn(n-1)$ edges, $m \geq 2$, $n \geq 2$. In $F$, there are two types of the 2-distance degree of edges as given in Table 4.

| $d_2(u), d_2(v) \setminus uv \in E(F)$ | $(0, (n-1)(m-1))$ | $((n-1)(m-1), (n-1)(m-1))$ |
|---|---|---|
| Number of edges | $m(n-1)$ | $\frac{1}{2}m(n-1)(n-2)$ |

**Table-4:** 2-distance degree edge partition of $F$.

**Theorem 7:** The general first leap Gourava index of $F_n^m$ is

$$LGO_1^a\left(F_n^m\right)=\left[(n-1)(m-1)\right]^a m(n-1)+\left[2(n-1)(m-1)+(n-1)^2(m-1)^2\right]^a \frac{1}{2}m(n-1)(n-2). \tag{9}$$

**Proof:** Let $F = F_n^m$. From equation (1) and by using Table 4, we have

$$\begin{aligned}LGO_1^a\left(F_n^m\right) &= \sum_{uv\in E(F)}\left[d_2(u)+d_2(v)+d_2(u)d_2(v)\right]^a \\ &=\left[0+(n-1)(m-1)+0(n-1)(m-1)\right]^a m(n-1) \\ &\quad +\left[(n-1)(m-1)+(n-1)(m-1)+(n-1)(m-1)(n-1)(m-1)\right]^a \frac{1}{2}m(n-1)(n-2) \\ &=\left[(n-1)(m-1)\right]^a m(n-1)+\left[2(n-1)(m-1)+(n-1)^2(m-1)^2\right]^a \frac{1}{2}m(n-1)(n-2).\end{aligned}$$

The following results are obtained by using Theorem 7.

**Corollary 7.1:** The first leap Gourava index of $F_n^m$ is

$$LGO_1\left(F_n^m\right)=m(m-1)(n-1)^3\left[1+\frac{1}{2}(m-1)^2(n-2)\right].$$

**Corollary 7.2:** The first hyper leap Gourava index of $F_n^m$ is

$$HLGO_1\left(F_n^m\right)=m(m-1)^2(n-1)^3+\left[2(m-1)(n-1)+(m-1)^2(n-1)^2\right]\frac{1}{2}m(n-1)(n-2).$$

**Corollary 7.3:** The sum connectivity leap Gourava index of $F_n^m$ is

$$SLGO\left(F_n^m\right)=\frac{m(n-1)}{\sqrt{(n-1)(m-1)}}+\frac{m(n-1)(n-2)}{2\sqrt{2(n-1)(m-1)+(n-1)^2(m-1)^2}}.$$

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

**Theorem 8:** The general second leap Gourava index of $F_n^m$ is

$$LGO_2^a\left(F_n^m\right)=\left[2(n-1)^3(m-1)^3\right]^a \frac{1}{2}m(n-1)(n-2). \tag{10}$$

**Proof:** Let $F = F_n^m$. By using equation (2) and Table 4, we obtain

$$\begin{aligned}LGO_2^a\left(F_n^m\right) &= \sum_{uv\in E(F)}\left[\left(d_2(u)+d_2(v)\right)\left(d_2(u)d_2(v)\right)\right]^a \\ &=\left[(0+(n-1)(m-1))0(n-1)(m-1)\right]^a m(n-1) \\ &\quad +\left[((n-1)(m-1)+(n-1)(m-1))(n-1)(m-1)(n-1)(m-1)\right]^a \frac{1}{2}m(n-1)(n-2) \\ &=\left[2(n-1)^3(m-1)^3\right]^a \frac{1}{2}m(n-1)(n-2).\end{aligned}$$

We obtain the following results by using theorem 8.

**Corollary 8.1:** The second leap Gourava index of $F_n^m$ is

$$LGO_2\left(F_n^m\right)=m(n-1)^4(m-1)^3(n-2).$$

**Corollary 8.2:** The second hyper leap Gourava index of $F_n^m$ is

$$HLGO_2\left(F_n^m\right)=2m(n-1)^7(m-1)^6(n-2).$$

**Corollary 8.3:** The product connectivity leap Gourava index of $F_n^m$ is

$$PLGO\left(F_n^m\right)=\frac{m(n-2)}{2(m-1)\sqrt{2(n-1)(m-1)}}.$$

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

 

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