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ON SYMMETRIC NEIGHBORS DEGREE SUM EXPONENT MATRIX

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Abstract. Recently, exponent matrices have emerged as a dynamic tool for studying networks by measuring node centrality. In this work, we define a Symmetric Neighbors degree sum exponent matrix $S_N E(G)$ of a graph G whose $(i,j)^{th}$ entry is $\delta_i^{\delta_j} + \delta_j^{\delta_i}$ for $i \neq j$, it is zero otherwise, where δ_i is the Neighbors degree sum of a vertex v_i in G. Inspired by the applications of Neighbors degree sum in redefining various degree based topological indices, we introduce characteristic polynomial of $S_N E(G)$, termed as Symmetric Neighbors degree sum exponent polynomial and the sum of absolute value of eigenvalue of $S_N E(G)$ matrix is called as Symmetric Neighbors degree sum exponent energy. In this paper, we obtain the Neighbors degree sum exponent polynomial and Neighbors degree sum exponent energy of some graphs.

Keywords: Graphs, Neighbors degree sum, Symmetric Neighbors degree sum exponent matrix, Symmetric Neighbors degree sum exponent polynomial and energy.

AMS Subject Classification: 05C20; 05C07.

1. Introduction

Let G be a simple, undirected graph with n vertices and m edges. Let $V(G) = \{v_1, v_2 \dots v_n\}$ and $E(G) = \{e_1, e_2 \dots e_n\}$ are the vertex set and edge set of a graph G respectively. If v_1 and v_2 are adjacent vertices of G, then the edge connecting them will be denoted by $v_1 v_2$. The degree of a vertex u in G is the number of edges incident to it and is denoted by $d(u)$. If the degree of a each vertex in a graph G is equal to r then it is called as r-regular graph. Neighborhood of a vertex u is defined as $N_G(u) = \{v \in V(G) : v \text{ is adjacent to } u \text{ in } G\}$. For graph theoretical notations we follow the book[1].

The Neighbors degree sum of a vertex u [6], denoted by $\delta(u)$ and is defined as the sum of degree of adjacent vertices u, that is,

$$\delta(u) = \sum_{v \in N_G(u)} d(v)$$

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Recently, Neighbors degree sum concept and some novel Neighbors degree sum polynomial and their energies have been studied in [2, 5, 7, 11]. Degree exponent polynomial and degree exponent energy of graphs have been studied in [8]. In this paper we introduce a new matrix called Symmetric Neighbors degree sum exponent matrix defined as $S_NE(G) = [ne_{ij}]$, in which

$$ne_{ij} = \begin{cases} \delta_i^{\delta_j} + \delta_j^{\delta_i}, & if \quad i \neq j \\ 0, & if \quad i = j \end{cases}$$

The characteristic polynomial $P_{S_NE(G)}(\mu) = det(\mu I - S_NE(G))$ of a matrix $S_NE(G)$ is called Symmetric Neighbors degree sum exponent polynomial of G, where I is an identity matrix. The roots of the equation $P_{S_NE(G)}(\mu) = 0$, denoted by $\mu_1, \mu_2, \dots \mu_n$ are called Symmetric Neighbors degree sum exponent eigenvalues of G and their collection is called Symmetric Neighbors degree sum exponent spectrum of G. Thus the sum of the absolute values of the Symmetric Neighbors degree sum exponent matrix of G is called Symmetric Neighbors degree sum exponent energy of G and is denoted by S_NEE(G). Thus

$$S_NEE(G) = \sum_{i=1}^{n} |\mu_i|. \tag{1}$$

It is noted that, the Eq. (1) is in full analogy with the ordinary graph energy, defined as the sum of absolute values of the eigenvalues of the adjacency matrix of G [3] and some recent work can be found in [10, 12]. For details on the energy of graph, it is suggested to refer the book [4] and the references cited there in.

In this paper, we obtain the Symmetric Neighbors degree sum exponent polynomial of some graphs and thereby obtain Symmetric Neighbors degree sum exponent energy. Following lemmas are required for the further results.

