A Study of power plant selection process – A graph theoretic approach

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Abstract: A power plant is an industrial facility that is utilized for the generation of electrical power on a large scale. Selecting the best suitable power plant depends upon a number of various factors such as cost, fuel, location, and availability of a water source. It is very important to select an appropriate power plant to be set-up taking all these parameters and their sub-factors into consideration. In this paper, a graph-theoretic approach has been used to select the best power plant among three of the major power plants which include hydroelectric power plant, thermal power plant, and nuclear power plant. A fishbone diagram is used to represent the factors and the cofactors affecting the power plant selection process. A digraph characteristic is sketched between the factors and cofactors which are involved in the selection of the power plant. The interdependency of the factors and their inheritances are identified and they have been represented by using numerical values in this work. These values are further represented in a matrix form for the above stated three power plants. An example is made to illustrate the use of this technique in decision-making problems with different alternatives and multiple interdependent factors.

Keywords: Power plant, Graph theory, Fishbone diagram, VPF.

1. INTRODUCTION

A power plant, sometimes known as a power generating station, is an industrial location where electric power is generated and distributed on a mass scale. The power generated is usually in the order of 1000 Watts. Power plants can be classified into different types based on the fuel used for the generation of electricity. These power plants can be broadly classified into three types namely hydroelectric power plants, thermal power plants, and nuclear power plants. Hydropower is one of the cleanest ways of producing electricity. Electricity is produced in a hydroelectric power plant by the flow of water from a height that is used to drive the turbine. The fast-flowing or falling water is converted into mechanical energy when the turbine rotates which is further converted into electric power by the generator. Power plants that convert heat energy into electricity are known as thermal power plants. In most thermal power plants, heat energy is used to convert fluid into gas which turns the turbine producing mechanical energy which is an intermediate in the process and is converted into electricity in the generators. A nuclear power plant is similar to a thermal power plant but in nuclear power plants, a nuclear reactor acts as the heat source. In a nuclear reactor, controlled nuclear fission takes place which produces an enormous amount of heat. This heat is dissipated in the water and it is converted into high-pressure steam which in turn runs the turbine.
1.1. Factors in consideration to choose a site
The identification of a site for a power plant selection depends on various factors like land, space, water, cost, transport, fuel, availability of cooling water, nature of the load, etc. Apart from these factors, there are a few sub-factors involving in this process.

Cost of Transmission of Energy
The location of a power plant should be as close to the load center as possible. This will help in reducing the losses in transmission and transmission costs. Hydroelectric, nuclear, and steam power plants cannot be located near the load centers. So, their transmission lines must be of larger, moderate, and shorter lengths respectively. Power plants which run on diesel and gas can be located near the load center and hence transmission losses can be minimized. However, modern power plants are of large capacities and they help us to feed a grid that supplies electrical power to large areas.

Cost of Fuel:
One of the most important criteria to be considered while choosing the type of power plant for setting up in some particular location is the cost of the fuel. But in hydroelectric power plants, fuel cost does not matter because the source of power here is water hence it must be available in large quantities and at sufficient head. In the case of thermal plants, the availability of coal and its cost are important considerations. Thermal power plants are most economical near coal mines and by the side of a river or canal. Fuel used in a nuclear power plant is expensive and hence it is difficult to get.

Cost of Land and Taxes:
The costs of land and the tax on it, depends on the proposed power plant. The land cost if it is near a load center like a big city will be much higher than at a remote place. The taxes for land in the center of a commercial city would also be higher than those in remote areas. Therefore, the cost of land and taxes is also a significant point to be considered in the economic selection of a site.

Space Requirement:
If the building to be built and space requirement are both large, then the cost of it will be high. Thus, large power plants located near the center of gravity of load like hearts of big cities are not economical. A hydroelectric power station requires tons of space for construction works like dams etc. and also the space required is much larger than other types of power plants. Also, several arrangements have to be made in the building as special features in a hydroelectric power plant. The location should be such that the cost of land is not excessive also water should be available at enough head.

Availability of Site for Water Power:
It is required to explore a suitable source of water and sites for a hydroelectric power plant before deciding the type of power plant for a given location. The land topography, rainfall, catchment area for water, a suitable site for storing the water behind the dam are some of the considerations. Other considerations include the cost for civil engineering works like the construction of a dam and a huge quantity of water at the required head.

Storage Space for Fuel:
A thermal power plant requires space for the storage of coal which depends on the size of the plant. Coal should be available for at least the next 2 to 3 weeks on site. The requirement of reserve stock changes for the power plant is based on its location. It may not be necessary to store a large quantity if the plant is near a coal mine, whereas a large stock may be required if it is not near a source of fuel.

