World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:4, No:3, 2010

Operational- Economics Based Evaluation And Selection of A Power Plant Using Graph Theoretic Approach

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Abstract—This paper presents a methodology for operational and economic characteristics based evaluation and selection of a power plant using Graph theoretic approach. A universal evaluation index on the basis of Operational and economics characteristics of a plant is proposed which evaluates and ranks the various types of power plants. The index thus obtained from the pool of operational characteristics of the power plant attributes Digraph. The Digraph is developed considering Operational and economics attributes of the power plants and their relative importance for their smooth operation, installation and commissioning and prioritizing their selection. The sensitivity analysis of the attributes towards the objective has also been carried out in order to study the impact of attributes over the desired outcome i.e. the universal operational-economics index of the power plant.

Keywords—Power plant evaluation, Digraph methods, Matrix method, operational characteristics of Power plant, Gas turbines

I. INTRODUCTION

FOR the operational and economic reliability of the power plant, a continuous assessment related to various aspects like capital costs, heat recovery rate of the power plant, fixed and variable costs, plant operating efficiencies and technology updates for improvement is to be done by the power plant managers in order to remain competitive in the global market. A remarkable progress has been assessed and observed in the power sector world wide where in feasibility & installation of new power plants has been assessed on the basis of technical, operational and economics factors into consideration in order to have sustainable solution for future demand- supply problem of power. The study related to Operational and economics characteristics of the power plants can be related especially to the capital investments, operational feasibility and net the net value of the plant contributing to the goals of installation of the power plant.

Many research studies have been carried out on the system modeling of power plants, for example, developing the mathematical model using the graph theory and matrix method to evaluate the performance of the coal based power plant [1] and qualitative evaluation of thermal power plants using graph theory [2]. Cost attributes related to maintenance and downtime losses have also been critically analyzed for reliable availability of the steam based power plant [3] and maintenance strategy has been proposed for the same.

The use of gas turbines for power generation has increased rapidly in past few years. Several power generation cycles including advanced cycles have been analyzed from thermodynamics and economic point of view [4] in order to establish their relative importance to future power generation sector. Due to various attractive features of the gas turbine engines like low capital cost, compact size, short delivery, high flexibility and reliability, better environmental performance etc., cogeneration systems have been studied [5] to utilize its merits and to boost its thermal efficiency. Various power generating options including coal fired Rankine cycle steam plants with advanced steam parameters, natural gas fired gas turbine-steam and coal gasification combined cycle plants [6] have been studied in terms of their efficiency, cost and operational availability which can help the system modeling of such power plants in detail through understanding the interdependencies of the attributes.

Thermoeconomic operating parameters have also been studied through exergy analysis of the cogeneration plants by [7]- [9] in order to get higher thermal efficiency and better operating conditions of such power plants. Development and implementation of software [10] for Thermoeconomic analysis and optimization of the plant have been carried out for efficient thermodynamic process modeling, economic analysis and their optimization. Similar kind of research work related to system modeling has been carried out for combined cycle power plants by [11] and their economic analysis by [12]. The research work has been further strengthened through optimization of combined gas turbine cycles by [13]. Various parameters or the attributes related to economic evaluation of the cycling plants contributing towards their operational flexibility have been discussed in detail by [14].

Even though, with due experience, several decisions related to above mentioned Operational and economics characteristics of the plant can be taken, yet there is always a need for the preliminary assessment and the economic-operational index evaluation of the power plant contributing to decision making related to various aspects of is installation, operations and its assessment relative to other alternatives available in the global market. Since, the economics of the power generation depends on the fuel costs, running efficiencies, maintenance costs and the first costs and environmental concerns, a comparison has been made in the literature [15] of various generation technologies from the initial costs to the operating costs of

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Open Science Index, Electrical and Computer Engineering Vol:4, No:3, 2010 publications.waset.org/2504.pdf

the such systems as well as the competitive standings of the various power plant available in market on the basis of their capital costs, heat rates, operation and maintenance costs, availability and reliability and their time of planning. In certain applications, the priority of the objectives may be different; a compromise may be made in the alternatives available during the assessment of the power plants.

II. OPERATIONAL-ECONOMIC ATTRIBUTES OF THE POWER PLANT

The basis of the Operational - economic evaluation of the power plant depends on the interests of the power plant designers and many other aspects related to their Economic and reliability based operation. For example, if a need arise to suggest an economic power plant with 30% efficiency, one may suggest either Bio-mass based or the simple cycle gas turbine, gas engine, diesel engine, micro-turbines, however, when aspects and constraints are taken into consideration, the domain of alternative choices shrinks, yet alternative selection becomes more or less a designers choice. The solution to these difficulties has eluded researchers and practicing engineers for decades. Since there is no universally adapted methodology for the economic-operational evaluation of the power plant, various technologies in power plants, the installation and operational constraints, a need has been felt for the demonstration of reliable, dynamic and robust methodology like Graph theoretic approach which is capable of solving such power sector problems.

The operational and economic evaluation of a Power plant are characterized by a number of independent and dependent constraint variables which are associated with each other by a number of complex relationships or equations. The independent constraint variable are the system input variables and includes: Capital costs, Variable operation and Maintenance costs, Fixed operation and Maintenance costs, Availability and the estimated time for plant to be functional from startup activity. Dependent constraint variables are the system output variables and include the heat rates, net efficiencies of the selected power plants, reliability of the power plant. The above attributes are used for the selection of the power plants from a number of alternatives like simple cycle gas turbine natural gas fired, simple cycle gas turbine with oil fired, simple cycle gas turbine with crude fired, regenerative gas turbine with natural gas fired, combined cycle gas turbine, advanced gas turbine with combined cycle power plant, combined cycle with coal gasification, combined cycle with fluidized bed combustion, nuclear power plant, coal fired steam power plant, Diesel fired Diesel generators, oil fired Diesel generator power plants and gas engine generator power plants.

The dependent constraint variables refer to the performance of the plant in terms of the economic and operational consequences are directly related to plant functionality and hence to Operational - economic characteristics of the power plant. The Operational - economic attribute is characterized as a constraint variable which may be dependent or independent. In the present work, the constraint output variables were taken into consideration for the purpose of Operational - economic index evaluation of the power plant, since the constraint output variables are the functions of the system input variables.

III. METHODOLOGY

A methodology for the proposed operational- economics based evaluation of the power plants is suggested on the basis of digraph and matrix methods. The Graph theoretic approach (Digraph) evaluates the operational- economics performance of the power plant in terms of single numerical index. This takes into consideration the effects of various factors, subfactors and their inter-dependencies. Various steps of the proposed approach are presented below, which will be helpful in evaluating the power plants with stated objectives in this paper.

