Isomorphism on Irregular Intuitionistic Fuzzy Graphs and Its Complements

S. Yahya Mohamed and R. Jahir Hussain

Abstract: In this paper, we study more results of isomorphism on highly irregular intuitionistic fuzzy graphs discussed. Isomorphism on neighbourly irregular intuitionistic fuzzy graphs and its complement are established. Also we extend the isomorphic properties of neighbourly total irregular intuitionistic fuzzy graphs.

Keywords: Intuitionistic fuzzy graph, degree, total degree, neighbourly IFG, neighbourly Total IFG.

I. Introduction:


In this paper, we discuss more results on highly irregular intuitionistic fuzzy graphs. Isomorphism on neighbourly irregular intuitionistic fuzzy graphs and its complement established. Also we extend some result on isomorphism on neighbourly total irregular intuitionistic fuzzy graphs and this concept is useful in Information analysis and computer networks.

II. Preliminaries

Definition 2.1: An intuitionistic fuzzy graph is of the form \( G = (V, E) \) where

(i) \( V = \{v_1, v_2, ..., v_n\} \) such that \( \mu_i : V \rightarrow [0,1] \) and \( \gamma_i : V \rightarrow [0,1] \) denote the degree of membership and non-membership of the element \( v_i \) in \( V \) respectively, and \( 0 \leq \mu_i (v_i) + \gamma_i (v_i) \leq 1 \) for every \( v_i \) in \( V \) (\( i = 1, 2, ..., n \)),
(ii) \( E \subseteq V \times V \) and let \( \mu_{ij} : V \times V \rightarrow [0,1] \) and \( \gamma_{ij} : V \times V \rightarrow [0,1] \) be such that \( \mu_{ij} (v_i, v_j) \leq \mu_{ij} (v_i, v_j) \) and \( \gamma_{ij} (v_i, v_j) \leq \gamma_{ij} (v_i, v_j) \), where \( \mu_{ij} (v_i, v_j) + \gamma_{ij} (v_i, v_j) \leq 1 \) for every \( (v_i, v_j) \) in \( E \), (\( i, j = 1, 2, ..., n \)).

Definition 2.2: Let \( G = (V, E) \) be an IFG. Then the degree of a vertex \( v \) is defined by \( d(v) = (d\mu(v), d\gamma(v)) \) where \( d\mu(v) = \sum u\neq v \mu_{u,v}(v,u) \) and \( d\gamma(v) = \sum u\neq v \gamma_{u,v}(v,u) \).

Definition 2.3: The minimum degree of \( G \) is \( \delta(G) = (\delta\mu(G), \delta\gamma(G)) \) where \( \delta\mu(G) = \Lambda \{d\mu(v)/v \in V\} \) and \( \delta\gamma(G) = \Lambda \{d\gamma(v)/v \in V\} \).

Definition 2.4: The maximum degree of \( G \) is \( \Delta(G) = (\Delta\mu(G), \Delta\gamma(G)) \) where \( \Delta\mu(G) = V \{d\mu(v)/v \in V\} \) and \( \Delta\gamma(G) = V \{d\gamma(v)/v \in V\} \).

Definition 2.5: The total degree of a vertex ‘\( v \)’ is defined as \( t(v) = (t\mu(v), t\gamma(v)) \), where \( t\mu(v) = \sum \mu_{u,v}(v,u) + \mu_{u,v}(v,u) \) and \( t\gamma(v) = \sum \gamma_{u,v}(v,u) + \gamma_{u,v}(v,u) \).

Definition 2.6: The complement of an IFG \( G = (V, E) \) is denoted by \( \bar{G} = (\bar{V}, \bar{E}) \) and is defined as

i) \( \bar{\mu}_i(v) = 1 - \mu_i(v) \) and \( \bar{\gamma}_i(v) = 1 - \gamma_i(v) \)

ii) \( \bar{\mu}_{u,v} = \mu_i(u) \wedge \mu_i(v) \) and \( \bar{\gamma}_{u,v} = \gamma_i(u) \vee \gamma_i(v) \) for \( u, v \) in \( V \).

Definition 2.7: An intuitionistic fuzzy graph \( G = (V, E) \) is said to be regular, if every vertex has same degree.

Definition 2.8: Let \( G = (V, E) \) be IFG. Then \( G \) is irregular, if there is a vertex which is adjacent to vertices with distinct degrees.

