Journal of Multidisciplinary Engineering Science Studies (JMESS)
ISSN: 2458-925X
Vol. 10 Issue 11, November - 2024

Simulation Of Maintenance Scheduling For Medium-Voltage Electric Motors In A Combined Cycle Power Plant Using PERT/CPM

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***Abstract*— In Mexico, the industrial and business sectors tend to be increasingly competitive and it has become essential to have both technical and administrative tools that allow access and permanence in the market. Regardless of the product or service offered by any industry, one of the key points for its competitiveness is to have an excellent maintenance plan for its equipment, since this represents the basis for its productivity. Industrial maintenance within the combined cycle power plants is a topic of great importance for the generation of electric energy and also avoids accidents to the operators as well as damage to the different existing equipment. This article will address the scheduling of maintenance of medium voltage (460v) electric motors within a combined cycle power plant by applying the tools of project analysis and network modeling along with the topics of PERT and CPM.**

Keywords—Combined Cycle; Power Plant; CPm; Industrial Maintenace; PERT

I. INTRODUCTION

A. Background

On the occasion of the major maintenance that it carries out every year, a certain Combined Cycle Power Plant launches a tender with the purpose of inviting tenders from various companies that are experts in providing major maintenance services to combined cycle power plants. Among the maintenance activities is the provision of maintenance services for medium voltage (460 V) electric motors.

B. Problem statement

Given that a given company wishes to offer its services for the maintenance of medium voltage electric motors (460 V), the first step to be taken is to determine the human resources (specialised labour), material resources (tools, consumables, personal protective equipment, etc.), logistical resources (transport of personnel, accommodation, mobile offices on site, etc.) and financial resources (payroll payments, equipment rental payments, accommodation service payments, etc.) to be taken into account.), logistics (transport of personnel, accommodation, mobile offices on site, etc.) and financial resources (payroll payments, equipment rental payments, lodging service payments, etc.) that will be used to consider them in the cost of its services, in addition to the profit that must be generated for the service to be profitable. Therefore, the company must carry out an in-depth study and determine what strategies it will implement to execute the project. To carry out the elaboration and development of the whole project, the PERT/CPM planning and control technique will be implemented.

C. Justification and relevance of the project

In Mexico there are a large number of companies dedicated to the construction and industrial maintenance sector, however, many of them are unaware of the techniques that exist today for the formulation and evaluation of projects and the benefits that these can bring them to make their analysis in a methodological way, saving them time, resources and costs.

II. CONCEPTUAL FRAMEWORK

A. *Project formulation and evaluation*

In general terms, a project can be described as the union of the efforts of different disciplines, both administrative and technical, to develop and carry out a product or service within a set timeframe, allocating the available resources appropriately to satisfy a given need.

However, the progress of a project from inception to closure cannot merely rely on the good wishes of the investors and staff involved for the development of the project; it is relevant to have project planning, even at an early stage, to establish how it will be possible to achieve the objectives defined in the project, creating profits and making it profitable.

The study of projects, taken as a process of generating information to support management activity, has reached an indisputable position among the most widely used instruments in the difficult task of facing decision-making [1].

B. *PERT and CPM*

Analyses of project formulation and evaluation problems that have been approached from the criteria of network models help in project programming and their benefits become more noticeable when projects are large and involve many activities.

If the duration of each activity is known with a high degree of certainty, then the *Critical Path Method* (CPM) is used to determine the length of time required to complete the Project [2]. Other values that are possible to establish by network analysis through the CPM method is to forecast how much each project activity can be delayed or advanced without compromising the completion of the project. Otherwise, if it is not possible to determine the duration of activities, the *Program Evaluation Review Technique* (PERT) is applied to assess the probability that the project will be completed by a specific date [2].

C. *Combined Cycle Power Plants*

Electric power is produced as a result of a series of necessary transformations of an existing available energy (be it fuel, water from a dam, steam from underground, etc.) that occur within the man-made installation until finally arriving at electric power. A combined cycle power plant consists of two power generation cycles:

- *Simple cycle*. It is called simple cycle when the unit operates only as a turbogasse.
- *Combined cycle*. In this mode, the considerable amount of heat (energy) remaining in the exhaust gases of the gas turbine is directed to a boiler called a heat recovery steam generator. The steam generated in the heat recovery steam generator is sent to an associated steam turbine, which significantly increases the efficiency of the cycle.