(a). The entire power plant is assumed as a system and all the operational features including economic factors are critically reviewed.

(b). Identify the various attributes affecting the operational economics of the power plant. However, for varieties of applications, the critical attributes may be varying and different. Enlist all such attributes which are responsible for affecting the desired outcomes of the problem. In order to analyze complex systems, the system as a whole may be divided into subsystems and further sub-subsystems up to the component level in order to analyze the dependency and affect of one variable at the sub-system levels up to the component level and its cumulative effect at the system level.

(c). Obtain the values of the attributes and analyze their level of inter-dependencies on a normalized scale of 0-10. The inherent attribute value (i.e. D_i's) are generally calculated from the standard tests or retrieving the experimental data. Whenever, the quantitative data is not available, and then a criterion of ranked values by judgments over a scale of 0-10 is generally adopted. Preference information of subjective and objective attributes within the judgments may be incorporated for converting data intervals into crisp type for this purpose. The equivalent value over a scale of 0-10 for the qualitative measure of an attribute is given in Table I.

TABLE I
VALUE OF ATTRIBUTES(D_i's)

Qualitative measures of attributes	Assigned values of attributes (D_i)
Exceptionally Low	0
Extremely Low	1
Very Low	2
Low	3
Below Normal	4
Normal	5
Above Normal	6
High	7
Very High	8
Extremely High	9
Exceptionally High	10

Further, the response of the attribute contributing to system performance evaluation index is initially categorized as benefit type attributes or the cost type attributes so that all the attributes can be ranked and evaluated on a standard scale 0-10 in similar fashion, such as, if the higher attribute value contributes to increased value of performance evaluation index of the system, then the attribute is called as of benefit type and its higher values are ranked near to '10' on a scale of 0-10 whereas the attributes whose higher values leads to lowering of the system performance index values are called cost type attributes and its higher values are generally ranked in the proximity of '0' on a scale of 0-10.

since most of the attributes are dissimilar in sense, operating units and measured value ranges, the attribute values can not be directly used in the per(A) function. The values of all such attributes are to be normalized using suitable normalizing functions on a scale 0-10 also for their variation limits keeping benefit type criteria and cost type criteria into consideration. It helps in evaluating the generic effect of inter-dependency of attributes contributing towards the overall index measures and sensitivity index evaluation for such attributes which will be helpful for critical analysis of the system as a whole.

The relative importance between the two attributes is also assigned a value on a scale of 0-10 and is arranged into classes as mentioned in Table II. Due to complexity of the system as a whole, it becomes infeasible to calculate the relative inter- dependency of one attribute over the other. However, for simplicity, a relationship has been suggested in the literature for such cases which assigns the relative importance of '*i*'th attribute over '*j*'th attribute and vice-versa as given in equation (1).

$$\begin{aligned} a_{ij} &= 1 - a_{ji} \\ a_{ji} &= 1 - a_{ij} \end{aligned} \qquad (1)$$

TABLE II
RELATIVE IMPORTANCE OF ATTRIBUTES(a_{ij}'s)

Class description	Relative importance of attributes	
	a_{ij}	a_{ji} =10- a_{ij}
Two attributes are of equal importance	5	5
One attribute is slightly more important than the other	6	4
One attribute is more important than the other	7	3
One attribute is much more important than the other	8	2
One attribute is extremely more important than the other	9	1
One attribute is exceptionally more important than the other	10	0

Since various attributes affects the permanent function over class intervals or operating ranges, normalization of values over the operating ranges of the attributes are to be done using standard algorithms.

(d). identify the nature of the attributes as Benefit type or the cost type. Also identify the sense of the desired outcome index as benefit type or the cost type. Normalization of all the values of the attributes must be in conformance to the nature of the outcome Index. Modifications, if required, can be made accordingly. For example, if an attribute is of benefit type i.e. increase or decrease in the attribute value contributes in the same sense as that of the objective or index of the problem then the assigned values (D_is) within the limits of 0-10 are normalized using the equation (2) as below.

$$\begin{aligned} D_i &= \left(\tfrac{10}{D_{iu}}\right) * D_{ii} \quad for \quad D_{ii} = 0 \\ D_i &= \tfrac{10}{(D_{iu} - D_{il})} * (D_{ii} - D_{il}) \quad for \quad D_{ii} > 0 \end{aligned} \qquad (2)$$

Where
D_{il}: lowest range value of the attribute
D_{iu}: highest range value of the attribute
D_{ii}: value of the attribute (diagonal value in the matrix representation D_{MXM} and M is the order of the Matrix
However, if the attribute is of cost type i.e. increase or decrease in the attribute value contributes to the decrease or increase in the value of the objective or the index variable respectively, then the normalization of the attribute value is generally done between range of 0-10 by using the equation (3).

$$\begin{aligned} D_i &= 10 * \left(1 - \tfrac{D_{ii}}{D_{iu}}\right) \quad for \quad D_{ii} = 0; \\ D_i &= \tfrac{10}{(D_{iu} - D_{il})} * (D_{iu} - D_{ii}) \quad for \quad D_{ii} > 0 \end{aligned} \qquad (3)$$

where notations have their usual meanings

(e).Logically, develop a digraph between the factors or attributes depending on their inter-dependencies. A logical digraph of seven attributes having interdependencies with in the systems and each contributing to the overall system evaluation index or the objectives is shown in Figure 1. Here $V_1, V_2, V_3, V_4, V_5, V_6, V_7$ are the attributes of the system represented with interconnections thus reflecting the interdependencies with in the system.