Nature of Load:
The nature of the load to be supplied affects the choice of the power plant to a certain extent. If there are sudden variations in load and in turn the load factor is poor and also if the load is small, it is smarter to choose a thermal power plant as they are more adaptable than nuclear power plants. This is because a thermal plant can be started quickly and can be put to share full load within a few minutes.
which is not the case with nuclear power plants. The reactor in a nuclear power plant does not respond to the fluctuations of load efficiently hence a Nuclear power plant is not well suited for varying loads. Nuclear power plants also need a longer time (2-3 hours) for starting and taking the load. If a hydroelectric power plant of small or suitable capacity is available, it can be started quickly and take up the load, and thus can be employed for the varying loads.

1.2. Mathematical method – graph theory
Graph theory is the implementation of data as graphs and the study of such graphs. Vertices and edges make up a graph. Vertices are also known as points or nodes, similarly, edges are also known as lines or links. Graphs are classified into directed and undirected graphs. When the edges link two vertices asymmetrically then it is called a directed graph or digraph. If the edges are linked in a way that has a direction or flow then it is called an undirected graph. Almost all the problems in engineering can be modeled as a graph. When it is modeled as a graph, it helps us to understand the problem easier, and also it becomes easy to do a component-wise analysis. We can use various concepts like centrality measures, labeling, domination theory, and coloring on these graphs to give an optimal solution to these problems. Many research articles have already been published which uses graph theory as an efficient way to analyze and solve problems. In this paper, we will be using directed graphs to show the relationship between different entities. We will be also using matrix representation and Variable Permanent Function (VPF) in this paper.

1.3. Literature survey
Graph theory [1-2] is an orderly and sensible approach that has been applied in various fields including electrical engineering, computer science, operation research, and applied mathematics. The matrix approach is helpful in investigating the graph models to develop the system function and index to meet the purposes. Moreover, the representation of matrix graph solves the problem to make use of computers for numerous intricate operations. Graph theoretic approach involves matrix modeling, digraph and matrix representation and variable permanent representation. The digraph is the optical depiction of the factors and their interdependence which affects the power plant. The matrix helps to convert the digraph to a mathematical expression. The permanent function is a mathematical model that resolves power plant index. Graph theoretic and matrix approach is a robust tool to calculate single numerical index for interpretation of significant factors pertaining to any engineering problems. Failure mode and effects analysis (FMEA) based on a digraph and matrix approach was introduced and used on the mechanical and hydraulic systems by Gandhi et al. [3]. Sandeep et al. [4] provided a digraph approach to TQM evaluation of an industry. Venkataswamy et al. [5] have developed a simple and efficient analytical method of system and structural analysis of a vehicle, using graph theory, depicting it as a matrix and variable permanent function (VPF). Holbert et al. [6] presented the impact of solar thermal power plants on electricity costs and water resources in the southwest. Ren [7] investigated the method of site selection for a power plant using the concepts of rough sets and multi-objective programming. A graph theoretic and matrix algebra approach on the structural modeling and analysis of composite product system its constituents and their interactions including the curing kinetics, molding processes, etc. was developed by Prabhakaran et al. [8]. Guoqiang et al. [9] analyzed the 300MW thermal system of Xiaolongtan power plant components discretely and found out and enumerate the sites having largest energy and energy losses. Kiran et al. [10] explained a methodology that incorporates permanent multinomial, graph theory and concurrent considers all the x-abilities/design aspects. Criteria for the optimum site selection of nuclear power plant using AHP and GIS was determined by Idris et al. [11]. Kumar et al. [12], the efficiency enhancement for thermal power plant model has been done through the use of refrigerant - R600a, as the coolant in the secondary cycle. The lifetime costs analysis of a coal-fired power plant have been analyzed by Kumar et al. [13]. Khattak et al. [14] reviewed the features, advantages and disadvantages of the common fuels used, the waste products from the fuels, and cost of the fuels. Mendes et al. [15] have analyzed the financial impacts due to pollution from a thermal power plant in the Brazilian public health system. Annisa et al. [16] investigated an environmental impact assessment from all generation process in Muara Karang using life cycle assessment (LCA) methodology. Hong et al. [17] have
1.4. Fishbone diagram (cause and effect diagram)

A cause and effect diagram is a tool that helps to identify the causes for variations, defects, failures, and other factors involved in a particular real-time problem. This is also known as the Ishikawa diagram. Since this representation looks like the skeleton of a fish with the objective of the problem at its head and the spine consisting of the causes for the problem. When all the causes (factors) and sub-factors that involve the problem have been identified, then we can determine the solutions to the problem. This is one of the efficient methods or tools to improve the product development process.

