Maximizing the Lifespan of Hydraulic Power Plants with Application of the Integrated Preventive Maintenance Program

Layth Abed Hasnawi Al-Rubae

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Mechanical Engineering

Eastern Mediterranean University
January 2013
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Mechanical Engineering.

Assoc. Prof. Dr. Uğur Atikol
Chair, Department of Mechanical Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Mechanical Engineering.

Assist. Prof. Dr. Hasan Hacışevki
Supervisor

Examining Committee

---

1. Prof. Dr. Majid Hashemipour ____________________

2. Assoc. Prof. Dr. Fuat Egelioğlu ____________________

3. Assist. Prof. Dr. Hasan Hacışevki ____________________

ABSTRACT

Hydropower plant became one of the main resources for electricity production. This research mentions the Iraq hydropower plant as a case study, there is lack in Iraq electricity production. One of the important drawbacks of these plants in Iraq is poor maintenance. In this study the program for maintenance has been suggested. It is a preventive maintenance program that depends on seven steps (inspection and testing, lubrication, planning and scheduling, documentation, training, stimulation and control of spare part). These steps cover all types of hydropower plant maintenance problems. To evaluate the preventive maintenance work a new technique by using Microsoft Office Access 2007 & Visual Basic 2008 based program is prepared. The proposed technical program depends on four major criteria: time, weight activity, percentage completion and duration of activity. The objectives of this study are to keep the level of electricity production at the desirable level, reduce the down time of hydropower plant for the maintenance, reduce the cost of maintenance and finally to prepare a successful planning for the future maintenance program.

Keywords: Integrated preventive maintenance, Hydraulic Power Plants or hydroelectric, Maintenance program, Periodic evaluation, Maintenance cost, Maintenance.

ÖZ

Hidroelektrik santrali elektrik üretimi için en önemli kaynaklardan biri haline geldi. Bu araştırmada bir Irak hidroelektrik santrali örnek çalışma olarak incelenmiştir. Irak'ta elektrik üretiminde yetersizlik vardır. Irak'ta bu santrallerin önemli sorunlardan biri yetersiz bakımdır. Bu çalışmada, bakım için yeni bir bakım ve onarım programı önerilmiştir. Bu program yedi ana kısma (denetim ve test, yağlama, planlama ve çizelgeleme, dokümantasyon, eğitim, stimülasyon ve yedek parça kontrolü) bağlı önleyici bir bakım programıdır. Bu adımlar her türlü hidroelektrik santralinin bakım sorunlarını kapsamaktadır. Önleyici bakım çalışmasını değerlendirmek için yeni bir çözüm tekniği olarak Microsoft Office Access 2007 ve Visual Basic 2008 kullanmak önerilmiştir. Önerilen teknik program dört ana kritere bağlıdır; zaman, ağırlıklı aktivite, tamamlama yüzdesi ve faaliyet süresi. Bu çalışmanın amacı elektrik üretimini istenilen düzeyde tutmak, bakım için hidroelektrik santralinin kapalı kalma süresini, bakım maliyetini azaltmak ve nihayet gelecekteki bakım programı için başarılı bir planlama hazırlamaktır.

Anahtar kelimeler: Birleştirilmiş önleyici bakım, Hidrolik güç santrali, hidroelektrik, operasyon ömrü, bakım programı, hidrolik türbin, periyodik değerlendirme, bakım maliyeti, bakım.

To my family

ACKNOWLEDGMENT

Before anything, thanks to God Almighty for the blessings and giving me the health and strength to complete my thesis successfully. Hopefully, God will always help and blessing me in the future.

I would like to express my grateful and my sincere appreciation to my kind supervisors, Assist. Prof. Dr. Hasan Hacışevki for his continuous support and valuable guidance in the preparation of this study. Without his continued support and encouragement, this thesis would not have been the same as presented here.

I would like also to convey my special thanks to all my instructors of the Mechanical Engineering Department for giving me the opportunity to carry out my graduate studies and this research. I would also like to thank my cousin surgeon Dr. Luay Al-Nasser, who gave a helping hand and help me to get to this place.

I also want to appreciate the valuable efforts of the Iraqi Cultural Attaché in Ankara for their outstanding efforts. Many thanks to my friends for their words of encouragement. Thanks and gratitude to all employees in the main dam station in Mosul dam for facilitating the practical completion of my studies in this area.

My deep thanks also to Eastern Mediterranean University and College of Engineering in Diyala University for giving me the opportunity to carry out my graduate studies in North Cyprus.

Finally, I wish also to express my love and gratitude to my beloved family for their emotional support and encouragement through the duration of my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations

PM	Preventive Maintenance
IT	Inspection and Testing
TBI	Time Between Interruption
TBF	Time Between Failure
MT	Maintenance Time

Chapter 1

INTRODUCTION

1.1 The Concept of Maintenance

The importance of the concept of maintenance has increased in recent years due to the impact of technology and the degree of complex maintenance methods. Maintenance mix of engineering and administrative work relates to the conservation of the human resources available to the industrial units. The specifications and designs are ensuring of the reliability and conduct, for the necessary maintenance to remain in constant readiness to perform its function efficiently. It is certain that the main objective of the adoption of industrial plants an annual plan programmed for maintenance of machinery and capital equipment which exemplified the provision to ensure greater continuity of production with the least damage possible [1].

1.2 The Concept of Effective Preventive Maintenance System

The importance of basic maintenance and role is development operation for production. There is a need for the help of a group of tools such as charts and criteria to evaluate this role. Therefore, standards are part of these tools which help reach the best ways to perform activities for the purpose of standing at the level of implementation of plans [2]. The most important of maintenance concepts which is a collection of activities like oiling, lubrication, cleaning inspection and replacement of some parts in a fixed period before the damages in the equipment take place.