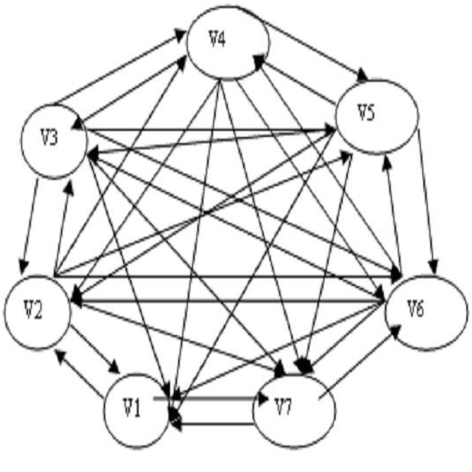

Fig. 1. Digraph showing seven attributes and their interdependencies in the system

(f). Develop a universal operational- economics attributes based Variable Permanent Function Matrix (VPFM) which will be of order MxM, where M is the total number of attributes affecting the system desired outcome. The matrix representation of the digraph (Figure 1) is shown by equation

(4).

$$
[A] = \begin{array}{cc}
factors & \begin{array}{ccccccc} V_1 & V_2 & V_3 & V_4 & V_5 & V_6 & V_7 \end{array} \\
\begin{array}{c} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \end{array} &
\begin{pmatrix}
D_1 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} \\
a_{21} & D_2 & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} \\
a_{31} & a_{32} & D_3 & a_{34} & a_{35} & a_{36} & a_{37} \\
a_{41} & a_{42} & a_{43} & D_4 & a_{45} & a_{46} & a_{47} \\
a_{51} & a_{52} & a_{53} & a_{54} & D_5 & a_{56} & a_{57} \\
a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & D_6 & a_{67} \\
a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & D_7
\end{pmatrix}
\end{array} \tag{4}
$$

(g). Obtain the permanent function for the attribute matrix as in step (f). Both digraph and matrix representation are not unique as they change by changing the labeling of nodes represented for the attributes considered. In order to have a unique representation independent of the labeling behaviour of the nodes, the permanent of the matrix (i.e. per(A)) is calculated which is a standard matrix function and is generally used in combinatorial mathematics. The permanent of the matrix is calculated in similar manner as determinant. However, during the calculation of permanent, all negative signs introduced as in case of determinant are to be replaced by positive signs. This computation results in multinomial whose every term has a significance related to the overall evaluation of the system and no term significance is lost due to negative signs. This multinomial representation of the permanent includes all the information regarding all critical factors or attributes and their interdependencies with in the system as a whole. The permanent function of the matrix form as represented above is given in equation (5).

$$Per(A) = \prod_{i=1}^{7} V_i$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).V_k.V_l.V_m.V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{ki}).V_l.V_m.V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{kl}.a_{li}).V_m.V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).(a_{kl}.a_{lk}).V_m.V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{ki}).(a_{lm}.a_{ml}).V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mi}).V_n.V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).(a_{kl}.a_{lk}).(a_{mn}.a_{nm}).V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).(a_{kl}.a_{lm}.a_{mn}.a_{nk}).V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{ki}).(a_{lm}.a_{mn}.a_{nl}).V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mn}.a_{ni}).V_p$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).(a_{kl}.a_{lk}).(a_{mn}.a_{np}.a_{pm})$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{ji}).(a_{kl}.a_{lm}.a_{mn}.a_{np}.a_{pk})$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{ki}).(a_{lm}.a_{mn}.a_{np}.a_{pm})$$

$$+\sum_{i=1}^{i=7}\sum_{j=1}^{j=7}\sum_{k=1}^{k=7}\sum_{l=1}^{l=7}\sum_{m=1}^{m=7}\sum_{n=1}^{n=7}\sum_{p=1}^{p=7}(a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mn}.a_{np}.a_{pi}))$$

The permanent of the matrix (i.e. equation (5)) represented is a mathematical expression in symbolic form. It ensures an estimate of the system as a whole. The equation (5) contains 7! terms. Each term is useful for system assessors as each term serves as a test of the effectiveness of the relevant group in permanent of the matrix A, i.e. per(A). Equation (5) contains terms arranged in N+ 1 groups, where N is the number of elements.

In the permanent, per(A) various groupings have their own physical significance. The first term (grouping) represents a set of seven independent subsystem characteristics as $V_1, V_2, V_3, .V_7$. As there are no self loops with in the system itself, second groupings are absent. Each term of the third grouping represents a set of two elements attribute loops (i.e. $a_{ij}.a_{ji}$) and is the resultant dependence of attribute 'i' and 'j' and the evaluation measure of N-2 connected terms. Each term of the fourth grouping represents a set of three element attribute loops ($a_{ij}.a_{jk}.a_{ki}$ or its pair $a_{ik}.a_{kj}.a_{ji}$) and the evaluation measure of N-3 unconnected elements or attributes with in the system. The fifth grouping contains two subgroups. The terms of first subgrouping consists of four element attribute loops (i.e. $a_{ij}.a_{jk}.a_{kl}.a_{li}$) and the 3- subsystem evaluation index component ($V_m.V_n.V_p$). The terms of the second grouping are the product of two element attributes loops $(a_{ij}.a_{ji}).(a_{kl}.a_{lk})$) and the index evaluation component (i.e.

$V_m.V_n.V_p$). The terms of the sixth grouping are also arranged in two subgroupings. The terms of the first subgroupings are of five element attribute loop (i.e. $(a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mi})$ or its pair $(a_{im}.a_{ml}.a_{lk}.a_{kj}.a_{ji})$. the second subgrouping consists of a product of two attributes loops (i.e. $a_{ij}.a_{ji}$) and a three attribute loop (i.e. $a_{kl}.a_{lm}.a_{mk}$) or its pair (i.e. $a_{km}.a_{ml}.a_{lk}$) and the index evaluation component (i.e. $V_n.V_p$). The terms of seventh groupings are also arranged in four subgroupings. The first subgrouping of the seventh grouping is a set of 3- two element attribute loops (i.e.$a_{ij}.a_{ji}$, $a_{kl}.a_{lk}$, $a_{mn}.a_{nm}$) and a one - subsystem evaluation index component (V_p). The terms of second subgrouping of seventh grouping are of two element attribute loop (i.e. $a_{ij}.a_{ji}$) and four element attribute loop (i.e.$a_{kl}.a_{lm}.a_{mn}.a_{nk}$) with one - subsystem evaluation index component (V_p). The terms of the third subgrouping of the seventh grouping are of 2- three element attribute loops (i.e.$a_{ij}.a_{ji}.a_{ki}$ and $a_{lm}.a_{mn}.a_{nl}$) with one - subsystem evaluation index component (V_p).The terms of fourth subgrouping of seventh grouping are of six elemental attribute loop (i.e. $a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mn}.a_{ni}$). The terms of eighth grouping are also arranged in four subgroupings. The first subgrouping of the eighth grouping is a set of three element attribute loop (i.e. $a_{mm}.a_{np}.a_{pm}$) and two element structural diads as $(a_{ij}.a_{ji})$ and $(a_{kl}.a_{lk})$. The second subgrouping is a set of a two element diad $(a_{ij}.a_{ji})$ and a five element attribute loop (i.e.$a_{kl}.a_{lm}.a_{mn}.a_{np}.a_{pk}$). The third subgrouping consists of a three element attribute loop (i.e. $a_{ij}.a_{jk}.a_{ki}$) and a four element attribute loop (i.e. $a_{lm}.a_{mn}.a_{np}.a_{pl}$) respectively. Similarly, the fourth subgrouping of the eighth grouping is a seven elemental attribute loop (i.e.$a_{ij}.a_{jk}.a_{kl}.a_{lm}.a_{mn}.a_{np}.a_{pi}$). Thus the permanent function characterizes a system for selected number of attributes as it contains all possible components of attributes and their relative importance.