Let I be the identity matrix and J be the matrix whose all entries are equal to one.

Lemma 1.1. [1] *The eigenvalues of $n \times n$ matrix $aI + bJ$ are a with multiplicity $n-1$ and $a + nb$ with multiplicity one.*

Lemma 1.2. [1] *If a,b,c and d are real numbers then the determinant of order $n_1 + n_2$ of the form*

$$\begin{vmatrix} (\mu+a)I_{n_1} - aJn_1 & -cJ_{n_1 \times n_2} \\ -dJ_{n_2 \times n_1} & (\mu+b)I_{n_2} - bJ_{n_2} \end{vmatrix}$$

can be expressed as, $(\mu+a)^{n_1-1}(\mu+b)^{n_2-1}\{[\mu-(n_1-1)a][\mu-(n_2-1)b] - n_1n_2cd\}$

Lemma 1.3. [9] *Let G be a graph with n vertices and m edges. Then,*

$$\delta_{\overline{G}}(u) = \delta_G(u) - (n-2)d_G(u) + (n-1)^2 - 2m$$

2. Symmetric Neighbors degree sum exponent polynomial of some graphs

It is simple to see that if G is an r-regular graph, then its Symmetric Neighbors degree sum exponent matrix can be expressed as $S_NE(G) = -2r^{2r^2}I + 2r^{2r^2}J$. Therefore by Lemma 1.1, for an r-regular graph G of order n,

$$P_{S_NE(G)}(\mu) = \left(\mu + 2r^{2^{r^2}}\right)^{n-1}\left(\mu - 2r^{2^{r^2}}(n-1)\right) \tag{2}$$

The complete graph K_n is a $(n-1)$-regular graph and the cycle C_n is a 2-regular graph. Therefore, from Eqn. (2),

$$P_{S_NE(K_n)}(\mu) = \left[\mu + 2(n-1)^{2n^2-4n+2}\right]^{n-1}\left[\mu - 2(n-1)^{2n^2-4n+3}\right]$$

$$P_{S_NE(C_n)}(\mu) = [\mu + 512]^{n-1}\,[\mu - 512(n-1)]$$

Let $V(G)$ be the vertex set of G. The complement of a graph G is a graph $\overline{G}$ with vertex set $V(G)$ and two vertices in $\overline{G}$ are adjacent if and only if these are not adjacent in G. If G is an r-regular graph with n vertices and m edges, Symmetric Neighbors degree sum of every vertex is $2r^2$ then by Lemma 1.3, $\overline{G}$ is an $(n-r-1)$-regular graph on the same number of vertices and edges with Symmetric Neighbors degree sum of every vertex $2(r^2-(n-2)r+(n-1)^2-2m)$. Therefore from Eqn. (2), if G is an r-regular graph on n vertices, then the Symmetric Neighbors degree sum exponent polynomial of its complement graph is given as:

$$P_{S_NE(\bar{G})}(\mu) = \left[\mu + 2(r^2-(n-2)r+(n-1)^2-2m)^{2(r^2-(n-2)r+(n-1)^2-2m)^2}\right]^{n-1}$$
$$\left[\mu - 2(r^2-(n-2)r+(n-1)^2-2m)^{2(r^2-(n-2)r+(n-1)^2-2m)^2}(n-1)\right]$$

A graph G is said to be bipartite if its vertex set $V(G)$ can be partitioned into two sets V_1 and V_2 such that each edge of G has one end vertex in V_1 and other end vertex in V_2. A complete bipartite graph is bipartite graph with partite sets V_1 and V_2 in which every vertex of V_1 is adjacent to all vertices of V_2. The complete bipartite graph is denoted by K_{n_1,n_2}, where $|V_1| = n_1$ and $|V_2| = n_2$.