1.3 Increase the Life Span of Hydraulic Plants

This occurs by averment of the important of industrial maintenance generally and protection maintenance in particular, as well as and the effective role it plays in the minimization of cost by diagnosing the malfunction before it happens.

Preventing part's replacement with a new once eliminates high costs of the owner. In case of the application of integrated preventive maintenance programs, can be protect the hydraulic plants from malfunction and sometimes predict malfunction, leading to reduced down time and, which in turn lead to increased production of electric power [3].

The present works focused on the study of the most important problems that accompany the operation of the hydraulic turbine, it identifies the ways of preventive maintenance integrated after the application of programs based on the examination and inspection (external and internal), oiling, planning, scheduling and documentation (record evidence) to train a team of maintenance and control inventories of spare parts. Figure 1.1 shows the principle of the proposed maintenance work.

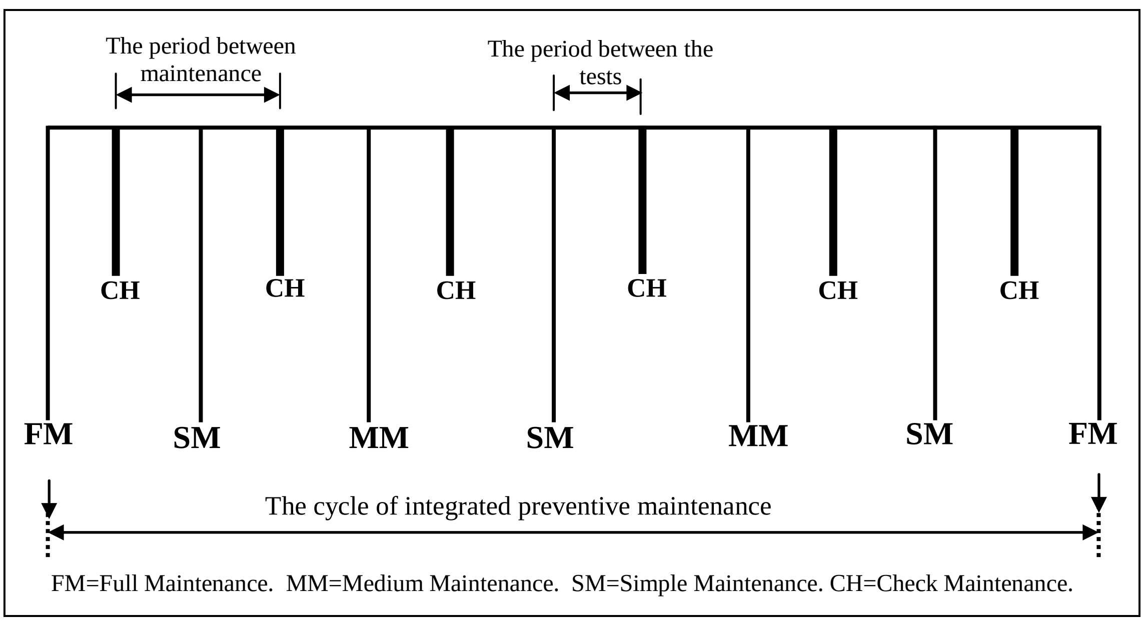


Figure 1.1. Integrated preventive maintenance cycle.

1.4 Criteria and Evaluation of the Integrated Preventive Maintenance

The purpose of application of the integrated preventative maintenance system is to find the best preset time within specific standards for maintenance, there are many proposed standards. The evaluation profits for maintenance program are:

1. The program parameters used contributes to reduce the waste time spent in schedule maintenance.
2. The new proposed program helps the maintenance team to put right and best plan to solve all emergency and planning problems.
3. Advance planning is the main feature of the preventive maintenance; it is helping to prevent a lot of mistakes that can be occurring during maintenance.
4. When the percentage of scheduling performance to be 100% then incentives should be given to the maintenance team.

1.6 Objectives

The objectives of this study are (keep the level of electricity production, reduce the stopping time of hydropower plant for do maintenance, make the cost of maintenance less and finally prepared the successful planning for future maintenance program.

The chapters of this thesis are organized as followed:

Chapter 2, this chapter explains the literature review for the last study and compression between these types.

Chapter 3, in this chapter the researcher studied the types of hydro power plants used in the dams, and fined the problems faced by these plants.

Chapter 4, shows the systems for the efficiency of the effectiveness measuring of integrated programs preventive maintenance.

Chapter 5, through this chapter studied the technique that will follow to conduct a comprehensive assessment of the computer program.

Chapter 6, conclusions and recommendation.

Chapter 2

LITREATURE REVIEW

The importance of maintenance, its main role in the development process and keep the parts from the failure or damage is obvious. There are many types of maintenance methods such as the maintenance in hydraulic plants including maintenance therapeutic, preventive maintenance and maintenance forced. For that will give a review of these types and trying to find or suggest the best maintenance program.

In particular, Alkhamis and Yellen [4] said the solution for the maintenance scheduling problem for refinery units, by put the problem as a model like a (0-l) optimization problem. By means of design the program to solve the model problem by using mathematical techniques depending on formulation. Whilst the basic idea of Chareonsuk et al [5], needs for the organization between different functional groups, such as production and maintenance. Then support function of production activity if it is high that mean good maintenance. That does will be taken as a procedure in our study. In 1997, Gertsbakh and Kordonsky [6] worked to build preventive maintenance program depend on two factors (time of flight and maintenance). This is consistent with the researcher’s maintenance program, where the focus was on the time factor as interruptions experienced by the hdropower plant. For the purpose of maintenance greatly affect the production of electric power, but differ from this study being based on other criteria.