D. *Maintenance in industry*

As mentioned González [3] "maintenance in industry starts with basic tasks such as tidying, cleaning, elementary lubrication and minor adjustments. As complexity increases, activities such as inspection and lubrication routes, punctual measurements with specialised instruments, and the implementation of online data acquisition systems are included".

Montilla [4] points out that a formal definition of maintenance is "a set of activities (planned and coordinated) that proposes to maintain equipment (of various kinds) in an operational condition, as close as possible to its theoretical or nominal state, with the minimum investment (economic, time, inputs), in a safe manner for personnel and the environment, positively supporting the fulfilment of the goals of an organisation".

From a planning and programming perspective, maintenance involves the execution of technical-administrative activities that require continuous management. This is essential to ensure that the results are satisfactory and sustainable over time [5]. The implementation of a preventive maintenance programme can also significantly reduce operating costs and increase the useful life of equipment [6].

It is necessary for companies to implement predictive maintenance strategies, which use advanced technologies such as sensors and data analytics to anticipate failures and minimise downtime [7]. To maintain control of costs and expenses, it is vital that a company manages indicators that allow it to determine if the situation is under control or if it is deviating more than expected [8]. In addition, continuous training of personnel in maintenance techniques and the use of new technologies is fundamental to ensure the effectiveness of these strategies [9]. According to Díaz [10] "an organisational culture that promotes continuous improvement is also essential for the success of maintenance practices".

III. MATERIALS AND METHODS

Knowing what network analysis is about and how the PERT/CPM project management methodology is derived from it, together with the way a combined

cycle power plant works and the importance of industrial maintenance for any company, we will now return to the example that emulates an industrial problem, which was presented in the section Problem Statement.

We begin by recalling the activities necessary to carry out the maintenance of medium voltage electric motors (460V) and it should also be borne in mind that their execution is considered to take approximately 35 days. With the above, time is assigned to each of the activities, as shown in table 3.1.

Table 3.1
Activities for the maintenance of medium voltage (460V) electric motors.

No.	Activity	Letter	Predecessora 1	Predecessora 2	Single Estimate	3-Time estimation		
						Op	Me	Pe
1	Dismantling	A			5	3	4	5
2	Adjustment and checking of seals and gaskets against moisture ingress	B	A		3	2	3	3
3	Winding	C	A		3	3	3	4
4	Bearing replacement	D	A		2	2	2	3
5	Adjustment and verification of bearing dimensions	E	B		1	1	2	3
6	Oil change of bearings and filters	F	E	D	4	2	2	3
7	Shaft machining	G	F		3	2	3	5
8	Rear locking	H	C	G	1	1	2	3
9	Front casing	I	H		1	1	2	3
10	Static electrical testing	J	I		2	1	2	3
11	Adjustment and verification of power and control circuits	K	J		2	1	2	3
12	External cleaning	L	K		1	1	2	3
13	Painting	M	L		2	2	2	4
14	Assembly	N	M		3	2	3	5
15	Machine alignment	O	M		1	1	2	3
16	Adjusting and checking alignment with laser equipment	P	O		1	1	2	3

Note: The unit of time is given in days. Source: Authors.

The PERT analysis will comprise both a single time, which will give the time required for the completion of the project activities, and a triple time estimation analysis, i.e. a study that will consider the most probable time, an optimistic time and a pessimistic time. The objective of these analyses is to be able to determine whether the medium voltage (460) electric motor maintenance project is feasible to be carried out in the estimated time of 35 days. The analyses were carried out using the POM-QM software for Windows, which is a software specialised in operations problem solving and quantitative methods, suitable for application in operations research and quantitative problems.

IV. RESULTS AND DISCUSSION

We return to the data shown in table 3.1 and indicate to the software that our study will be carried out using the PERT singular method, and it immediately provides us with the calculation of the time it would take to carry out the project, which appears in figure 4.1, indicating an approximate duration of 30 days to carry out the project. At the same time, each of the activities of the project is shown with its determined time. The activities in red are those that make up the critical route, i.e. they are the activities that cannot be delayed or brought forward, as this would mean that the project could not be completed within the estimated time.