(h). perform the sensitivity analysis for the attributes over the domains of influence for a few cases.

(i). Arrange the type of systems in descending order of the evaluation index. The system having the highest value of the calculated index is the best choice for the given set of attributes over their prescribed operating ranges.

IV. SOLUTION

A. Universal Operational-Economic Attributes Digraph

A universal Operational - economic attributes digraph models the economic and operational attributes and their relative importance. The digraph consists of a set of nodes $V = v_i$, with i= 1,2,3,M and a set of directed edges D=d_{ij}. A node 'V_i' represents the $'i'$th economic-operational attribute and the edges represents the relative importance between the attributes. The number of nodes in the digraph represents the total number of Operational - economic attributes considered for the given study of evaluation and selection of alternative power plants. In the present digraph method , if a node 'i' has a relative importance over node 'j' during the Operational - economic evaluation and prioritizing power plants, then a directed edge or arrow is drawn from node 'i' to node 'j' (i.e. a_{ij}). If a node 'j' have relative importance over node 'i' then a directed edge is drawn from node 'j' to node 'i' (i.e. a_{ji}).

In order to demonstrate the Operational - economic attributes digraph, an example of the selection of power plant on the basis of attributes taken into account is considered. Since, the objective is to prioritize the selection of the power plant from the number of options available on the basis of their optimum performance and other constraint variables (dependent or independent), it is assumed that all the attributes affect the selection of the power plant in one way or the other. Hence, for this desired objective, all the generalized system constraint variables becomes system input variables and hence are to be used for modeling the digraph. However, every system input attribute contributes to the overall selection of the best alternative of the power plant. For example, a plant designer may give more weightage to net efficiency of the plant over the heat rate and other attributes like capital costs and other costs may be a secondary priority for him. However, in some cases, reliability of the power plant and its net efficiency may be more significant attributes relative to other. Fixed operation and maintenance costs, invariably a constant term but a constraint attribute as is affected by the type of power plant selection and its subsystems or components. It has been seen that with the technological investments with a particular type of power plant selected, with increase in the capital cost, the variable operation and maintenance cost also becomes higher as addition and modification of new technology based materials may cost higher but results in overall better performance of the whole power plant as a system. The overall operation and maintenance cost of the power plant is considered as a constraint attribute for modeling the digraph and is generally taken as algebraic sum of variable and fixed operation and maintenance costs of the system. A balance is generally made over the fixed operation and maintenance cost verses variable operation and maintenance costs keeping completion time of the power plant project into consideration.

It has been observed that some attributes affect the power plant performance over class intervals and may exhibit an overlapping zone during optimum performance of the system which makes the system complex for decision making and their selection or prioritizing becomes a tedious task. A sensitivity analysis of such complex systems is generally made over the class intervals of the attributes responsible for system performance and prioritizing them. The Operational - economic attribute digraph gives a graphical representation of the attributes and their relative importance for quick interactive and visual appraisal. With increase in the number of constraint attributes, the number of nodes in the digraph increases which makes the modeled power plant system more complex. In order to overcome this constraint, the modeled system as digraph is represented in matrix form also.

B. Matrix Representation of the Universal Operational-Economic Attributes Digraph

The matrix representation of the universal Operational - economic attribute digraph represents one to one mapping of the attributes. The size of the matrix is of the order of MxM, where M is the total number of attributes (D_i, i=M) as taken into account for modeling universal Operational - economic digraph of the power plants. The matrix representation of the digraph as given in Figure 1 is represented by equation (6)).

$$[V] = \begin{array}{c} factors \\ CC \\ HR \\ EFF \\ OMC \\ AVB \\ RLB \\ TPC \end{array} \begin{array}{c} \begin{array}{ccccccc} CC & HR & EFF & OMC & AVB & RLB & TPC \end{array} \\ \begin{pmatrix} D_1 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} \\ a_{21} & D_2 & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} \\ a_{31} & a_{32} & D_3 & a_{34} & a_{35} & a_{36} & a_{37} \\ a_{41} & a_{42} & a_{43} & D_4 & a_{45} & a_{46} & a_{47} \\ a_{51} & a_{52} & a_{53} & a_{54} & D_5 & a_{56} & a_{57} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & D_6 & a_{67} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & D_7 \end{pmatrix} \end{array} \tag{6}$$

the notations used have their usual means as :
CC: Capital cost in Currency /unit power output
HR : Heat rate in Kj/kWh
EFF: net efficiency in percentage
OMC : Operation and Maintenance cost consisting of variable and fixed cost components in Currency/MWh
AVB : Availability in percentage
RLB: Reliability in percentage
TPC: Estimated time required from planning stage of project inception till its completion in months and
D_i is the value of the $'i'$th attribute represented by node 'i' in the digraph as shown in Figure 2 and a_{ij} is the relative importance of the $'i'$th attribute over the $'j'$th attribute as represented by edge d_{ij}. Since, the objective is to calculate the operational- Economic Index of the power plant which may help in the selection of the power plants, the interdependencies have been shown by the joining edges between the all the attributes, irrespective of its magnitude. Lower level of interdependencies may be represented in terms of smaller magnitudes in the digraph matrices and larger magnitude terms for strong interdependency level with in the same matrices for its solution.

C. Universal Operational-Economic Index

The universal Operational - economic index is the performance index of the power plant which reflects the performance of the power plant for a set economic and operational attribute levels. It is used for the evaluation of a particular type of power plant and for its comparison to other one within the same attribute limits as it contains the presence of all the attributes and their relative importance in the form of interdependencies. The numerical value of the Operational - economic function is called the universal Operational - economic index of the power plants. To calculate the Universal Operational - economic index of the power plant, the quantification of the D_i's and a_{ij}'s are to be done. Since, the proposed index in the per(A) contains all positive values of D_i's and a_{ij}'s, higher the values, higher will be the value of per(A) and thus the Index proposed to be used for Operational - economic performance based rating of the power plants.The universal Operational - economic index for each type of power plant may be evaluated using equation (2) by substituting the values of D_i's and a_{ij}'s. The various power plants may be arranged in ascending or descending order of the performance index values so calculated to rank them for a particular set of attributes. The type of power plant for which the value of the universal Economic-operational evaluation index is highest is the best choice for the operating attributes considered. However, as various attributes show their dominance over the class intervals, it becomes desirable for the power plant designers and assessors to do sensitivity analysis over the operational ranges of the attributes.