Many researchers have studied that like David et al [7] and Sanmarti et al [8], and agree suggestion of planning strategy helps to enhance the durable schedule, bounding the productivity to cover that fixed by the demand.

There are a series of studies which dealt with the topic of maintenance scheduling activities such as all of the Duffuaa and Al-Sultan [9], Deris et al [10] and Wang and Handschin [11] used algorithms and computer programming to prepare timeline and resource bond of maintenance scheduling. All of these studies agree with the current study, in terms of the use of a computer, for the purpose of assessing events and maintenance program.

Some studies used ready-made systems such as Gopalakrishnan et al [12] which adopted a "Tabu Search". The procedure cycle moving from a solution to the best among it's beside solutions. He creates cycle for solution depends on four steps (initial solutions, adaptive memory, new incumbent solution and new improved solution). While stopping criterion not met with solution will be feed back to the second stage, these shown in figure 2.1.

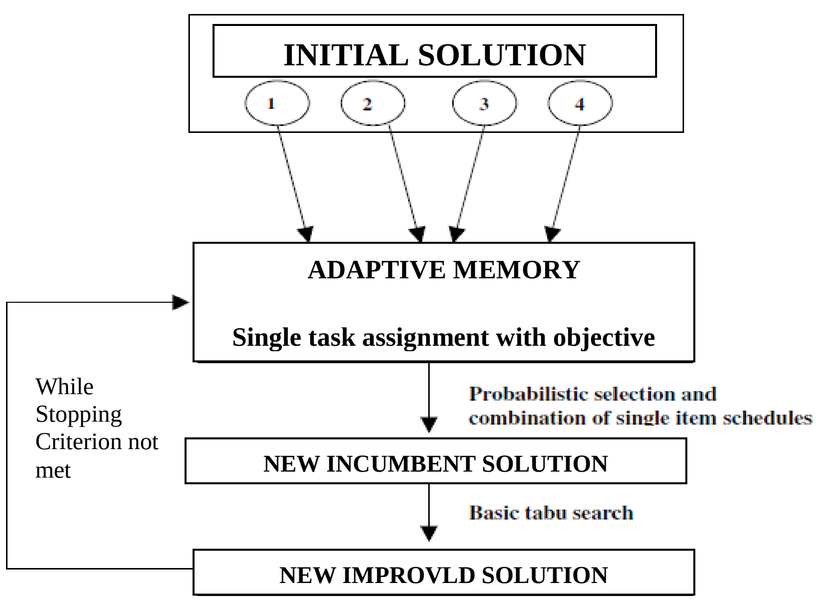


Figure 2.1. Preventive Maintenance (TABU) heuristic [15].

According to a study Dohi et al [13], make a computer program depend on the amount of spare part in the storage. If the spare part storage equal zeros the shortage occur. Our study supported by the same idea for a schedule as represent the movement of spare part from the storage to location for replacement. That is shown in the figure number (4.5).

The scheduling of maintenance activities is an important component in operations planning process, this is confirmed by the Haghani, A and Shafahi,Y [14] during his steady maintenance of bus transit several formulations for scheduling preventive maintenance in a bus transit system were presented.

Table 2.1 shows the times during which the ten buses that are to be scheduled for, inspection have a scheduled 3-day services (72 h) planning period. This information can be used to determine the idle and busy times for each bus. This is consistent with what this thesis is aiming to prepare a special maintenance time, specifying a set period of time and has a specific measure infants to ensure the implementation of events that have been recorded in this table.

Table 2.1 Daily service window for 10 buses for the 3-day planning period .

Bus no.	First day				Second day				Third day			
	Service 1		Service 2		Service 1		Service 2		Service 1		Service 2	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
1	6	22	–	–	30	34	39	45	54	67	–	–
2	6	14	–	–	38	47	–	–	54	67	–	–
3	11	19	–	–	35	34	–	–	62	71	–	–
4	6	18	–	–	30	34	39	45	59	67	–	–
5	6	22	–	–	30	34	39	45	54	70	–	–
6	6	19	–	–	30	38	–	–	62	71	–	–
7	11	19	–	–	38	47	–	–	54	58	63	69
8	6	14	–	–	30	46	–	–	54	67	–	–
9	11	19	–	–	30	34	39	45	54	67	–	–
10	14	22	–	–	35	43	–	–	54	70	–	–

This will correspond with the current study because it is concerned with a timetable to ensure maintenance without a turbine exiting the service and thereby ensuring the continuation of electric power from the dam.

One year later, El-Sharkh, M.Y and El-Keib, A.A [15] used the same technique for the maintenance scheduling (MS) that gives a very important procedure to manege the power system cost and risk.

In a different way adopted Mohanta et al [16] some of maintenance scheduling roles have been suggested using traditional mathematical programming ways or heuristic techniques. The conventional branch suffers from mistakes of dimensionality with the rise of system variables. These approaches tend to suffer from an excessive computational time with increase of variables.

Sortrakul et al [17] and Limbourg and Kochs [18] focused on using algorithms to produce schedules for maintenance, but characterized them through the getting result from traditional roles of production and preventive maintenance scheduling. Multiple way manufacturing models are not generally enough to provide a good level of desired performance.

The results of Guo et al [19] basis of planning and programming of time prior and designed to avoid a sudden failure in machines and equipment, including the replacement of parts nearing the high consumption as well as conducting other operations and are works that can be made during the operation of the machine and the other stops during the optional. The figure below shows the applicability of each depends on various system parameters such as the scheduling.