Theorem 2.1. *The Symmetric Neighbors degree sum exponent polynomial of the complete bipartite graph K_{n_1,n_2} is*

$$(\mu + 2(n_1n_2)^{n_1n_2})^{n_1+n_2-2}\left\{\left[(\mu - 2(n_1-1)(n_1n_2)^{n_1n_2})(\mu - 2(n_2-1)(n_1n_2)^{n_1n_2}) - 4(n_1n_2)^{2n_1n_2+1}\right]\right\}$$

Proof. The Symmetric Neighbors degree sum exponent matrix of the complete bipartite graph K_{n_1,n_2} is

$$\begin{bmatrix} 2(n_1n_2)^{(n_1n_2)}J_{n_1} - 2(n_1n_2)^{(n_1n_2)}I_{n_1} & 2(n_1n_2)^{(n_1n_2)}J_{n_1\times n_2} \\ 2(n_1n_2)^{(n_1n_2)}J_{n_2\times n_1} & 2(n_1n_2)^{(n_1n_2)}J_{n_2} - 2(n_1n_2)^{(n_1n_2)}I_{n_2} \end{bmatrix}$$

Therefore,

$$\begin{aligned} P_{S_NE(K_{n_1,n_2})}(\mu) &= |\mu I - S_NE(K_{n_1,n_2})| \\ &= \begin{vmatrix} \left[\mu + 2(n_1n_2)^{(n_1n_2)}\right]I_{n_1} - 2(n_1n_2)^{(n_1n_2)}J_{n_1} & -2(n_1n_2)^{(n_1n_2)}J_{n_1\times n_2} \\ -2(n_1n_2)^{(n_1n_2)}J_{n_2\times n_1} & \left[\mu + 2(n_1n_2)^{(n_1n_2)}\right]I_{n_2} - 2(n_1n_2)^{(n_1n_2)}J_{n_2} \end{vmatrix} \end{aligned} \quad (3)$$

By Lemma 1.2 to Eqn. (3), we get the result.

Corollary 2.1. *Let $S_n = K_{1,n-1}$ be the star graph with n vertices. Then the Symmetric Neighbors degree sum exponent polynomial of S_n is*

$$P_{S_NE(S_n)}(\mu) = \left[\mu + 2(n-1)^{n-1}\right]^{n-2}\left[\mu^2 - 2(n-2)(n-1)^{n-1}\mu - 4(n-1)^{2n-1}\right]$$

Theorem 2.2. *Let P_n be a path with $n > 4$ vertices. Then the Symmetric Neighbors degree sum exponent polynomial of P_n is*

$$P_{S_NE(P_n)}(\mu) = \left(\mu + 2(4^4)\right)^{n-5} \left(\mu + 2(3^3)\right) \left(\mu + 2(2^2)\right) \left[\mu^3 + (2498 - 512n)\mu^2 + (16948 - 12354n)\mu + 186640n - 1117248\right]$$

Proof. The characteristic polynomial of Symmetric Neighbors degree sum exponent matrix of path P_n is

$$\begin{aligned} P_{S_NE(S_n)}(\mu) &= |\mu I - S_NE(P_n)| \\ &= \begin{vmatrix} \mu & -2^3-3^2 & -2^4-4^2 & -2^4-4^2 & \cdots & -2^4-4^2 & -2^3-3^2 & 2(-2^2) \\ -3^2-2^3 & \mu & -3^4-4^3 & -3^4-4^3 & \cdots & -3^4-4^3 & 2(-3^3) & -3^2-2^3 \\ -4^2-2^4 & -4^3-3^4 & \mu & 2(-4^4) & \cdots & 2(-4^4) & -4^3-3^4 & -4^2-2^4 \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & \mu & \cdots & 2(-4^4) & -4^3-3^4 & -4^2-2^4 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & 2(-4^4) & \cdots & \mu & -4^3-3^4 & -4^2-2^4 \\ -3^2-2^3 & 2(-3^3) & -3^4-4^3 & -3^4-4^3 & \cdots & -3^4-4^3 & \mu & -3^2-2^3 \\ 2(-2^2) & -2^3-3^2 & -2^4-4^2 & -2^4-4^2 & \cdots & -2^4-4^2 & -2^3-3^2 & \mu \end{vmatrix} \end{aligned} \tag{4}$$