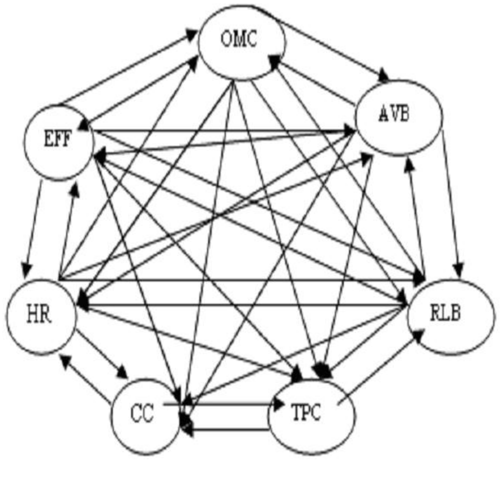

Fig. 2. Digraph showing Operational-Economic attributes of a Power plant

V. IDENTIFICATION AND COMPARISON OF POWER PLANTS

The universal operational- economics function is useful for identification and comparison of power plants for a given set of attributes over their prescribed operating ranges. The number of terms in each grouping of the universal operational-economics function for all power plants for a given set of attributes will be same for a typical application. However, their values will be different. Two power plants may be similar from the operational-economics point of view, if their operational-economic attribute digraphs are isomorphic. Two such digraphs are isomorphic, if they have identical permanent function matrix set representation. This means not only the number of terms in the groupings as well as subgrouping as same but also their values are also same. Based on this, composite operational-economics identification set of the power plants are written as given in equation (7).

$$\begin{aligned} &[(J_1'^T/J_2'^T/J_3'^T/J_4'^T/J_{51}'^T/J_{52}'^T/J_{61}'^T/J_{62}'^T/J_{71}'^T/J_{72}'^T/J_{73}'^T \\ &/J_{74}'^T/J_{81}'^T/J_{82}'^T/J_{83}'^T/J_{84}'^T)(V_1'^T/V_2'^T/V_3'^T/V_4'^T/V_{51}'^T/V_{52}'^T \\ &/V_{61}'^T/V_{62}'^T/V_{71}'^T/V_{72}'^T/V_{73}'^T/V_{74}'^T/V_{81}'^T/V_{82}'^T/V_{83}'^T/V_{84}'^T)] \end{aligned} \tag{7}$$

where J_i^T represents the total number of terms in the D_is and a_{ij}s grouping, J_{ij}^T represents the total number of terms of the $'jth$ subgrouping in the $'i'th$ grouping. Similarly, V_i^T represents the numerical value the $'i'th$ grouping and V_{ij}^T represents the numerical value of the $'j'th$ subgrouping in the $'i'th$ grouping. The identification set visualizes the effect of the sub-groupings present in the permanent index and by comparison of their total values in the identification set evaluates the dominance of the subgrouping of two different power plants with same kind of digraph. This assessment can be helpful in improving the weak domains of influence of attributes in the digraph used and thus leading to better judgments and system improvement for its critical analysis.

VI. EXAMPLE

In order to demonstrate the proposed Graph theoretic approach for the universal operational- economic index of the power plants, the following example is considered. The database related to Operational and Economic factors or the attributes of various power plants has been taken into consideration and is well illustrated in [15]. A concise representation of the same to facilitate the implementation of the proposed methodology has been given in Table III in which various attributes have been specified over the class intervals or operating ranges for the type of the power plants. The cost type and benefit type attributes or the factors of the power plant systems are identified and proposed technique has been implemented.

The various steps of methodology proposed for the Operational- Economic evaluation of power plants are summarized as:

(i). First, all the attributes are identified. In the present case, all the attributes as specified in the Table III are used for the operational- economic index evaluation through a permanent function, per (A). The various attributes have been listed as Capital cost (CC), Hear rate (HR), net efficiency (EFF), Operation and Maintenance cost consisting of variable and fixed cost components (OMC), Availability(AVB), Reliability (RLB) and the estimated time required from planning stage of project inception till its completion (TPC). As observed, the two attributes net efficiency (EFF) and Operational & Maintenance costs are specified as numerical values and can be represented over a normalized scale of 0-10 directly for all the power plant options available. Further, the all other attributes are given over a range domain, which can not be used directly in the permanent calculation as well as the sensitivity analysis. Here, the mean operating value of the attribute is taken as reference for calculation of permanent index calculation which can be normalized directly over a scale of 0-10. During the calculations of permanent index, attributes values are varied over the operating range for the sensitivity analysis of the digraph.

It is found that the net efficiency (EFF), Heat rate (HR), Availability (AVB) and the reliability (RLB) attributes are benefit type, while the Capital cost (CC), operation and Maintenance costs (OMC) and the time (TPC) attributes are cost type, hence, during the normalization of the values of the attributes, care is to be taken that higher values of EFF, HR, AVB and RLB are in the proximity of 10 on a scale of 0-10 while for CC, OMC and TMC, their higher values are normalized in the proximity of '0' on a scale of 0-10. The calculated mean value of the attributes is given in Table IV. Using equation (2)-(3) and Table II, the values of these attributes are normalized and are given in Table V. Table V shows the values of D_is for the different power plants- attributes combinations. Due to assignment procedure as mentioned in Table I, the normalized attribute values can also be represented as whole numbers and not in fractions in cases where realistic data is not available. However, for the deterministic forms of attributes, the values of D_is can be in fractions. It is clear from the calculated data pertaining to inheritance level of the factors or the attributes for various power plants that during normalization of the data, the mean operating ranges of the attributes are assigned values 0.005. This kind of assignments have been proposed for the minimum limiting value of the attributes covered under benefit type criteria and maximum limiting value of the attributes covered under cost type criteria. During the process of normalization, such values will be automatically assigned 0 values. As a result, most of the information pertaining to data analysis of inheritance and interdependencies of other attributes coupled with synergic effects of such attributes being assigned 0 values for their inheritance levels in the system. In order to quantify such coupling effects of the other attributes with the benefit type attributes with their mean operating ranges as minimum and cost type attributes with their mean operating ranges as maximum over a range of alternative power plants, these attributes are assigned values 0.005 instead of zero. For example, in case of heat rate (HR) attributes being a benefit type attribute for all the alternative power plant, the advanced gas turbine combined cycle power plant has minimum specified operating range and should be assigned 0 value. Similarly, the minimum operation and maintenance costs (OMC) of the power plants can be considered as desirable. Hence, the operation and maintenance costs (OMC) of the power plants are covered under cost type attributes. It is observed that this attribute has maximum value for the simple cycle gas turbine crude fired type power plants, hence are to be assigned 0 values during the normalized representation. Due to the inherent diminishing characteristics of 0 values in the matrix calculations, its usage may be avoided in system modeling. As the uncoupled effect of some of the attributes may be a very large in magnitude which may be completely lost during matrix transformation for the coupling characteristics of all such attributes with a specific different attribute, decision making may be severely affected. Even, the effect of experts opinion may also be diminished during interpretation and calculations. As there is always a need for improvements in system modeling, through expert opinions including reduction in information loss, the minimum ranges are assigned as 0.05.