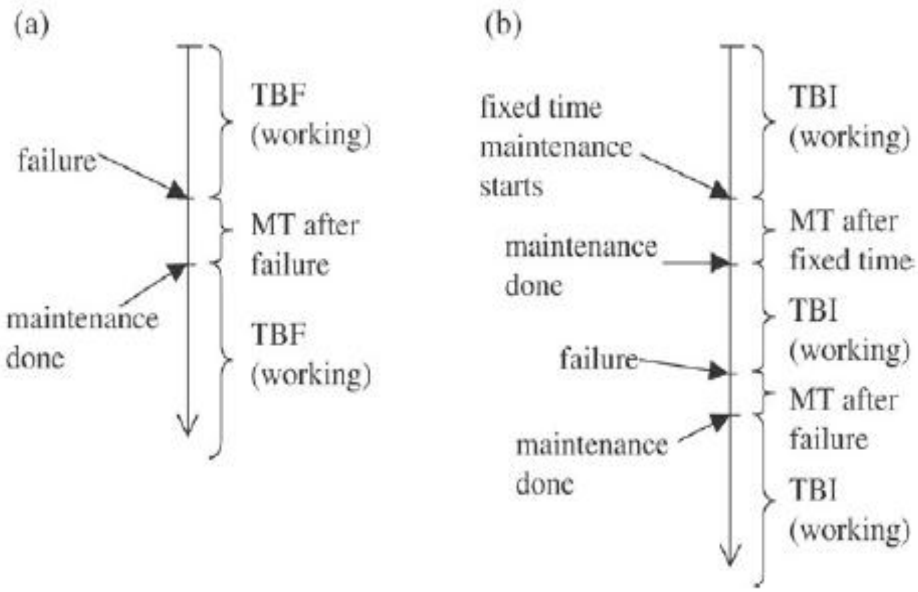


Figure 2.2. (a) And (b) are sample time lines for corrective maintenance and preventive maintenance, respectively [23].

Interested in current research Radhakrishna et al [20] the non-planned maintenance is a maintenance operations taking place on the machine and one for a crash suddenly to lead to the stoppage of work which makes them put out of work conditions right. These processes require the presence of technical skills with thorough experience and speed at work to avoid loss in production. And this problem avoid by preventive maintenance program.

The main idea of Lamptey et al [21] was an important turning point in the study of how to prepare maintenance schedules by using PM schedules (hereinafter referred to as candidates) which can be established and the optimal schedule can be identified from such candidates as well. A life-cycle is herein defined as the resurfacing interval, that is, the period of time between two consecutive treatments at least one of which is a resurfacing or higher treatment. As it is done for all facility preservation processes, it is necessary to plan PM activities in order to allocate future resources to meet any future need for this activity. The task of planning has generally been defined as the process by which the long-term goals of an “agent” are translated into short-term tasks and objectives subject to the resource constraints facing the “agent”, and involves the generation of temporally separated a sequence, inter-dependent decisions to be made over a period of time. For each candidate PM schedule, this cost cans be estimated using models. Each PM schedule has its associated expected performance model (level of condition at each year of the schedule). Then using cost-condition models the user cost associated with each PM schedule can be determined.

In case study Zhou et al [22] was based on dynamic programming with the integration of the imperfect effect into maintenance actions. Based on a proposed numerical simulation for a multi-unit series system; based on short-term optimization with the integration of imperfect effect into maintenance actions. The optimal activities are determined by maximizing the short-term cumulative OM (Opportunistic Maintenance) cost savings of the whole system based on the set-up cost. The program includes the following steps:

1) The unit undergoes relatively constant conditions involving stress, its environment and the maintenance in a given mission time.
2) Showed the unit fails, a small repair is implemented on that unit. Minimal fixed can only recover the units work and without change the units. Furthermore, the duration of minimal repair is Careless.
3) Whenever the unit arrival it’s certain sill, a Preventive Maintenance action will be run on the unit. This assumption assures that the suggested imperfect model is soure centered, which implies that the damage risk in each cycle of Preventive Maintenance is equal.

4) The costs associated with smaller repair are much higher than those connected with Preventive Maintenance, which implies [22].

More recent studies on maintenance scheduling carried out by Jong [23] to addressed the problem of time for maintenance of that part which is determined by the manufacturer and the represented here in hours, where every part of the machine works for a specific period and cannot be overcome in order to prevent failure. The second problem is the availability of spare parts in stock, where the model works at the expense of the level of inventories with PM schedule. This study suggests a dynamic approach to solving maintenance scheduling problems. An algorithm for the problem is developed and tested with a numerical example.

The algorithm developed and tested in this study contributes to the existing studies with three major factors. First, although the algorithm resides under the backward allocation category in general, it provides a unique solution process in particular and is the first attempt for solving this kind of problems. Next, the algorithm can incorporate additional supply variables such as number of orders received in each period and spare modules available after overhaul, and, thus, can handle complex situations. Finally, the algorithm is flexible for dealing with variables changing over time.

This is confirmed by the study Wang and Yu [24], in this work, a scheduling problem with both fixed and non-fixed machine availability constraints due to maintenance activities is considered in the flexible job-shop manufacturing environment. Two cases of maintenance resources (i.e., unlimited maintenance resources and only one maintenance resource) are also considered. Thus, the extended flexible job-shop (FJSP) scheduling problem with maintenance activities is much closer to the scheduling problems in realistic applications and possesses much more difficult algorithm for FJSP, the modified FBS-based heuristic should also solve four major elements:

(1) Search tree representation to define a solution space.