Figure 1 shows the fishbone diagram representing the factors that influence the selection of a power plant. The relationship between these factors, that is the location ($P_1$), water ($P_2$), cost ($P_3$), and fuel ($P_4$). The interactions between the factors are plotted as a digraph shown in Figure 2.

\[ P_1 \rightarrow P_2 \rightarrow P_3 \rightarrow P_4 \]

2. MATRIX REPRESENTATION AND VPF VALUE

A digraph is used to easily visualize the factors and their corresponding sub-factors. The increasing number of factors make the digraph complicated and as a result, make it difficult to understand. So, to help in a better understanding of the factors and their interdependence on each other they can be represented in the form of a $N \times N$ matrix where $N$ represents the factors along the main diagonal and each element $P_{ij}$ in the matrix represents the dependence of the factor $j$ on $i$. From the fishbone diagram, the major factors affecting the selection of the power plant are the location of the power plant, water source, cost, and fuel. This information can be encoded into a matrix for further analysis.
plant \( (P_1) \), water \( (P_2) \), cost \( (P_3) \), and fuel \( (P_4) \).

\[ VPM = \begin{pmatrix} P_1 & P_{12} & P_{13} & P_{14} \\ P_{21} & P_2 & P_{23} & P_{24} \\ P_{31} & P_{32} & P_3 & P_{34} \\ P_{41} & P_{42} & P_{43} & P_4 \end{pmatrix} \]

The interpretation of the factors and their dependence on each other can be seen clearly when viewed in the form of a matrix, but it cannot help much in decision making. The variable permanent function is used to simplify the matrix so that it becomes easier to take productive decisions. The Variable Permanent Function (VPF) is computed in a similar way to that of a determinant with a positive sign.

The VPF value of the given matrix is determined as shown below.

\[ VPF = P_1 P_2 P_3 P_4 + P_{12} P_{21} P_3 P_4 + P_{13} P_3 P_2 P_4 + P_{14} P_4 P_3 P_2 + P_{23} P_2 P_3 P_1 + P_{24} P_2 P_4 P_1 + P_{34} P_3 P_4 P_1 + P_{12} P_{23} P_3 P_4 + P_{13} P_{32} P_2 P_4 + P_{14} P_{42} P_3 P_2 + P_{23} P_{24} P_4 P_3 + P_{24} P_{43} P_3 P_2 + P_{34} P_{32} P_2 P_3 + P_{13} P_{32} P_2 P_3 + P_{23} P_{24} P_1 P_4 + P_{24} P_{43} P_1 P_3 + P_{34} P_{32} P_1 P_2 + P_{13} P_{32} P_1 P_2 + P_{23} P_{24} P_1 P_3 + P_{24} P_{43} P_1 P_2 + P_{34} P_{32} P_1 P_2 \]

### Table 1. Value of interdependence within factors \( (W_{ij}) \) (For off-diagonal entries)

| S.No | Qualitative Measure of interdependency | Value Assigned for Factor |
|------|--------------------------------------|--------------------------|
| 1    | Very strong                          | 5                        |
| 2    | Strong                               | 4                        |
| 3    | Medium                               | 3                        |
| 4    | Weak                                 | 2                        |
| 5    | Very Weak                            | 1                        |

### Table 2. Value of interdependence between factors \( (P_{ij}) \) (For diagonal entries)

| S.No | Qualitative Measure of interdependency | Value Assigned for Factor |
|------|--------------------------------------|--------------------------|
| 1    | Extremely low                        | 1                        |
| 2    | Low                                  | 2                        |
| 3    | Below average                        | 3                        |
| 4    | Average                              | 4                        |
| 5    | Above average                        | 5                        |
| 6    | High                                 | 6                        |
| 7    | Extremely High                       | 7                        |

### 3. DIGRAPH REPRESENTATION OF THE FACTORS

#### 3.1. Location based digraph

The location factor \( (L) \) has four cofactors such as the price of land \( (L_1) \), distance from load \( (L_2) \), storage space \( (L_3) \), and Reachability \( (L_4) \). To determine their interdependency, a location based digraph is drawn as shown in Figure 3.