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Definition 2.9:
A homomorphism of Intuitionistic fuzzy graphs \( h: G \rightarrow G' \) is a map h: \( S \rightarrow S' \) which satisfies

(i) \( \mu_1(x) \leq \mu_1'(h(x)) + \gamma_1(x) \geq \gamma_1'(h(x)) \) for every \( x \in S \).

(ii) \( \mu_2(x,y) \leq \mu_2'(h(x), h(y)) + \gamma_2(x,y) \geq \gamma_2'(h(x), h(y)) \) for every \( x \in S \).

Definition 2.10:
A weak isomorphism of Intuitionistic fuzzy graphs \( h: G \rightarrow G' \) is a map h: \( S \rightarrow S' \) which is a bijective homomorphism that satisfies \( \mu_1(x), \gamma_1(x) = (\mu_1'(h(x)), \gamma_1'(h(x))) \) for every \( x \in S \).

Definition 2.11:
A co-weak isomorphism of intuitionistic fuzzy graphs \( h: G \rightarrow G' \) is a map h: \( S \rightarrow S' \) which is a bijective homomorphism that satisfies \( \mu_2(x,y), \gamma_2(x,y) = (\mu_2'(h(x), h(y)), \gamma_2'(h(x), h(y))) \) for every \( x,y \in S \).

Definition 2.12:
An isomorphism of intuitionistic fuzzy graphs \( h: G \rightarrow G' \) is a map h: \( S \rightarrow S' \) which is a bijective homomorphism that satisfies

(i) \( (\mu_1(x), \gamma_1(x)) = (\mu_1'(h(x)), \gamma_1'(h(x))) \) for every \( x \in S \).

(ii) \( (\mu_2(x,y), \gamma_2(x,y)) = (\mu_2'(h(x), h(y)), \gamma_2'(h(x), h(y))) \) for every \( x,y \in S \).

This will denote as \( G \cong G' \).

Definition 2.13:
An Intuitionistic Fuzzy graph \( G \) is said to be self complementary if \( G \cong \overline{G} \).

Definition 2.14:
An Intuitionistic Fuzzy graph \( G \) is said to be self weak complementary if \( G \) is weak isomorphic with \( \overline{G} \).

III. Isomorphic properties of highly irregular IFG and its complement

Definition 3.1:
Let \( G = (V, E) \) be a connected IFG. Then, \( G \) is said to be a highly irregular IFG if every vertex of \( G \) is adjacent to vertices with distinct degrees.

Theorem 3.2:
Let \( G \) and \( G' \) be two highly irregular intuitionistic fuzzy graphs. If \( G \) is co-weak isomorphic with \( G' \), then there exists a homomorphism between \( G \) and \( \overline{G} \), but the complements need not be highly irregular IFG.

Proof:
Suppose \( G \) is co-weak isomorphic with \( G' \), then \( G \rightarrow S' \) is a bijective map that satisfies

\[ \mu_1(x) \leq \mu_1'(h(x)) + \gamma_1(x) \geq \gamma_1'(h(x)) \]

for every \( x \in S \).

\[ (\mu_2(x,y), \gamma_2(x,y)) = \mu_2'(h(x), h(y)), \gamma_2'(h(x), h(y)) \]

Similarly, \( \overline{G} \) will be co-weak isomorphic with \( \overline{G'} \), but the complements need not be highly irregular IFG.

Hence, we have \( h \) is a bijective homomorphism between \( G \) and \( \overline{G} \). Also the complements need not be highly irregular IFG

Proposition 3.3:
If there is a co-weak isomorphism between two highly irregular intuitionistic fuzzy graphs \( G \) and \( G' \), then \( G \) and \( \overline{G} \) need not be co-weak isomorphic. Also the complements need not highly irregular IFG.

Example 3.4:
Let \( G = (V, E) \) be IFG with \( V = \{ a, b, c, d \} \) and defined by \( (\mu_1(a), \gamma_1(a)) = (0.6,0.3) \), \( (\mu_1(b), \gamma_1(b)) = (0.4,0.5) \), \( (\mu_1(c), \gamma_1(c)) = (0.5,0.5) \), \( (\mu_1(d), \gamma_1(d)) = (0.7,0.2) \), \( (\mu_2(a,b), \gamma_2(a,b)) = (0.3,0.2) \), \( (\mu_2(b,c), \gamma_2(b,c)) = (0.2,0.4) \), \( (\mu_2(c,d), \gamma_2(c,d)) = (0.3,0.1) \), \( (\mu_2(d,a), \gamma_2(d,a)) = (0.5,0.2) \).