Through the use of experts opinions, the relative importance of these attributes (i.e. a_{ij}) is also assigned in the range of 0-10 using Table II and equation (1),which are given in Table VI.

(ii). A universal operational- economic attribute digraph is developed for this example. The present digraph consists of seven nodes representing all the attributes considered above. The developed digraph as shown in Figure 1 can serve the purpose of this example (iii). The universal operational-economic attribute matrix of order 7x7 for this digraph is

TABLE III
OPERATING RANGES OF OPERATIONAL-ECONOMIC ATTRIBUTES FOR VARIOUS POWER PLANTS [15]

TYPE OF POWER PLANT	OPERATIONAL-ECONOMIC ATTRIBUTES						
	CAPITAL COSTS (CC) IN $/KW	HEAT RATE (HR) IN KJ/KWH	NET EFFICIENCY (EFF) IN%	OPERATION & MAINTENANCE COST (OMC) IN $/MWH	AVAILABILITY (AVB) IN %	RELIABILITY (RLB) IN %	TIME FROM PLANNING TO COMPLETION (TPC) IN MONTHS
SIMPLE CYCLE GAS TURBINE- NATURAL GAS FIRED	300-350	7500-8000	45	6.03	88-95	97-99	10-12
SIMPLE CYCLE GAS TURBINE- OIL FIRED	400-500	8300-8700	41	6.45	85-90	95-97	12-16
SIMPLE CYCLE GAS TURBINE- CRUDE FIRED	500-600	10600-11300	32	13.75	75-80	90-95	12-16
REGENERATIVE GAS TURBINE- NATURAL GAS FIRED	375-575	6850-7350	50	6.25	86-93	96-98	12-16
COMBINED CYCLE GAS TURBINE	600-900	6200-6500	55	4.35	86-93	95-98	22-24
ADVANCED GAS TURBINE COMBINED CYCLE POWER PLANT	800-1000	5200-5550	65	4.9	84-90	94-96	28-30
COMBINED CYCLE WITH COAL GASIFICATION	1200-1400	6950-7350	49	8.45	75-85	90-95	30-36
COMBINED CYCLE WITH FLUIDIZED BED COMBUSTION	1200-1400	7300-7700	47	8.45	75-85	90-95	30-36
NUCLEAR POWER PLANT	1800-2000	10000-10450	34	10.28	80-89	92-98	48-60
STEAM PLANT- COAL FIRED	800-1000	9770-10330	35	4.43	82-89	94-97	36-42
DIESEL GENERATOR- DIESEL FIRED	400-500	7500-8000	45	10.9	90-95	96-98	12-16
DIESEL GENERATOR- POWER PLANT OIL FIRED	600-700	8100-8550	42	11.9	85-90	92-95	16-18
GAS ENGINE- GENERATOR POWER PLANT	650-750	7300-7700	47	9.9	92-96	96-98	12-16

represented where the diagonal elements are D_is and the off-diagonal elements are a_{ij}s. For a simple cycle gas turbine-natural gas fired, the permanent function matrix is given by equation (8).

$$[V] = \begin{array}{cc} factors & \begin{array}{ccccccc} CC & HR & EFF & OMC & AVB & RLB & TPC \end{array} \\ \begin{array}{c} CC \\ HR \\ EFF \\ OMC \\ AVB \\ RLB \\ TPC \end{array} & \begin{pmatrix} 10 & 2 & 1 & 4 & 3 & 2 & 2 \\ 8 & 4.298643 & 4 & 8 & 4 & 4 & 6 \\ 9 & 6 & 3.939394 & 7 & 6 & 4 & 8 \\ 6 & 2 & 3 & 8.212766 & 3 & 2 & 6 \\ 7 & 6 & 4 & a_7 & 8.484848 & 5 & 7 \\ 8 & 6 & 6 & 8 & 5 & 10 & 8 \\ 8 & 4 & 2 & 4 & 3 & 2 & 10 \end{pmatrix} \end{array} \tag{8}$$

(iv). The evaluation and comparison of the various alternative power plants is carried out by using the identification set for a given system of the power plants. For example, a comparison is made for a common set of attributes as contained in the generalized Operational-economics digraph of the problem, the variable Permanent Function matrix (VPFM) contain the following information about inheritance, T_is and the interactions, T_{ij}s of the attributes: for the Simple cycle gas turbine- natural gas fired, the inheritance functions are given be equation (9).

$$T_1 = 10, \quad T_2 = 4.298643, \quad T_3 = 3.939394, \\ T_4 = 8.212766, \quad T_5 = 8.484848, \quad T_6 = 10, \quad T_7 = 10 \tag{9}$$

Similarly, for the simple cycle gas turbine-oil fired, the inheritance functions are given by equation (10).

$$T_1^{'} = 9.206349, \quad T_2^{'} = 5.656109, \quad T_3^{'} = 2.727273, \\ T_4^{'} = 7.765957, \quad T_5^{'} = 6.060606, \quad T_6^{'} = 6.363636, \\ T_7^{'} = 9.302326 \tag{10}$$

Assuming that the interdependencies for the two power plants are isomorphic in nature, therefore $T_{ij} = T_{ij}$ for all i,j = N, where N is the number of attributes considered for the operational- economic digraph and values equal to the vector sets as contained in variable Permanent Function Matrix (VPFM) above. Then the identification set for Simple cycle gas turbine- natural gas fired power plant is given by equation (11).