![Figure 3. Digraph for location](image-url)
Location based weight matrix
From the fishbone diagram, the co-factors of the location of the power plant are the price of land ($L_1$), distance from the load ($L_2$), storage space ($L_3$), and Reachability ($L_4$). Their interdependence was depicted in the digraph in figure 3 and its weight matrix is formed as given below.

$$L = \begin{pmatrix} 
L_1 & 3 & 5 & 5 \\
3 & L_2 & 4 & 5 \\
3 & 4 & L_3 & 4 \\
4 & 5 & 5 & L_4 
\end{pmatrix}$$

The location factor that is taken for consideration is the power generating points linked with the cofactors. Price of land is often in the remote area due to environmental effects of the power plant. The raw materials of the power plant need to be within the permissible limits for the operation of the power plant and the reachability of the power plant will be at the higher side due to its location. The weightages are given based on the linked cofactors.

3.2. Water based digraph
The factor $W$, Water is having three co-factors: disposal of waste ($W_1$), Cooling ($W_2$) and, Heat Exchange ($W_3$). To determine their interdependency, a water based digraph is drawn as shown in Figure 4.

![Fig 4. Digraph for water](image)

Water based weight matrix
From the fishbone diagram, the co-factors of the availability of water are the Disposal of Waste ($W_1$), Cooling ($W_2$) and, Heat Exchange ($W_3$). Their interdependence was depicted in the digraph in figure 4 and its weight matrix is modeled as given below.

$$W = \begin{pmatrix} 
W_1 & 0 & 0 \\
5 & W_2 & 4 \\
0 & 4 & W_3 
\end{pmatrix}$$

The water factor is linked with the interlinked factors such as waste, cooling and heat exchange. The power plants need water as cooling medium, creation of steam and disposal of waste & other impurities in the process. The water used for waste disposal does not involve in the cooling process directly or indirectly and also the water does not directly affect the heat exchange process. The cooling process can involve process in cooling the hot steam exhaust and directly condense the various gases in the process of waste disposal and also in the heat exchange process of the steam. The heat exchange process has a direct impact on heat transfer to the steam and also it can also have an impact of cooling the steam in the power plant operations.

3.3. Cost based digraph
Factor $C$, the cost is having three co-factors: machinery cost ($C_1$), Energy transmission cost ($C_2$) and,
Transportation cost($C_3$). To determine their interdependency, a cost based digraph is drawn as shown in Figure 5.

![Fig 5. Digraph for water](image)

**Cost based weight matrix**

From the fishbone diagram, the co-factors of the cost are machinery cost($C_1$), Energy transmission cost ($C_2$) and, Transportation cost($C_3$). Their interdependence was depicted in the digraph in figure 5 and its weight matrix is modeled as given below.

$$C = \begin{pmatrix}
C_1 & 3 & 2 \\
3 & C_2 & 3 \\
2 & 3 & C_3
\end{pmatrix}$$

The cost factor is most important factor in the operation of the any power plant. Here the cost factor is related with machinery cost, energy transmission cost and transportation cost. The machinery cost of the power plant has moderate effect on the energy transmission cost. Because the transmission system poses high energy transmission lost and this cost is considered more in the long-run period of the power plant. The machinery cost may be high related to transportation during the initial period. But the running period will have less effect on the cost. The energy transmission cost also depends on the machinery used for power generation and transportation cost to a moderate level. The transportation cost has a moderate impact on the machinery used and energy transmission cost in the long-run of the power plant.

3. 4. Fuel based digraph

The factor $F$, Fuel is having three co-factors: Nature($F_1$), Quality ($F_2$) and, Availability($F_3$). To determine their interdependency, a fuel based digraph is drawn as shown in Figure 4.

![Fig 6. Digraph for fuel](image)

**Fuel based weight matrix**

From the fishbone diagram, the co-factors of the fuel are cost($F_1$), Quality ($F_2$) and, Availability($F_3$). Their interdependence was depicted in the digraph in figure 6 and its weight matrix is modeled as given below.

$$F = \begin{pmatrix}
F_1 & 5 & 3 \\
5 & F_2 & 3 \\
3 & 4 & F_3
\end{pmatrix}$$

The fuel decides the type of power plant and also the amount of fuel used may directly impact on the amount of power generation in the power plants. The nature of fuel used has a very high impact on the quality. Higher the quality, higher will be the generation. Also, the nature of fuel that is used for a particular power plant are subjected to the availability. The quality factor of the fuel will have more impact on the nature of fuel used in the different power plants. The quality fuel is also subjected to availability factor to the moderate level. The same realization happens with the nature and quality of...
the fuel subject to availability.