Then \( G \) will be \( (\mu_1(a), \gamma_1(a)) = (0.6,0.3) \), \( (\mu_1(b), \gamma_1(b)) = (0.4,0.5) \), \( (\mu_1(c), \gamma_1(c)) = (0.5,0.5) \), \( (\mu_1(d), \gamma_1(d)) = (0.7,0.2) \), \( (\mu_2(a,b), \gamma_2(a,b)) = (0.3,0.2) \), \( (\mu_2(b,c), \gamma_2(b,c)) = (0.2,0.4) \), \( (\mu_2(c,d), \gamma_2(c,d)) = (0.3,0.1) \), \( (\mu_2(d,a), \gamma_2(d,a)) = (0.5,0.2) \).

\( G \) is also co-weak isomorphic with \( G' \), but the complements need not be highly irregular IFG.

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In this example, G is co-weak isomorphic with G'. However, G is not co-weak isomorphic with G'. Therefore, there is isomorphism between G and G'. Also, G is not highly irregular IFG because the vertices c and d have the same degree. But G' is highly irregular IFG.

**Theorem 3.5:**
A highly irregular IFG need not be self complementary.

**Proof:** In the complement IFG, to every vertex, the adjacent vertices with distinct degree or the non-adjacent vertices with distinct degrees may happen to be adjacent vertices with same degrees. So the complement may not be highly irregular IFG.

**Example 3.5:**

G = (V, E) be IFG with V = {a, b, c, d} and defined by 
\[(\mu(a, b), \gamma(a)) = (0.5, 0.3), (\mu(b, c), \gamma(b)) = (0.4, 0.2), (\mu(c, d), \gamma(c)) = (0.7, 0.3), (\mu(d, c), \gamma(d)) = (0.8, 0.3), (\mu(d, a), \gamma(d, a)) = (0.5, 0.3), (\mu(b, d), \gamma(b, d)) = (0.2, 0.1)\].

Then \(G\) will be \(G = (\bar{V}, \bar{E})\) with \(\bar{V} = \{a, b, c, d\}\) and defined by \(\bar{\mu}(a, b, \gamma(a)) = (0.5, 0.3), (\bar{\mu}(b, c, \gamma(b)) = (0.4, 0.2), (\bar{\mu}(c, d, \gamma(c)) = (0.7, 0.3), (\bar{\mu}(d, c, \gamma(d)) = (0.8, 0.3)\) and \(\bar{G}(c, d, \gamma(c, d)) = (0.3, 0.2)\), \(\bar{G}(d, c, \gamma(d, c)) = (0.4, 0.2)\), \(\bar{G}(d, a, \gamma(d, a)) = (0.3, 0.1)\), \(\bar{G}(d, a, \gamma(d, a)) = (0.4, 0.2)\).

Here, G is highly irregular IFG, but G is highly irregular. Hence G is not weak isomorphic with G. Hence G is not a self weak complementary highly irregular IFG.

**Example 3.6:**

**Example 3.7:**

G = (V, E) be IFG with V = {a, b, c, d} and defined by \((\mu(a, b), \gamma(a)) = (0.5, 0.4), (\mu(b, c), \gamma(b)) = (0.4, 0.2), (\mu(c, d), \gamma(c)) = (0.7, 0.3), (\mu(d, c), \gamma(d)) = (0.8, 0.3)\) and defined by \(\mu(a, b, \gamma(a)) = (0.2, 0.2), (\mu(b, c, \gamma(b)) = (0.2, 0.2), (\mu(c, d, \gamma(c)) = (0.3, 0.2), (\mu(d, c, \gamma(d)) = (0.2, 0.3), (\mu(c, a, \gamma(c, a)) = (0.5, 0.4)\).

Then \(G\) will be \(G = (\bar{V}, \bar{E})\) with \(\bar{V} = \{a, b, c, d\}\) and defined by \(\bar{\mu}(a, b, \gamma(a)) = (0.4, 0.1), (\bar{\mu}(b, c, \gamma(b)) = (0.4, 0.2), (\bar{\mu}(c, d, \gamma(c)) = (0.7, 0.3), (\bar{\mu}(d, c, \gamma(d)) = (0.8, 0.3)\) and defined by \(\bar{\mu}(a, b, \gamma(a)) = (0.2, 0.1)\).