(2) Determination of beam width and filter width.

(3) Branching scheme.

(4) Local and global evaluation functions selection [24].

And through follow up findings Sun and Li [25] they found corresponding to the other methods that rely on genetic algorithms to obtain maintenance schedule, , where two types of maintenance activities were considered. In the first model, the maintenance activities are fixed and performed periodically. They study the problems of processing a set of n jobs on two identical parallel machines subject to these two types of maintenance.

Two scheduling models are considered. In the first model, the maintenance activities are performed periodically and the objective is to schedule the jobs on two machines that minimize the span. In the second model, the maintenance activities are determined jointly with the scheduling of jobs, and the objective is to minimize the total completion time of jobs.

The objective of Moghaddam and Usher [26] was to determine a plan of actions for each component in the system while minimizing the total cost and maximizing overall system reliability over the planning horizon. Heuristic and metaheuristic algorithms designate a computational method that optimizes a problem by trying to improve a candidate solution with regard to a given measure of quality. Metaheuristics make few or no assumptions about the problem being optimized, allowing a very large space for searching for candidate solutions. However, metaheuristics do not guarantee an optimal solution is ever found. Because of complexity of the optimization models developed for preventive maintenance problem, metaheuristic algorithms and in particular genetic algorithms have been used in several research papers as a major optimization approach. It is also a study Nodem et al [27] mentioned about stochastic dynamic programming method that is used to obtain maintenance scheduling.

Zhou et al [28] was to ensure production effectiveness and therefore the preventive maintenance models must have the ability to be adaptive to changes in job shop schedule and preventive maintenance is an indispensable part of a manufacturing process and it is important to integrate production decisions into developing optimal PM policies. The proposed model is based on dynamic programming and on short-term optimization. The decision time interval of the model is consistent with the duration of the current job, which is adaptive to the changing of the job schedule.

Suliman and Jawad [29] were approaching a lot of work, of which the researcher will analyze results by the trauma gotten order to prepare and build a turbine maintenance schedule. In order to solve the proposed model for optimal values and the complexity of the problem, they used the developed computer program that has the structure, and is coded using Matlab.

All data inputs used are arbitrary while being realistic. However, a decrease in the total expected cost and an increase of optimal preventive maintenance age was noticed. The reason behind this change is due to the effect of having fewer inventories. The introduction of failure possibility increased the level of model realism which decreased the optimal preventive maintenance age.

Chapter 3

HYDROWPOWER PLANT PROPLEMS

There are more than way for identification and classification of hydropower plants. One of theam depends on the power generation and another one depends on the size and capacities [30]. In this figure can show the classification of hydropower plants .

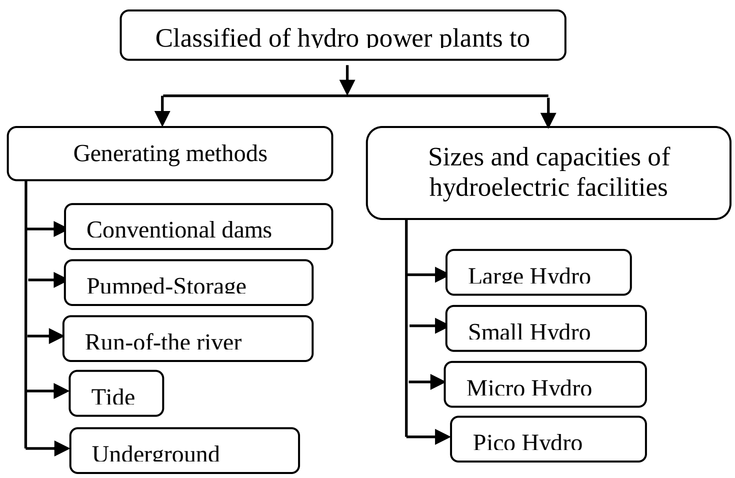


Figure 3.1. Classified of hydropower plants.

3.1 The Most Common Problems in Hydropower Plant

There are many reasons that lead to halt the work of these plants. That can be divided into two main types:

1- Problems related to design and include (construction works).

2- Problems with the dynamic properties of the plant represented (Turbine).

The first type of problems regard to construction materials, so the focus was on the second type, and the following points are most important of these faults:

1- Circumstances affecting mechanical components:

    a- Cavitations.

    b- Erosion.

    c- Vibrations.

    d- Increasing in (Noise, Temperature, hydraulic pressure pulsations, Rust).

2- Problems of lubrication.

3.2.1 Circumstances Affecting Mechanical Components

There are four main effects that reasons in the hydropower plants.

3.2.1.1 Cavitations

Cavitation is bubble in a liquid, caused usually by the pressure of the liquid falling below its vapor pressure. Cavitation is affecting the performance of the turbine, which led to decreasing efficiency. Cavitation can be divided into three sections.

These bubbles are strongly influenced by the air content of the liquid. However, their power of being an erosive is considered comparatively little. To detect and evaluate the cavitation can use the analysis of structural vibration, phonic emission and hydrodynamic pressure. Therefore, detection technology can be used observation system to now consider as an important part of modern control system.

The process of cavitation detection process is not very easy, because there are a lot of factors. That will help in the complexity of this process and can be summarized in the following points:

1. Based on the design.
2. The measured signals can be contaminated by noise coming from other excitation sources of hydrodynamic, mechanical or electromagnetic origin.

For choose the best and the most suitable location for the sensing process and operation of the sensor and detection of cavitation, it can adopt one of the following locations:

- ❖ The guide of the bearing pedestal of the turbine.
- ❖ The draft tube wall and the guide vane.
- ❖ The turbine guide bearing pedestal.
- ❖ The guide vane arm and the draft tube wall.
- ❖ The measurements of pressure in draft tube and the spiral casing walls.