4. POWER PLANT SELECTION

4.1. Hydroelectric power plant

As discussed earlier, the hydroelectric power plant runs on the kinetic energy derived from moving water or when it falls from a height that is used to run the turbine. This kind of power plant has to be situated near a dam which has been built close to a source of water. The kinetic energy of the moving water is converted to mechanical energy in a turbine. The most commonly used turbine for the hydroelectric power plant is the Francis turbine. The turbine consists of blades that rotate when water flows through it. The speed of the water directly affects the production of energy. This mechanical energy is then converted to electrical energy in a generator. Hydroelectric energy is considered as the cleanest energy of all the types of energy generation.

4.2. Thermal power plant

A thermal power plant is a power plant that utilizes the heat generated by burning a fuel mostly coal. The heat generated from the fuel is used to heat up water which converts into steam and runs the turbine. Here the heat energy is converted into mechanical energy and the generator converts it into electrical energy. There are several types of coal used in a thermal power plant. Anthracite coal is the mainly used solid fuel in these. But, the majority of the thermal power plants also used bituminous coal. The thermal power plant is not a very clean way of producing energy as it releases a lot of harmful gases into the environment mainly if the coal is not burnt properly. Also, it releases greenhouse gases like carbon dioxide which in turn contributes to global warming.

4.3. Nuclear power plant

The nuclear power plant is closely related to the thermal power plant. This is because, in a nuclear power plant, nuclear fission takes place in which the nucleus of an atom splits into two or more smaller nuclei. When this happens a lot of energy is let out in the form of heat. This is used to convert water into steam like in a conventional thermal power plant and further, it turns the turbine which is attached to a generator and the generator converts the mechanical energy produced in the turbine into electrical energy.

5. DIGRAPH & MATRIX REPRESENTATION OF THE SELECTION OF POWER PLANTS

The selection of the power plant is done based on the factors discussed above and its co parameters. The digraph showing the correlation between the three different types of power plants - hydroelectric power plant (HPP), thermal power plant (TPP), and nuclear power plant (NPP) is as shown in Figure 7. The system design was made considering the operation of the different power plants during the day time conditions and night time conditions. During the day time, the power demand required by the customers is very high due to the functioning of industries and other domestic usage. During the night time, the power demand will be less. The operation of the three power plants such as hydro power plants, thermal power plants and nuclear power plants are made to operate to meet the demand. There are certain conditions that the operation of the coal driven thermal power plants is first considered to meet the demand. If the demand is not met with the thermal power plants, the nuclear power plants
are made to operate to meet the surplus demand which could not be met by thermal power plants. If both the power plants fail to supply the demand, the last option will be hydro power plants to come into operation to meet the demand. The conditions apply to both during the night time and the day time. The prioritized operation of the different power plants make the effective use of fuel, the corresponding change will affect the cost of operation of the plant and also enables effective transmission of power through the power line to the customers. Considering the above factors, the selection of cost, location and fuel is made based on the coordinated power generation by the different power plants. The values considered below are from an expert or an experienced person in this field.

**Case (i):** The following digraph can be drawn based on day time load demand

![Digraph for Daytime load demand](image)

**Fig 8.** Digraph for Daytime load demand

The matrix representation of the three Power plants in Day time are given below

| Cost(C), Location (L), Fuel (F) |
|-----------------|-----------------|-----------------|
| Hydroelectric power plant | Thermal power plant | Nuclear power plant |
| $P_H = \begin{pmatrix} CH & 5 & 5 \\ 4 & LH & 4 \\ 0 & 1 & FH \end{pmatrix}$ | $P_T = \begin{pmatrix} CT & 4 & 5 \\ 3 & LT & 5 \\ 5 & 4 & FT \end{pmatrix}$ | $P_N = \begin{pmatrix} CN & 4 & 4 \\ 3 & LN & 4 \\ 5 & 3 & FN \end{pmatrix}$ |

In the process of applying graph theory in finding the best power plant from the three, first and the most important step is that we find the significant factors affecting the selection of the power plants. Then we represent them as weight matrices using the Variable Permanent Function. The VPF of the distinct matrices are evaluated and the highest one is selected. The most important factors and their co-factors which affect the selection process of the power plant are as follows:

1. **Location –** land price, storage space, distance from load, and reachability.