Here G and G are highly irregular IFG, but G is not highly irregular. Hence G is not self weak complementary highly irregular IFG.

**Theorem 3.8:** Let G be self weak complementary highly irregular IFG, then
\[\sum_{x, y} \mu_2(x, y) \leq \frac{1}{2} \sum_{x, y} \mu_1(x) \mu_1(y) \text{ and } \sum_{x, y} \gamma_2(x, y) \geq \frac{1}{2} \sum_{x, y} \gamma_1(x) \gamma_1(y)\]

**Proof:**

Given G is self weak complementary IFG then G is weak isomorphic with G. Therefore the weak isomorphism of intuitionistic fuzzy graphs h: \(G \rightarrow \bar{G}\) is a map h: S \(\rightarrow \bar{S}\) which is a bijective homomorphism that satisfies \(\mu_1(x, \gamma_1(x)) = (\bar{\mu}_1(h(x)), \bar{\gamma}_1(h(x)))\) for every x \(\in S\).

Now by using definition of complement,
\[\mu_2(x, y) \leq \mu_1(h(x), \mu_1(h(y)) - \mu_2(h(x), h(y))) = \mu_1(x, \gamma_1(x)) \text{ and } \mu_2(h(x), h(y)) \leq \mu_1(x) \Lambda \mu_1(y)\]

Taking summation on both sides
\[\sum_{x, y} \mu_2(x, y) + \sum_{x, y} \mu_2(h(x), h(y)) \leq \sum_{x, y} \mu_1(x, \mu_1(y)\Lambda \mu_1(y)\]

Since S is finite set, we have
\[\sum_{x, y} \mu_2(x, y) \leq \sum_{x, y} \mu_1(x) \Lambda \mu_1(y)\]

Similarly,
\[\sum_{x, y} \gamma_2(x, y) \geq \frac{1}{2} \sum_{x, y} \gamma_1(x) \Lambda \gamma_1(y)\]

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Consider two neighborly irregular intuitionistic fuzzy graphs $G = (V, E)$ and $G' = (V', E')$ (i.e.)

Also by using in (2),

Using this

As $h \in \text{h}^{-1}(G)$, $G$ and $G'$ are isomorphic if and only if their complements are isomorphic, but the complements need not be neighbourly irregular IFG.

**Theorem 4.2:** Let $G = (V, E)$ and $G' = (V', E')$ be two neighbourly irregular intuitionistic fuzzy graphs. $G$ and $G'$ are isomorphic if and only if their complements are isomorphic, but the complements need not be neighbourly irregular IFG.

**Proof:** Let $G = (V, E)$ and $G' = (V', E')$ be two neighbourly irregular intuitionistic fuzzy graphs.

Assume $G \cong G'$.

(i.e) There exists a bijective map $h: S \rightarrow S'$ satisfying $\mu_1(x, y) = \mu_1(h(x), h(y)), \gamma_1(x, y) = \gamma_1(h(x), h(y)))$ for every $x, y \in S$ and

Using definition of complement,

By the definition of complement of IFG, $\mu_1(x, y) = (\mu_1(x) \land \mu_1(y) - \mu_2(x, y), \gamma_1(x, y) \lor \gamma_2(x, y))$ and

Using definition of complement,

Using the previous two equations, we get

Hence, $G \cong G'$.

**Example 4.3:** Consider two neighbourly irregular intuitionistic fuzzy graphs $G = (V, E)$ and $G' = (V', E')$ defined by $(\mu_1(a), \gamma_1(a)) = (0.6, 0.3), (\mu_2(a), \gamma_2(a)) = (0.5, 0.4), (\mu_1(b), \gamma_1(b)) = (0.5, 0.3), (\mu_2(b), \gamma_2(b)) = (0.6, 0.2), (\mu_1(c), \gamma_1(c)) = (0.8, 0.1), (\mu_2(c), \gamma_2(c)) = (0.4, 0.1)$ and $(\mu_1(d), \gamma_1(d)) = (0.6, 0.3), (\mu_2(d), \gamma_2(d)) = (0.4, 0.1), (\mu_1(e), \gamma_1(e)) = (0.5, 0.4), (\mu_2(e), \gamma_2(e)) = (0.6, 0.3), (\mu_1(f), \gamma_1(f)) = (0.8, 0.2), (\mu_2(f), \gamma_2(f)) = (0.3, 0.2), (\mu_1(g), \gamma_1(g)) = (0.4, 0.1), (\mu_2(g), \gamma_2(g)) = (0.4, 0.1).