3.2.1.2 Erosion

To find a specific definition of the phenomenon of erosion, must first identify the causes that led to the emergence of this phenomenon, which can be summarized the following points:

1- The machine's operating condition (flow rate, head and rotation speed).

2- The sediment content in rivers, as intensity of the erosion relies on the sediment type, its characteristics (particle size distribution, shape, and quantity).

3- The hydraulic turbine design.

4- The kinds of material the turbine are made.

5- The sand abrasion risk.

Through the above, that erosion occurs due to high focus of hard particles in river water. Erosion is brought upon by sand particles in the flow, which is considered to be one of the major problems. Especially those parts of the hydraulic turbine which are exposed to high flow velocities bear a considerable risk of being damaged by erosion processes [31]. The following procedures are considered the best methods to reduce this problem.

Coating with several layers (this process has a high hardness and is very dense and shows a very high resistance against hydro-abrasive erosion).

1. Replacement of blades made of titanium
2. Mechanical processes such as (Metalwork's, replacement parts).
3. Water treatment in the tank to reduce the deposition of water in the storage basin.

3.2.1.3 Vibrations

Hydraulic power plants are regularly subjected to the vibrations, because changes occurring in the electrical loads or in the pressure of the water. To maintain it and increase the lifespan, must keep these vibrations within normal limit. Through the periodic maintenance and conduct diagnostic tests and expect faults before they occur. Vibration is a phenomenon of rotating machines and is motion that is periodic around an equilibrium position.

If no remedial measures are taken in bringing down these vibrations, then failure of effected components occurs abruptly without any further notice. This process of failure is called fatigue failure [32]. To determine this case can follow the following methods:

1. Radial Vibration Measurement.
2. Phase/Speed Measurement**.**
3. Speed is a measurement of shaft rotation in revolutions per minute.

3.2.1.4 Increasing in (Noise, Temperature, Hydraulic Pressure Pulsations, Rust)

3.2.1.4.1 Noise

Vibrations are one of the main reasons that lead to noise generating in hydraulic turbines. To reduction of noise resulting must be change the locating of fan and undisturbed air flow. However the minimizing velocity of fluid flow and increase crosssection of fluid streams, and minimizing fluid turbulence where possible (e.g. avoid obstructions in the flow), all contribute to reducing the phenomenon of noise.

3.2.1.4.2 Temperature

The change in the temperature of the water when enters to the turbine, effect directly on the formation of bubbles or cavities.

The change in temperature of the turbine depends on two main factors:

- Change in water temperature in the tank, which increase and decrease because of the circumstances surrounding the dam of climate and night and day.
- Speed of entry or exit of water from the turbine so that the temperature increases with increasing speed, especially for the turbine outlet.

To minimize the damage below steps must be fallowed:

1. The established cast cobalt-chromium base alloy is one of a range of commercial alloys which have been devised to meet a variety of arduous service environments involving wear, of both low and elevated temperatures.
2. To ensure low temperature of the turbine to be operated at low speed between (300-400) rpm [33].
3. Increase the flow's velocity in water which is aimed at promoting the formation of a longitudinal vortex. Such vortices have the property of causing an increase of the velocity of flow, and a contraction of the diameter of the space needed by the body of water. They also cause a lowering of the water's temperature and thus an increase in its density. (The highest specific density of water is reached at a temperature of + 4°C) [33].

3.2.1.4.3 Hydraulic Pressure Pulsations

Pressure pulsations cannot be avoided in hydraulic turbines pressure pulsation but it will affect on lifespan . The intensity and amplitude of pressure depends on the: flow pattern, flow rate, pipe diameter, operating head and load fluctuations on the machine. Under these conditions, outside air is pulled and mixes with the water. This creates froth on the pressure side of the turbine.

That lessens system efficiency and creates excessive noise as the air bubbles whistle past components in the system. Aeration often occurs simultaneously with cavitation.

3.2.1.4.4 Rust

In many hydroelectric plants, compressed air is required to maintain pressure in the accumulators. This compressed air is one of the main factors that lead to a rust. All the reasons that lead to the corrosion and cavitation are the same reasons lead to the formation of rust. Can be follow the same steps maintenance to get rid of these problems to eliminate rust which is paint, the use of metallic materials, stainless steel and the use of materials.

3.2.2 Problems of Lubrication

The process of lubrication is the most important processes that apply to the hydraulic turbine. These affects direct impact on the increase or reduce the lifespan of the parts. Fluid cleanliness or lubricant cleanliness refers to the absences of contamination. Microscopic particles are the most harmful form of contamination in lubricants. They can irreversibly damage bearing surfaces, shorten life of equipment and cause early unexpected equipment failure.

Chapter 4

INTEGRATING PREVENTIVE MAINTENANCE PROGRAM

4.1 Introduction

Today, all the countries are witness to rise of cost for hydroelectric plants and electric energy; it is natural to be maintaining those high-value assets through maintenance, and operation with correct methods, for save it from rapid deterioration and increase the long term lifespan. In 1954 the Japanese scientists and engineers discovered the preventive maintenance [34]. In a preventive maintenance system, workers are based on the machines in the production of goods using machinery, while the maintenance team does the maintenance work for these machines.