   LH,HT,LN are calculated from the location based three different power plants - matrix representation.

   | Hydroelectric power plant | Thermal power plant | Nuclear power plant |
   |-----------------|-----------------|-----------------|
   | LH = $\begin{pmatrix} 5 & 3 & 5 & 5 \\ 3 & 5 & 4 & 5 \\ 3 & 4 & 5 & 4 \\ 4 & 5 & 5 & 4 \end{pmatrix}$ = 8251 | LT = $\begin{pmatrix} 5 & 3 & 5 & 5 \\ 3 & 4 & 4 & 5 \\ 3 & 4 & 4 & 4 \\ 4 & 5 & 5 & 4 \end{pmatrix}$ = 7280 | LN = $\begin{pmatrix} 5 & 3 & 5 & 5 \\ 3 & 4 & 4 & 5 \\ 3 & 4 & 5 & 4 \\ 4 & 5 & 5 & 5 \end{pmatrix}$ = 8117 |

2. **Water –** Disposal of waste, Cooling, and Heat Exchange

   WH,WT,WN are calculated from the water based three different power plants - matrix representation.

   | Hydroelectric power plant | Thermal power plant | Nuclear power plant |
   |-----------------|-----------------|-----------------|
   | WH = $\begin{pmatrix} 1 & 0 & 0 \\ 5 & 4 & 4 \\ 0 & 4 & 5 \end{pmatrix}$ = 36 | WT = $\begin{pmatrix} 4 & 0 & 0 \\ 5 & 5 & 4 \\ 0 & 4 & 5 \end{pmatrix}$ = 144 | WN = $\begin{pmatrix} 5 & 0 & 0 \\ 5 & 5 & 4 \\ 0 & 4 & 5 \end{pmatrix}$ = 180 |
3. Cost – Machinery, Transportation and energy transmission cost

| CH, CT, CN are calculated from the cost based three different power plants - matrix representation. |
|---------------------------------------------------------------|
| Hydroelectric power plant | Thermal power plant | Nuclear power plant |
| CH = \[
\begin{pmatrix}
4 & 3 & 2 \\
3 & 3 & 3 \\
2 & 3 & 4
\end{pmatrix}
\] = 168 | CT = \[
\begin{pmatrix}
4 & 3 & 2 \\
3 & 6 & 3 \\
2 & 3 & 6
\end{pmatrix}
\] = 294 | CN = \[
\begin{pmatrix}
7 & 3 & 2 \\
3 & 6 & 3 \\
2 & 3 & 4
\end{pmatrix}
\] = 327 |

4. Fuel – Quality, Nature and Availability

| FH, FT, FN are calculated from the fuel based three different power plants - matrix representation. |
|---------------------------------------------------------------|
| Hydroelectric power plant | Thermal power plant | Nuclear power plant |
| FH = \[
\begin{pmatrix}
1 & 5 & 3 \\
5 & 1 & 3 \\
3 & 4 & 3
\end{pmatrix}
\] = 204 | FT = \[
\begin{pmatrix}
7 & 5 & 3 \\
5 & 5 & 3 \\
3 & 4 & 5
\end{pmatrix}
\] = 534 | FN = \[
\begin{pmatrix}
7 & 5 & 3 \\
5 & 5 & 3 \\
3 & 4 & 5
\end{pmatrix}
\] = 534 |

Now, the calculated values of are substituted in \(P_H, P_T, \) and \(P_N\) matrices, and their VPF values are calculated

\[
P_H = \begin{pmatrix}
168 & 5 & 5 \\
4 & 28251 & 4 \\
0 & 1 & 204
\end{pmatrix}

\]

\[
P_T = \begin{pmatrix}
294 & 4 & 5 \\
3 & 7280 & 5 \\
5 & 4 & 534
\end{pmatrix}

\]

\[
P_N = \begin{pmatrix}
327 & 4 & 4 \\
3 & 8117 & 4 \\
5 & 3 & 534
\end{pmatrix}

\]

Thus, it is observed that nuclear power plant is the best for day time conditions when compared to thermal and hydroelectric power plant.

Case (ii): The following digraph can be drawn based on night time load demand.

![Fig 9. Digraph for Night time load demand](image)

The matrix representation of the three Power plants in Night time are given below

| Hydroelectric power plant | Thermal power plant | Nuclear power plant |
|--------------------------|---------------------|---------------------|
| \(P_H = \) \[
\begin{pmatrix}
CH & 1 & 1 \\
0 & LH & 1 \\
0 & 1 & FH
\end{pmatrix}
\] | \(P_T = \) \[
\begin{pmatrix}
CT & 3 & 5 \\
4 & LT & 5 \\
5 & 4 & FT
\end{pmatrix}
\] | \(P_N = \) \[
\begin{pmatrix}
CN & 2 & 3 \\
2 & LN & 3 \\
3 & 2 & FN
\end{pmatrix}
\] |

In the process of applying graph theory in finding the best power plant from the three, first and the most important step is that we find the significant factors affecting the selection of the power plants. Then we represent them as weight matrices using the Variable Permanent Function. The VPF of the individual matrices are computed and their highest value is chosen. The most important factors and their co-factors which affect the selection process of the power plant are as follows:
1. Location – land price, storage space, distance from load, and reachability.