$$[(J_1^{'T}/J_2^{'T}/J_3^{'T}/J_4^{'T}/J_{51}^{'T}/J_{52}^{'T}/J_{61}^{'T}/J_{62}^{'T}/J_{71}^{'T}/J_{72}^{'T}/J_{73}^{'T} \\ /J_{74}^{'T}/J_{81}^{'T}/J_{82}^{'T}/J_{83}^{'T}/J_{84}^{'T})(V_1^{'T}/V_2^{'T}/V_3^{'T}/V_4^{'T}/V_{51}^{'T}/V_{52}^{'T} \\ /V_{61}^{'T}/V_{62}^{'T}/V_{71}^{'T}/V_{72}^{'T}/V_{73}^{'T}/V_{74}^{'T}/V_{81}^{'T}/V_{82}^{'T}/V_{83}^{'T}/V_{84}^{'T})] \\ = [(1/0/21/70/105/210/420/504/105/630/280/840/ \\ 210/504/420/720)(1180033/0/1.0595E+7/2.2684E+7/ \\ 1.9794E+7/4.14855E+7/4.8376E+7/5.9408E+7/ \\ 6688852/4.2314E+7/1.9391E+7/5.7951E+7/ \\ 7878240/1.9423E+7/1.6699E+7/2.8569E+7)] \tag{11}$$

TABLE IV
MEAN VALUE APPROXIMATIONS OF THE OPERATING RANGES OF THE ATTRIBUTES

Type of power plant	Mean value approximations for the Operational-economic attributes						
	Capital Costs (CC) in $/KW	Heat Rate (HR) in Kj/KWh	Net Efficiency (EFF) in%	Operation & Maintenance Cost (OMC) in $/MWh	Availability (AVB) in %	Reliability (RLB) in %	Time from planning to completion (TPC) in months
Simple cycle gas turbine- Natural Gas fired	325	7750	45	6.03	91.5	98	11
Simple cycle Gas turbine- Oil fired	450	8500	41	6.45	87.5	96	14
Simple cycle Gas turbine- Crude fired	550	10900	32	13.75	77.5	92.5	14
Regenerative Gas turbine- Natural gas fired	475	7100	50	6.25	89.5	97	14
Combined cycle Gas turbine	750	6350	55	4.35	89.5	96.5	23
Advanced Gas turbine combined cycle power plant	900	5375	65	4.9	87	95	29
Combined cycle with coal gasification	1300	7150	49	8.45	80	92.5	33
Combined cycle with Fluidized bed combustion	1300	7500	47	8.45	80	92.5	33
Nuclear power plant	1900	10225	34	10.28	84.5	95	54
Steam plant- Coal fired	900	10220	35	4.43	85.5	95.5	39
Diesel Generator- Diesel fired	450	7750	45	10.9	92.5	97	14
Diesel Generator- power plant oil fired	650	8325	42	11.9	87.5	93.5	17
Gas engine- Generator power plant	700	7500	47	9.9	94	97	14

TABLE VI
OPERATIONAL-ECONOMIC ATTRIBUTE VALUES (D_iS)

Attributes	Attributes						
	CC	HR	EFF	OMC	AVB	RLB	TPC
CC	—	2	1	4	3	2	2
HR	8	—	4	8	4	4	6
EFF	9	6	—	7	6	4	8
OMC	6	2	3	—	3	2	6
AVB	7	6	4	7	—	5	7
RLB	8	6	6	8	5	—	8
TPC	8	4	2	4	3	2	—

Similarly, for the Simple cycle gas turbine- oil fired power plant, the identification set for comparison is represented below as equation (12) .

$$\begin{aligned}
&[(J_1^{'T}/J_2^{'T}/J_3^{'T}/J_4^{'T}/J_{51}^{'T}/J_{52}^{'T}/J_{61}^{'T}/J_{62}^{'T}/J_{71}^{'T}/J_{72}^{'T}/J_{73}^{'T}\\
&/J_{74}^{'T}/J_{81}^{'T}/J_{82}^{'T}/J_{83}^{'T}/J_{84}^{'T})(V_1^{'T}/V_2^{'T}/V_3^{'T}/V_4^{'T}/V_{51}^{'T}/V_{52}^{'T}\\
&/V_{61}^{'T}/V_{62}^{'T}/V_{71}^{'T}/V_{72}^{'T}/V_{73}^{'T}/V_{74}^{'T}/V_{81}^{'T}/V_{82}^{'T}/V_{83}^{'T}/V_{84}^{'T})]\\
&=[(1/0/21/70/105/210/420/504/105/630/280/840/\\
&210/504/420/720)(395678/0/4918682/1.2290E+7/\\
&1.2533E+7/2.6229E+7/3.5662E+7/4.3779E+7/\\
&5747662/3.6340E+7/1.6644E+7/4.9753E+7/\\
&7878240/1.9423E+7/1.6699E+7/2.8569E+7)]
\end{aligned} \tag{12}$$

The values of the subgroupings within the groupings represent the dominance or the effect of the attributes interdependencies and its inheritances when such identification sets are compared subgrouping wise and analyzed. From the above identification sets, it is clear that for almost all the subgroupings, the corresponding numerical values as calculated in the identification set for first kind of power plant considered are much higher than the second one. It can be deduced that the inheritances and the interdependencies in case of first kind of power plant are to be given more attention and hence, are more significant as compared to the second type of power plant considered for comparison. (v). The sensitivity analysis of the various power plants- attributes combinations has been carried out for operating ranges of the attributes taken into account as well as the effect of their subgrouping value variations in the universal operational- economic function for the power plants. The dominance of the plant attributes over the operating ranges has been analyzed using the Graph theoretic approach as mentioned. For example, the variation in the values of interdependencies of the attributes in case of Regenerative gas turbine- natural gas fired type power plant are to be analyzed and compared for a particular set of constraints such that the heat rate (HR) and net efficiency (EFF) have equal importance w.r.t. each other and the availability (AVB) has slightly more importance w.r.t. the reliability (RLB), then the

TABLE V
NORMALISED RELATIVE IMPORTANCE OF THE ATTRIBUTES

Type of power plant	Operational-Economic attributes						
	CC	HR	EFF	OMC	AVB	RLB	TPC
Simple cycle gas turbine- Natural Gas fired	10	4.298643	3.939394	8.212766	8.484848	10	10
Simple cycle Gas turbine- Oil fired	9.206349	5.656109	2.727273	7.765957	6.060606	6.363636	9.302326
Simple cycle Gas turbine- Crude fired	8.571429	10	0.005	0.005	0.005	0.005	9.302326
Regenerative Gas turbine- Natural gas fired	9.047619	3.122172	5.454545	7.978723	7.272727	8.181818	9.302326
Combined cycle Gas turbine	7.301587	1.764706	6.969697	10	7.272727	7.272727	7.209302
Advanced Gas turbine combined cycle power plant	6.349206	0.005	10	9.414894	5.757576	4.545455	5.813953
Combined cycle with coal gasification	3.809524	3.21267	5.151515	5.638298	1.515152	0.005	4.883721
Combined cycle with Fluidized bed combustion	3.809524	3.846154	4.545455	5.638298	1.515152	0.005	4.883721
Nuclear power plant	0.005	8.778281	0.606061	3.691489	4.242424	4.545455	0.005
Steam plant- Coal fired	6.349206	8.769231	0.909091	9.914894	4.848485	5.454545	3.488372
Diesel Generator- Diesel fired	9.206349	4.298643	3.939394	3.031915	9.090909	8.181818	9.302326
Diesel Generator- power plant oil fired	7.936508	5.339367	3.030303	1.968085	6.060606	1.818182	8.604651
Gas engine- Generator power plant	7.619048	3.846154	4.545455	4.095745	10	8.181818	9.302326