Based on what came in the third chapter of many problems surrounding the work of hydroelectric plants and specifically the work of the turbine. It can adopt the principle of integrated preventive maintenance as an optimum solution to this problem. That fits all types of hydropower plants. the maintenance program is not complex but simple, and depends on a number of major and subsidiary steps to operate under a plan and schedule time for implementation to ensure increased lifespan of these plants and this program can be divided into seven major steps include [34]:

1. Inspection and Testing.
2. Lubrication.
3. Planning and Scheduling.

4. Documentation (data recording).
5. Maintenance team training.
6. Stimulation methods.
7. Control (inventories) of spare parts.

The chart below shows work mechanism of integrated preventive maintenance program. Problem is inserting to the preventive maintenance program. Through joint the action for each of the organization process and proper planning. Then feedback to spare parts working .Finally get the output of maintenance activities.

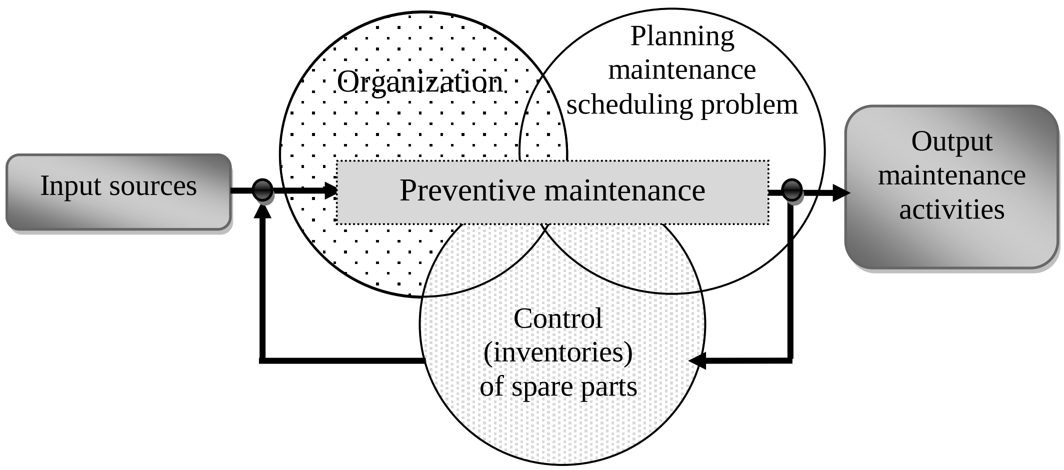


Figure 4.1. Integrated preventive maintenance operations.

There are a lot of basic features that distinguish integrated preventive maintenance for traditional maintenance:

1. Maintenance operations are maintaining the equipment and keep it in good condition constantly. And include simple maintenance tasks of cleaning, lubrication, examination, inspection tightening bolts and connecting links. The worker must know the equipment how to look on the equipment.

2. Preventive maintenance is very attentive hygiene equipment, because it helps the early detection of faults, as well as interested. Making the work environment was very clean, safe and tidy because this helps to reduce the accidents.
3. Maintaining the equipment at all times in very good condition is expensive, and allowing it to run in the presence of many of the more expensive defects. When something error happens in the equipment. The end result be a major breakdown in terms of the cost of reform and repair time

4.2 Inspection and Testing (IT)

This effectiveness regarded of the vital things for a preventive maintenance program. It can determine the operational status of the equipment. The activities of testing and inspection should be planned, controlled and managed to ensure effective communicate. The person responsible for IT must develop and documented this information. Therefore, prior to the application of maintenance program, inspection and testing must be carried out. In general, there are two types of IT in preventive maintenance:

1- External Inspection: - is to hold screening on the plants for the purpose of identifying the external symptoms. That may infect and that can be considered the first warning signals to malfunction. Which in turn reduces the efficiency of the turbine? For example vibrations and non-standard sounds those are emitted from the turbine and can be measured easily through the detectors.

2- Internal inspection: - means an examination on the internal parts of the turbine is done through the turbine downtime.

IT can be divided into two main sections as shown in the figure below and each section in turn is divided into several sections.