Subtract third column from the columns $4, 5 \ldots n-2$ and subtract first column from the last column and also second column from $n-1$ columns of Eqn. (4) to obtain Eqn. (5)

$$= \begin{vmatrix} \mu & -2^3-3^2 & -2^4-4^2 & 0 & \cdots & 0 & 0 & 2(-2^2)-\mu \\ -3^2-2^3 & \mu & -3^4-4^3 & 0 & \cdots & 0 & 2(-3^3)-\mu & 0 \\ -4^2-2^4 & -4^3-3^4 & \mu & 2(-4^4)-\mu & \cdots & 2(-4^4)-\mu & 0 & 0 \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & \mu+2(4^4) & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & 0 & \cdots & \mu+2(4^4) & 0 & 0 \\ -3^2-2^3 & 2(-3^3) & -3^4-4^3 & 0 & \cdots & 0 & \mu+2(3^3) & 0 \\ 2(-2^2) & -2^3-3^2 & -2^4-4^2 & 0 & \cdots & 0 & 0 & \mu+2(2^2) \end{vmatrix} \tag{5}$$

Adding last row to the first row and adding second row to the $(n-1)^{th}$ row and then adding rows $4, 5 \ldots n-2$ to the row of Eqn. (5) to obtain Eqn. (6).

$$= \begin{vmatrix} \mu-2(2^2) & 2(-2^3-3^2) & 2(-2^4-4^2) & 0 & \cdots & 0 & 0 & 0 \\ 2(-3^2-2^3) & \mu-2(3^3) & 2(-3^4-4^3) & 0 & \cdots & 0 & 0 & 0 \\ (n-4)(-4^2-2^4) & (n-4)(-4^3-3^4) & \mu-2(4^4)(n-5) & 0 & \cdots & 0 & 0 & 0 \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & \mu+2(4^4) & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ -4^2-2^4 & -4^3-3^4 & 2(-4^4) & 0 & \cdots & \mu+2(4^4) & 0 & 0 \\ -3^2-2^3 & 2(-3^3) & -3^4-4^3 & 0 & \cdots & 0 & \mu+2(3^3) & 0 \\ 2(-2^2) & -2^3-3^2 & -2^4-4^2 & 0 & \cdots & 0 & 0 & \mu+2(2^2) \end{vmatrix} \tag{6}$$

Eqn. (6) can be reduced to

$$\begin{aligned} P_{S_NE(P_n)}(\mu) &= \left(\mu + 2(4^4)\right)^{n-5} \left(\mu + 2(3^3)\right) \left(\mu + 2(2^2)\right) \begin{vmatrix} \mu-2(2^2) & 2(-2^3-3^2) & 2(-2^4-4^2) \\ 2(-2^3-3^2) & \mu-2(3^3) & 2(-3^4-4^3) \\ (n-4)(-4^2-2^4) & (n-4)(-4^3-3^4) & \mu-2(4^4)(n-5) \end{vmatrix} \\ &= \left(\mu + 2(4^4)\right)^{n-5} \left(\mu + 2(3^3)\right) \left(\mu + 2(2^2)\right) \\ &\quad \left[\mu^3 + (2498 - 512n)\mu^2 + (16948 - 12354n)\mu + 186640n - 1117248\right] \end{aligned}$$

The wheel W_n is a graph obtained from the cycle C_n by adding a new vertex u and joining it to all vertices of C_n.

Theorem 2.3. *Let W_n be a wheel graph with n vertices. Then the Symmetric Neighbors degree sum exponent polynomial is*

$$\begin{aligned} P_{S_NE(W_n)}(\mu) &= \left[\mu + 2(n+5)^{(n+5)}\right]^{n-2} \\ &\quad \left\{\mu^2 - 2\mu(n-2)(n+5)^{(n+5)} - (n-1)\left[3(n-1)^{n+5} + (n+5)^{3n-3}\right]^2\right\} \end{aligned}$$