LH, HT, LN are calculated from the location based three different power plants - matrix representation.

\[
\begin{array}{c}
\text{Hydroelectric power plant} \\
\text{Thermal power plant} \\
\text{Nuclear power plant}
\end{array}
\]

\[
LH = \begin{pmatrix} 4 & 2 & 3 & 3 \\ 2 & 5 & 4 & 5 \\ 2 & 3 & 5 & 4 \\ 2 & 2 & 3 & 4 \end{pmatrix} = 2740
\]

\[
LT = \begin{pmatrix} 5 & 2 & 3 & 2 \\ 2 & 4 & 2 & 3 \\ 1 & 2 & 4 & 4 \\ 2 & 2 & 2 & 5 \end{pmatrix} = 1614
\]

\[
LN = \begin{pmatrix} 4 & 1 & 2 & 2 \\ 1 & 3 & 2 & 3 \\ 1 & 2 & 5 & 2 \\ 2 & 2 & 3 & 4 \end{pmatrix} = 923
\]

2. Water – Disposal of waste, Cooling, and Heat Exchange

WH, WT, WN are calculated from the water based three different power plants - matrix representation.

\[
\begin{array}{c}
\text{Hydroelectric power plant} \\
\text{Thermal power plant} \\
\text{Nuclear power plant}
\end{array}
\]

\[
WH = \begin{pmatrix} 0 & 1 & 1 \\ 2 & 3 & 3 \\ 0 & 3 & 3 \end{pmatrix} = 12
\]

\[
WT = \begin{pmatrix} 2 & 1 & 2 \\ 3 & 3 & 3 \\ 2 & 4 & 3 \end{pmatrix} = 93
\]

\[
WN = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 3 & 3 \\ 1 & 2 & 3 \end{pmatrix} = 11
\]

3. Cost – Machinery, Transportation and energy transmission cost

CH, CT, CN are calculated from the cost based three different power plants - matrix representation.

\[
\begin{array}{c}
\text{Hydroelectric power plant} \\
\text{Thermal power plant} \\
\text{Nuclear power plant}
\end{array}
\]

\[
CH = \begin{pmatrix} 2 & 0 & 2 \\ 2 & 0 & 1 \\ 2 & 1 & 2 \end{pmatrix} = 6
\]

\[
CT = \begin{pmatrix} 2 & 2 & 2 \\ 1 & 2 & 3 \\ 3 & 1 & 3 \end{pmatrix} = 56
\]

\[
CN = \begin{pmatrix} 2 & 1 & 2 \\ 1 & 1 & 2 \\ 2 & 1 & 2 \end{pmatrix} = 20
\]

4. Fuel – Quality, Nature and Availability

FH, FT, FN are calculated from the fuel based three different power plants - matrix representation.

\[
\begin{array}{c}
\text{Hydroelectric power plant} \\
\text{Thermal power plant} \\
\text{Nuclear power plant}
\end{array}
\]

\[
FH = \begin{pmatrix} 1 & 1 & 2 \\ 1 & 1 & 3 \\ 1 & 2 & 2 \end{pmatrix} = 19
\]

\[
FT = \begin{pmatrix} 3 & 2 & 2 \\ 2 & 2 & 3 \\ 2 & 1 & 1 \end{pmatrix} = 43
\]

\[
FN = \begin{pmatrix} 2 & 2 & 2 \\ 1 & 1 & 2 \\ 2 & 1 & 1 \end{pmatrix} = 22
\]

Now, the calculated values of are substituted in \(P_H, P_T\), and \(P_N\) matrices, and their VPF values are calculated

\[
P_H = \begin{pmatrix} 6 & 5 & 5 \\ 4 & 2740 & 4 \\ 0 & 1 & 19 \end{pmatrix} = 312784
\]

\[
P_T = \begin{pmatrix} 56 & 4 & 5 \\ 3 & 1614 & 5 \\ 5 & 4 & 43 \end{pmatrix} = 3928658
\]

\[
P_N = \begin{pmatrix} 20 & 4 & 4 \\ 3 & 923 & 4 \\ 5 & 3 & 22 \end{pmatrix} = 425200
\]

Thus, it is observed that thermal power plant is the worthiest for night time conditions when compared to nuclear and hydroelectric power plant.