Then complement of $G$ and $G'$ will be

In this example, $G$ is isomorphic with $G'$, and $G$ is also isomorphic with $\overline{G'}$. But the complements are not neighbourly irregular IFG.

**Theorem 4.4:** Let $G = (V, E)$ and $G' = (V', E')$ be two neighbourly irregular intuitionistic fuzzy graphs, $G$ is weak isomorphic with $G'$, and $G'$ is weak isomorphic with $\overline{G'}$, but the complements need not be neighbourly irregular IFG.

**Proof:** If $h$ is a weak isomorphism between $G$ and $G'$, then $h: S \rightarrow S'$ is a bijective map that satisfies $h(x) = x$, $x \in S$, $(\mu_1(x), \gamma_1(x)) = (\mu_1(h(x)), \gamma_1(h(x)))$ for every $x \in S$.

Also $\mu_1(x, y) \leq \mu_2(x, y), \gamma_1(x, y) \geq \gamma_2(x, y)$ for every $x, y \in S$.

As $h^{-1}: S' \rightarrow S$ is also bijective for every $x', y \in S'$, there is and $x \in S$ such that $h^{-1}(x) = x$.

Using this in (1), $(\mu_1(x), \gamma_1(x')) = (\mu_1(h^{-1}(x)), \gamma_1(h^{-1}(x')))$. Also by using in (2), $\mu_2(h^{-1}(x), h^{-1}(y)) \geq \mu_2(x, y), \gamma_2(h^{-1}(x), h^{-1}(y))$. Also by using in (2), $h^{-1}(x', y') \leq h^{-1}(x, y)$.

(i.e) $\mu_2(h^{-1}(x), h^{-1}(y)) \geq \mu_2(x, y), \gamma_2(h^{-1}(x), h^{-1}(y)) \geq \gamma_2(x, y)$.
Similarly, \( f^{-1}(x') \leq f^{-1}(y') \) \( \leq f^{-1}(h(x), h(y)) \)
\[ = f^{-1}(x') \leq y'(x', y') \]
\[ = f^{-1}(x', y') \)
Thus, \( f^{-1} : S' \rightarrow S \) is a bijective map which is a weak isomorphism between \( G' \) and \( G \). But the complements need not be neighbouring Intuitionistic Fuzzy graphs.

**Example 4.5:**
Consider two neighbouring irregular Intuitionistic fuzzy graphs \( G = (V, E) \) and \( G' = (V', E') \) defined by
\[
\begin{align*}
(µ(a), γ(a)) &= (0.3, 0.4), (µ(b), γ(b)) = (0.5, 0.3), (µ(c), γ(c)) = (0.6, 0.4), (µ(d), γ(d)) = (0.7, 0.3), \\
(µ(a', b'), γ(a', b')) &= (0.1, 0.2), (µ(b', c'), γ(b', c')) = (0.2, 0.3), (µ(c', d'), γ(c', d')) = (0.5, 0.3), \\
(µ(d, a), γ(d, a)) &= (0.2, 0.3), (µ(a', b'), γ(a', b')) = (0.4, 0.6), (µ(b', c'), γ(b', c')) = (0.5, 0.3), \\
(µ(c', d'), γ(c', d')) &= (0.6, 0.4), (µ(d, a), γ(d, a)) = (0.5, 0.3), (µ(a', b'), γ(a', b')) = (0.6, 0.4), (µ(b', c'), γ(b', c')) = (0.5, 0.3), \\
(µ(c', d'), γ(c', d')) &= (0.6, 0.4).
\end{align*}
\]
Then \( G \) and \( G' \) are isomorphic if and only if their complements are isomorphic, but the complements need not be neighbouring Intuitionistic Fuzzy graphs.

**Theorem 4.6:** Let \( G = (V, E) \) be highly irregular and neighbouring irregular Intuitionistic fuzzy graph if and only if the degrees of all vertices are distinct.