set of constraints can be represented as :
$T'_{(}23)$ =5 , $T'_{(}32)$ =5 ,$T'_{(}56)$ =6, and other $T'_{ij} = T'_{ji}$,
the identification set for the Regenerative gas turbine- natural gas fired type power plant with standard values of T_{ij} is represented by equation (13).

$$[(J_1^{'T}/J_2^{'T}/J_3^{'T}/J_4^{'T}/J_{51}^{'T}/J_{52}^{'T}/J_{61}^{'T}/J_{62}^{'T}/J_{71}^{'T}/J_{72}^{'T}/J_{73}^{'T} /J_{74}^{'T}/J_{81}^{'T}/J_{82}^{'T}/J_{83}^{'T}/J_{84}^{'T})(V_1^{'T}/V_2^{'T}/V_3^{'T}/V_4^{'T}/V_{51}^{'T}/V_{52}^{'T} /V_{61}^{'T}/V_{62}^{'T}/V_{71}^{'T}/V_{72}^{'T}/V_{73}^{'T}/V_{74}^{'T}/V_{81}^{'T}/V_{82}^{'T}/V_{83}^{'T}/V_{84}^{'T})] = [(1/0/21/70/105/210/420/504/105/630/280/840/ 210/504/420/720)(680490/0/7140233/1.651E+7/ 1.5517E+7/3.2596E+7/4.1046E+7/5.0458E+7/ 6151167/3.893E+7/1.7838E+7/5.331E+7/ 7878240/1.9423E+7/1.67E+7/2.8569E+7)] \qquad (13)$$

The value of the permanent index i.e. the operational-economic index of the power plant is : 3.5276707E+08 and the changes as observed in the values of the subgroupings are represented in the form of modified identification set by equation (14).

$$[(J_1^{'T}/J_2^{'T}/J_3^{'T}/J_4^{'T}/J_{51}^{'T}/J_{52}^{'T}/J_{61}^{'T}/J_{62}^{'T}/J_{71}^{'T}/J_{72}^{'T}/J_{73}^{'T} /J_{74}^{'T}/J_{81}^{'T}/J_{82}^{'T}/J_{83}^{'T}/J_{84}^{'T})(V_1^{'T}/V_2^{'T}/V_3^{'T}/V_4^{'T}/V_{51}^{'T}/V_{52}^{'T} /V_{61}^{'T}/V_{62}^{'T}/V_{71}^{'T}/V_{72}^{'T}/V_{73}^{'T}/V_{74}^{'T}/V_{81}^{'T}/V_{82}^{'T}/V_{83}^{'T}/V_{84}^{'T})] = [(1/0/21/70/105/210/420/504/105/630/280/840/ 210/504/420/720)(680490/0/7237371/1.6957E+7/ 1.5939E+7/3.3763E7/4.2662E+7/5.2664E+7/ 6395824/4.0782E+7/1.8743E+7/5.607E+7/ 8278208/2.0487E+7/1.7672E+7/3.024E+7)] \qquad (14)$$

Similarly, the operational-economic Index for the modified values of the interdependencies based on the set of constraints is calculated as : 3.6857107E+08. From the above set of values placed in the identification set, again it is clear that the interdependency among the major attributes plays a vital role in the overall performance index and the selection criteria of the power plants. Once benchmarking standards are established for the attributes in terms of inheritance and the interdependencies, various power plants can be compared in terms of operational-economic performance index. For a same set of Variable Permanent Function Matrix (VPFM) elements, two or more power plants may be compared by considering the variation in values for their inheritance nature within the matrix.

(vi). The typical values of the universal operational- economic index has been calculated using the specified values of the D_is and a_{ij}s. This index represents the concise contribution of the inheritance levels of the attributes as well the level of interdependencies among them for all the alternative power plants. In the present study, in total 13 power plant types have been studied for a specified set of attributes and the performance of each power plant system is represented in the form of Universal Operational- Economic Index of the power plants. The value of this index as calculated for various power plants is represented in the descending order in Table

TABLE VII
PERMANENT FUNCTION VALUES OF THE POWER PLANTS IN DESCENDING ORDER

Sr. No.	Type of power plant	Universal Operational-economic Index value for the mean operating ranges of the attributes
1	Simple cycle gas turbine natural gas fired	4.024359E+08
2	Regenerative gas turbine natural gas fired	3.5276707E+08
3	Combined cycle gas turbine	3.2245126E+08
4	Gas engine - generator power plant	3.1691654E+08
5	Simple cycle gas turbine-oil fired	3.168615E+08
6	Diesel generator- diesel fired	3.125209E+08
7	Advanced gas turbine combined cycle power plant	2.6518453E+08
8	Steam plant- coal fired	2.4271906E+08
9	Diesel generator- power plant oil fired	2.1287526E+08
10	Simple cycle gas turbine-crude fired	1.6523846E+08
11	Combined cycle with coal gasification	1.5497093E+08
12	Combined cycle- fluidized bed combustion	1.5496381E+08
13	Nuclear power plant	1.3458578E+08

VII. CONCLUSION

The proposed methodology based on the Graph theoretic approach for the evaluation of the universal operational- economic index of the power plants has been suggested and a schematic implementation have been represented by taking suitable example. This approach incorporates all the assessment criteria and the concepts of evaluation and prioritizing the alternative selection of power plant for a given set of attribute which makes this methodology an important tool in analyzing the systems as well as effective scientific approach of decision making among most suited alternatives available. Practical implementation of the methodology in a systematic manner will help the power plant engineers to identify, analyze and evaluate factors responsible for Operational economics of the power plants. Evaluation and comparison will also lead to identify critical areas that are roadblocks to power plant system design.

This proposed approach is generic one and can be used in any kind of such applications independently. Various system options- attributes combinations can be effectively analyzed by using this proposed approach.

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