6. CONCLUSION

In this paper, we discussed a graph-theoretical approach to the selection of a power plant among three major power plants. The factors that were considered in this paper are cost, fuel, availability of water, and location. The sub-factors for each of these factors were discussed and represented in the form of a
digraph. The digraph was used to make a weighted matrix by using qualitative metrics. The variable permanent function values are calculated for each of the four factors of each for the three power plants taken into consideration. From the above values we can conclude that in the day time nuclear power plant is the best whereas during night time thermal power plant is the best.

REFERENCES

[1] Robinson DF and Foulds LR. 1980 *Digraphs: Theory and Techniques*, Gordon and Breach Science Publishers, London.

[2] Deo N. 2000 *Graph Theory with Application to Engineering and Computer Science*, Prentice-Hall, New Delhi, India.

[3] Gandhi OP and Agrawal VP. 1992 FMEA – A Digraph and Matrix Approach, *Reliability Engineering and System Safety*, 35(2) 147-158.

[4] Sandeep G, Agrawal VP and Khan IA. 2004 A Digraph Approach to TQM Evaluation of an Industry, *International journal of Production Research*, 42(19) 4031-4053.

[5] Venkataswamy R and Agrawal VP. 1995 System and Structural Analysis of an Automobile Vehicle – A Graph Theoretic Approach, *International Journal of Vehicle Design*, 16(4/5) 477- 503.

[6] K. E. Holbert and C. J. Haverkamp, "Impact of solar thermal power plants on water resources and electricity costs in the Southwest," 41st North American Power Symposium, Starkville, MS, 2009, pp. 1-6, DOI: 10.1109/NAPS.2009.5483989.

[7] F. Ren, "Optimal Site Selection for Thermal Power Plant Based on Rough Sets and Multi-Objective Programming," 2010 International Conference on E-Product E-Service and E-Entertainment, Henan, 2010, pp. 1-5.

[8] Prabhakaran RTD, Babu BJ and Agrawal VP. 2007 Structural Modeling and Analysis of Composite Product System: A Graph Theoretic Approach, *Journal of Composite Materials* 40 (22), 1987-2007.

[9] L. Guoqiang, W. Hua, M. Wenhui and Y. Chunwei, "Energy and Exergy Analysis for 300MW Thermal System of Xiaolongtan Power Plant," 2011 *International Conference on Computer Distributed Control and Intelligent Environmental Monitoring*, Changsha, 2011, pp. 180-184.

[10] Kiran CP, Clement S and Agrawal VP. 2011 Design for X-abilities of a Mechatronic System – A Concurrent Engineering and Graph Theory Based Approach, *Concurrent Engineering*. 19(1) 55–70.

[11] R. Idris and Z. Abd Latif, "GIS multi-criteria for power plant site selection," 2012 *IEEE Control and System Graduate Research Colloquium*, Shah Alam, Selangor, 2012, pp. 203-206.

[12] N. Kumar, D. K. Mohanta, E. Kispotta, D. Hansda and M. J. B. Reddy, "Efficiency enhancement of thermal power plants using refrigerant-R600a in condenser section," 2017 *International Conference on Innovations in Green Energy and Healthcare Technologies (IGEHT)*, Coimbatore, 2017, pp. 1-6.

[13] Kumar, Ravinder & Sharma, Avdhesh & Tewari, Puran. (2015). Cost analysis of a coal-fired power plant using the NPV method. *Journal of Industrial Engineering International*. DOI 10.1007/s40092-015-0116-8.

[14] M. A. Khattak, M. A. Ashraff, M. Ikmal, A. Syafiq and M. Hazritz, “Common Types of Fuels in Steam Power Plant: A Review”, *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, Vol. 23, No. 1. Pages 1-24, 2016.

[15] M. A. Mendes, P. R. Muniz, J. C. Marques, C. B. Donadel and J. F. Fardin, "Analysis of financial impacts caused by pollution from thermal power plants in Brazilian public health system," 2016 12th *IEEE International Conference on Industry Applications (INDUSCON)*, Curitiba, 2016, pp. 1-6, DOI: 10.1109/INDUSCON.2016.7874499.

[16] Rina Annisa, Linda Faridah, Dwi Muchtar Yuliawan, Ngapuli I.Sinisuka, Indra Surya Dinata, "Environmental Impact Assessment of Steam Cycle and Combine Cycle Power Plants Using Life Cycle Assessment Methodology," *IEEE Conference on...*
[17] Hong, Chul-Seung, and Eul-Bum Lee. "Power Plant Economic Analysis: Maximizing Lifecycle Profitability by Simulating Preliminary Design Solutions of Steam-Cycle Conditions", *Energies* 11.9 (2018): 2245.