**Proof:** Let \( G \) be an Intuitionistic fuzzy graph with \( n \) vertices \( v_1, v_2, \ldots, v_n \).
Assume \( G \) is highly irregular IFG and neighbouring irregular IFG.
Let the adjacent vertices of \( v_i \) be \( v_1, v_2, \ldots, v_n \) with degrees \((c_1, k_1), (c_2, k_2), \ldots, (c_n, k_n)\) respectively.
As \( G \) is highly irregular IFG, then either \( c_i = k_i \) or \( c_i \neq k_i \) and \( k_i \neq k_j \) for all \( i \neq j \).
Therefore \( d(v_i) \neq d(v_j) \) for all \( i \neq j \) as \( G \) is neighbourly irregular IFG, i.e., the degrees of all vertices of \( G \) are distinct.
Conversely, assume that the degrees of all vertices of \( G \) are distinct. That is every two adjacent vertices have distinct degrees and to every vertex the adjacent vertices have distinct degrees.
Hence \( G \) is neighbourly irregular IFG and highly irregular IFG.

**V. Isomorphic properties of Totally irregular IFG and its complement**

**Definition 5.1:** Let \( G = (V, E) \) be a IFG. Then \( G \) is totally irregular, if there is a vertex which is adjacent to vertices with distinct total degree.

**Definition 5.2:** If every two adjacent vertices of a IFG \( G = (V, E) \) have distinct total degree, then \( G \) is said to be a totally irregular IFG.

**Proposition 5.3:**
Totally irregular IFG need not be neighbourly totally Irregular IFG.

**Example 5.4:**
\[
(µ(a), γ(a)) = (0.5, 0.5), (µ(b), γ(b)) = (0.4, 0.6), (µ(c), γ(c)) = (0.6, 0.4), (µ(d), γ(d)) = (0.5, 0.3), \\
(µ(a, b), γ(a, b)) = (1.0, 0.1), (µ(b, c), γ(b, c)) = (0.2, 0.3), (µ(c, d), γ(c, d)) = (0.2, 0.3), \\
(µ(d, a), γ(d, a)) = (0.3, 0.4).
\]
Here, \( G \) is totally Irregular But the adjacent vertices \( c \) and \( d \) have same total degree (1,1), \( G \) is not neighbourly total irregular IFG.

**Remark:**
The converse is not true. That is, every neighbourly Total irregular IFG is totally Irregular IFG except Intuitionistic path graph.

**Proposition 5.5:** Let \( G = (V, E) \) and \( G' = (V', E') \) be two neighbourly Total irregular intuitionistic fuzzy graphs, \( G \) and \( G' \) are isomorphic if and only if their complements are isomorphic, but the complements need not be neighbourly total irregular IFG.

The proof is as same as Theorem 4.2.
Example 5.6: Consider two neighbourly total irregular IFGs $G = (V, E)$ and $G' = (V', E')$ defined by $(\mu(a), \gamma(a)) = (0.2, 0.3)$, $(\mu(b), \gamma(b)) = (0.4, 0.5)$, $(\mu(c), \gamma(c)) = (0.3, 0.4)$, $(\mu(a), \gamma_a(a)) = (0.1, 0.2)$, $(\mu(b), \gamma_a(b)) = (0.2, 0.4)$, $(\mu(c), \gamma_a(c)) = (0.3, 0.5)$. Then $G$ and $G'$ are self weak isomorphic, $G$ is neighbourly total irregular Intuitionistic fuzzy graph.

Similarly, by the definition of $\mu$ and $\gamma$, $G$ and $G'$ will be $(\mu(G), \gamma(G)) = (0.2, 0.3)$, $(\mu(G'), \gamma(G')) = (0.4, 0.5)$. Then $G$ and $G'$ are also neighbourly isomorphic.

Example 5.8:

$G$ is self weak isomorphic, $G$ is neighbourly total irregular IFG but $G'$ is not neighbourly total irregular IFG.

VI. Conclusion

Here we derived and discussed some more Isomorphism properties of highly Irregular Intuitionistic Fuzzy Graph and isomorphism properties of neighbourly Irregular Intuitionistic Fuzzy Graphs and its complement are discussed. Finally, we studied Isomorphism on neighbourly total Irregular IFG and its complements

References