Proof. The characteristic polynomial of Symmetric Neighbors degree sum exponent matrix of wheel W_n is

$$\begin{aligned} P_{S_NE(W_n)}(\mu) &= |\mu I - S_NE(W_n)| \\ &= \begin{vmatrix} \mu & -[3(n-1)]^{(n+5)} - (n+5)^{3(n-1)} & \cdots & -[(3n-3)]^{(n+5)} - (n+5)^{(3n-3)} \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & \mu & \cdots & -2(n+5)^{(n+5)} \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & \cdots & -2(n+5)^{(n+5)} \\ \vdots & \vdots & \ddots & \vdots \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & \cdots & \mu \end{vmatrix} \end{aligned} \quad (7)$$

Subtract second column from the columns $3, 4 \ldots n$ of Eqn. (7) to obtain Eqn. (8)

$$= \begin{vmatrix} \mu & -[3(n-1)]^{(n+5)} - (n+5)^{3(n-1)} & 0 & \cdots & 0 \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & \mu & -2(n+5)^{(n+5)} - \mu & \cdots & -2(n+5)^{(n+5)} - \mu \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & \mu + 2(n+5)^{(n+5)} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & 0 & \cdots & \mu + 2(n+5)^{(n+5)} \end{vmatrix} \quad (8)$$

Adding rows $3, 4 \ldots n$ to the second row in Eqn. (8) to obtain Eqn. (9)

$$= \begin{vmatrix} \mu & -[3(n-1)]^{(n+5)} - (n+5)^{(3(n-1))} & 0 & \cdots & 0 \\ (n-1)\left[-(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)}\right] & \mu - 2(n-2)(n+5)^{(n+5)} & 0 & \cdots & 0 \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & \mu + 2(n+5)^{(n+5)} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)} & -2(n+5)^{(n+5)} & 0 & \cdots & \mu + 2(n+5)^{(n+5)} \end{vmatrix} \quad (9)$$

On simplifying Eqn. (9), we get,

$$\begin{aligned} P_{S_NE(W_n)}(\mu) &= \left[\mu + 2(n+5)^{(n+5)}\right]^{n-2} \begin{vmatrix} \mu & -[3(n-1)]^{(n+5)} - (n+5)^{3(n-1)} \\ (n-1)\left[-(n+5)^{3(n-1)} - [3(n-1)]^{(n+5)}\right] & \mu - (n-2)2(n+5)^{(n+5)} \end{vmatrix} \\ P_{S_NE(W_n)}(\mu) &= \left[\mu + 2(n+5)^{(n+5)}\right]^{n-2} \\ &\quad \left\{\mu^2 - 2\mu(n-2)(n+5)^{(n+5)} - (n-1)\left[3(n-1)^{n+5} + (n+5)^{3n-3}\right]^2\right\} \end{aligned}$$

3. Symmetric Neighbors degree sum exponent Energy

The results of this section are straightforward by using the results of Section 2 via Eq.(1).

By Eqn. (2), the Symmetric Neighbors degree sum exponent eigenvalues of an r-regular graph G are $-2r^{2r^2}(n-1)$ times and $2r^{2r^2}$. Therefore for an r-regular graph G on n-vertices, $S_NEE(G) = 4r^{2r^2}(n-1)$. Hence, $S_NEE(K_n) = 4(n-1)^{2n^2-4n+3}$ and $S_NEE(C_n) = 1024(n-1)$.

If G is an r-regular graph on n vertices then

$$S_N EE(\overline{G}) = 4(n-1)\left[r^2-(n-2)r+(n-1)^2-2m\right]^{2\left[r^2-(n-2)r+(n-1)^2-2m\right]^2}$$

By Theorem 2.1,

$$S_N EE(K_{n_1,n_2}) = 2\left(\sqrt{[(n_1n_2)^{n_1n_2}(n_1+n_2-2)]^2-4n_1n_2^{2n_1n_2}(1-n_1-n_2)}\right)$$

$$+2(n_1+n_2-2)(n_1n_2^{n_1n_2})$$

For a wheel W_n,

$$S_N EE(W_n) = 2\left[(n-2)(n+5)^{n+5}+\sqrt{[(n+5)^{n+5}(n-2)]^2+(n-1)[(3n-3)^{n+5}+(n+5)^{3n-3}]^2}\right]$$

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