The software provides an estimate of the time in which the activities should start, whether they start early or late. It is also observed that the activities have no slack time at the begining, which means that in order to achieve the fulfilment of the project it will be necessary to carry out the activities continuously. The Slack column shows the time slack for each activity, where the project has slack only in activities C and D, up to 8 and 2 days respectively.

Figure 4.1
PERT results through singular analysis.

QM for Windows - [Data] Results

(untitled) Solution

Activity	Activity time	Early Start	Early Finish	Late Start	Late Finish	Slack
Project	30					
A	5	0	5	0	5	0
B	3	5	8	5	8	0
C	3	5	8	13	16	8
D	2	5	7	7	9	2
E	1	8	9	8	9	0
F	4	9	13	9	13	0
G	3	13	16	13	16	0
H	1	16	17	16	17	0
I	1	17	18	17	18	0
J	2	18	20	18	20	0
K	2	20	22	20	22	0
L	1	22	23	22	23	0

Source: Authors.

Subsequently, once the analysis of the single estimate has been carried out, we must take into account that the time estimates for each activity were determined by the company's experience; however, it is necessary to foresee both internal and external factors that could impact on the project's fulfilment. Therefore, a second PERT estimation is carried out: *the triple estimation*.

By taking the times in table 3.1 and inserting them into the POM QM programme, it can be seen that the most likely time in which the project will be completed is almost 34 days (figure 4.2).

Figure 4.2. Estimation with most likely, pessimistic and optimistic times.

QM for Windows - [Data] Results

(untitled) Solution

Activity	Activity time	Early Start	Early Finish	Late Start	Late Finish	Slack	Standard Deviation	Variance
Project	33.67						1.29	1.67
A	4	0	4	0	4	0	.33	.11
B	2.83	4	6.83	4	6.83	0	.17	.03
C	3.17	4	7.17	11	14.17	7	.17	.03
D	2.17	4	6.17	6.67	8.83	2.67	.17	.03
E	2	6.83	8.83	6.83	8.83	0	.33	.11
F	2.17	8.83	11	8.83	11	0	.17	.03
G	3.17	11	14.17	11	14.17	0	.5	.25
H	2	14.17	16.17	14.17	16.17	0	.33	.11
I	2	16.17	18.17	16.17	18.17	0	.33	.11
J	2	18.17	20.17	18.17	20.17	0	.33	.11
K	2	20.17	22.17	20.17	22.17	0	.33	.11
L	2	22.17	24.17	22.17	24.17	0	.33	.11

Source: Author.

The programme provides a detailed analysis of the exact estimated times in which each activity would be accomplished. It can also be seen in the "Activity time" column of figure 4.2, the times of an early start and finish for each activity, and on the contrary, a late start and finish. As in the single analysis, the only activities with time slack are activities C and D. Finally, information is provided on the variance and standard deviation of each activity.

Considering the results table provided by the POM QM software, it can be seen that the maintenance of medium voltage electric motors (460V) is a complex project and in general does not have a time frame; in order to carry out the maintenance within the established time of 35 days, it is necessary to have an experienced and well organised work team, as it is required that the activities are carried out in a timely manner, otherwise the proposed objectives would not be achieved, as well as having formal suppliers with a high capacity to comply with the requested time. If these two requirements are not met, it becomes impossible to complete the maintenance within the established timeframe.

V. CONCLUSIONS

The analysis and development of projects is becoming more and more indispensable within the business environment, in any type of production and service industry. Due to today's highly competitive environment, it is always necessary to be prepared to respond to new project opportunities, and also to foresee changes for the improvement of the company. There are a multitude of tools for both analysing the reliability of projects and for planning, controlling and measuring project developments. The PERT/CPM methodology, together with the network diagram, are effective tools for the determination of the activities within a project and the measurement of the time required for their realisation. Nowadays, several specialised software tools are available to carry out these analyses. The POM QM software is an effective and specialised tool in problem solving and quantitative methods, providing a visualisation of the project and helping us to determine with greater precision the times that will be required. With these tools it is feasible to determine the feasibility of projects and avoid taking risks in business decisions.

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