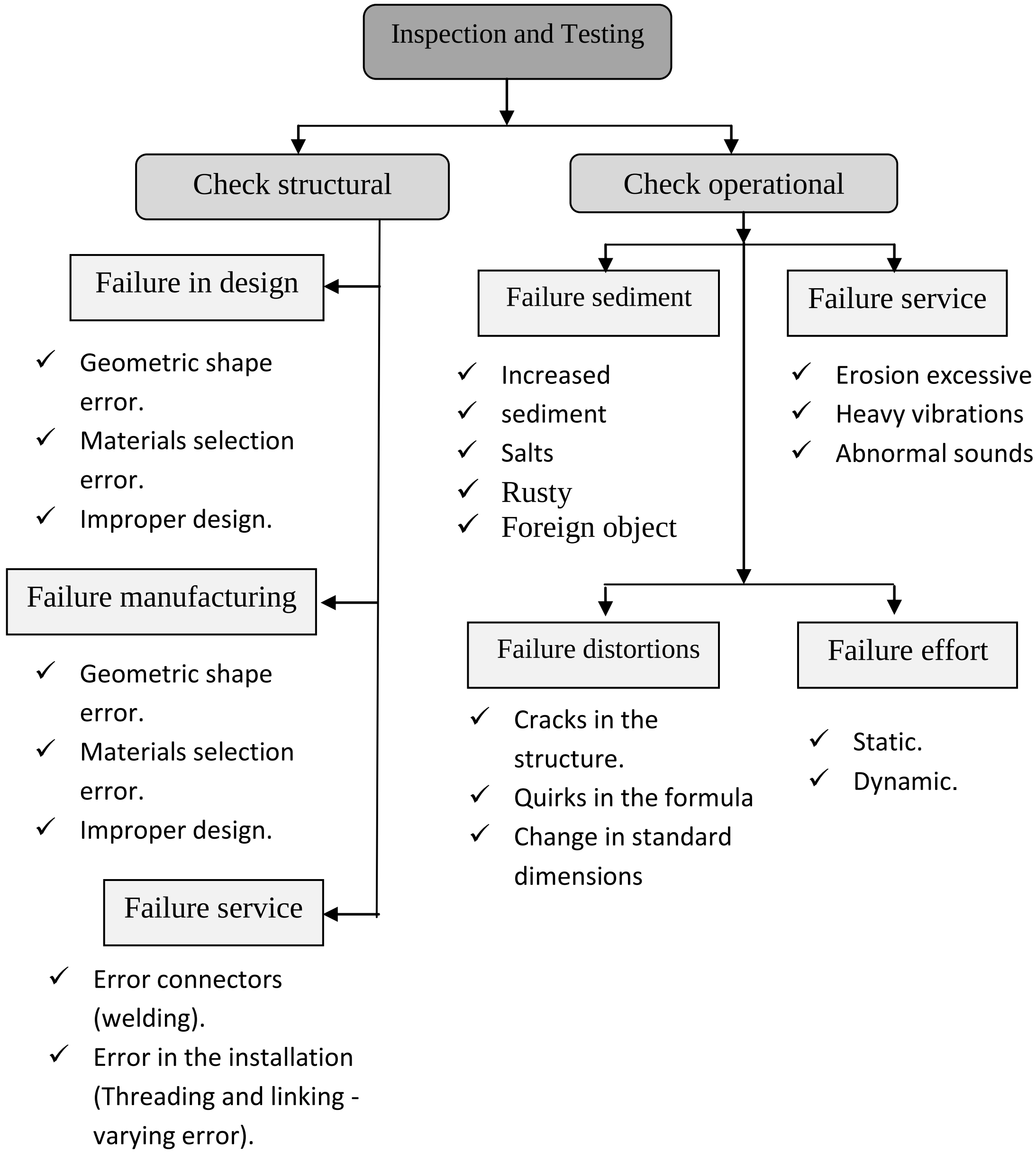


Figure 4.2. The program of inspections internal and external applied to plants.

The following example can be considered as a good example of inspection and testing .Through the control room number of signals were up from the station to the control screen as show in the table below. Through maintenance team the can select the type of failures and determine the cause. Then maintenance team provides the solution to this problem. The maintenance team will learn how to avoid such a problem in the future.

Table 4.1. Sample of signals.

N.	Type of signal that showing	type of failure	Maintenance to be performed
1	FEEDERS FAILURE (CONVERTER)	Exit feeders DC	Check (F431, F432, M.CB)
2	CURRENT DIFFERENTIAL	Functioning of the system to protect teams because of the difference between the current input and output of the system	Operation of the protection circuit current teams.
3	COOLING FAILURE	Malfunction in the cooling system frequency changer	To know the reasons for the difference and processed.
4	SYNCHRONISM FAILURE	The failure of the synchronization process	Ensure the functioning of the cooling system
5	EXTERNAL DEVICES	Defect from outside the system frequency changer	Ensure access speed and voltages to the values of the system approach
6	RECTIFIRE VOLTAGE DIFFERENTIAL	Operation to protect a voltage difference between the input and output (RECTIFIRE)	Checking assistive devices and Note signals (GCB)
7	INVERTER VOLTAGE DIFFERENTIAL	Operation to protect a voltage difference between the input and output (INVERTER)	Screening system
8	START UP MAX. TIME	Higher than the time period scheduled	Screening system
9	RECTIFIRE MAX. CURRENT	Stream higher RECTIFIRE of scheduled	Screening system
10	INVERTER MAX. CURRENT	Stream INVERTER higher than planned	Screening system
11	INVERTER MAX. VOLTAGE	Higher voltages on both sides of the (INVERTER)	Screening system
12	MAX. SPEED	Speed access to top decision	Check circle (INVERTER)
13	N01.THYRISTOR FAILED ALARM	Exit one Althaersturat work	Screening system
14	N02. THYRISTOR FAILED TRIP	Out two or more Althaersturat work	Department examination Althaersturat

- This information was collected from pumped storage station in Mosul Dam-Iraq on 25/06/2012.

After faults were identified using the IT method. Many maps built by these two levels namely:-

1- Carte of information built to identify the problems: Contain the knowledge of identifying more problems in anticipation of the equipment under the research and analyzing the complaints and observations are specific to the equipment.

Be placed symbols of faults and observations that led to the discovery of these faults in the columns.

2- Carte information to identify the causes and treatment: Gives the knowledge required to find possible causes and treatment for each problem.

Table 4.2. Cared diagnose faults, depending on Inspection and Testing.

Turbine parts	Inspection and Testing		Proposed Maintenance (Treatment)	The potential causes						
				A					B	C
	Subsections	Expected Problems		1	2	3	4	n		
A- RUNNE	1- Compressed Air System.			●		●				
	2- SHAFT SEAL				●					
	3- The Main Lubricating System.						●			
	4- Stay Gate.				●		●			
	5- Moving gates.			●						
	6- Distributing Ring.					●				
	7- Servo Motors.					●	●			
	8- Speed Regulator.			●						
	9- Mechanic's position.				●	●		●		
	10- Bearing Turbine Guide.			●			●			
	11- Generator Lower Guide Bearing.				●		●			
	12- Generator Upper Guide Bearing.			●						
	13- Thrust Bering.				●					
B- Compressed air system for pressing water	Hardware of this unit									

After all that has been mentioned faults can be classified by showing us to use external and internal inspections to nine types, as shown in figure (4.3):

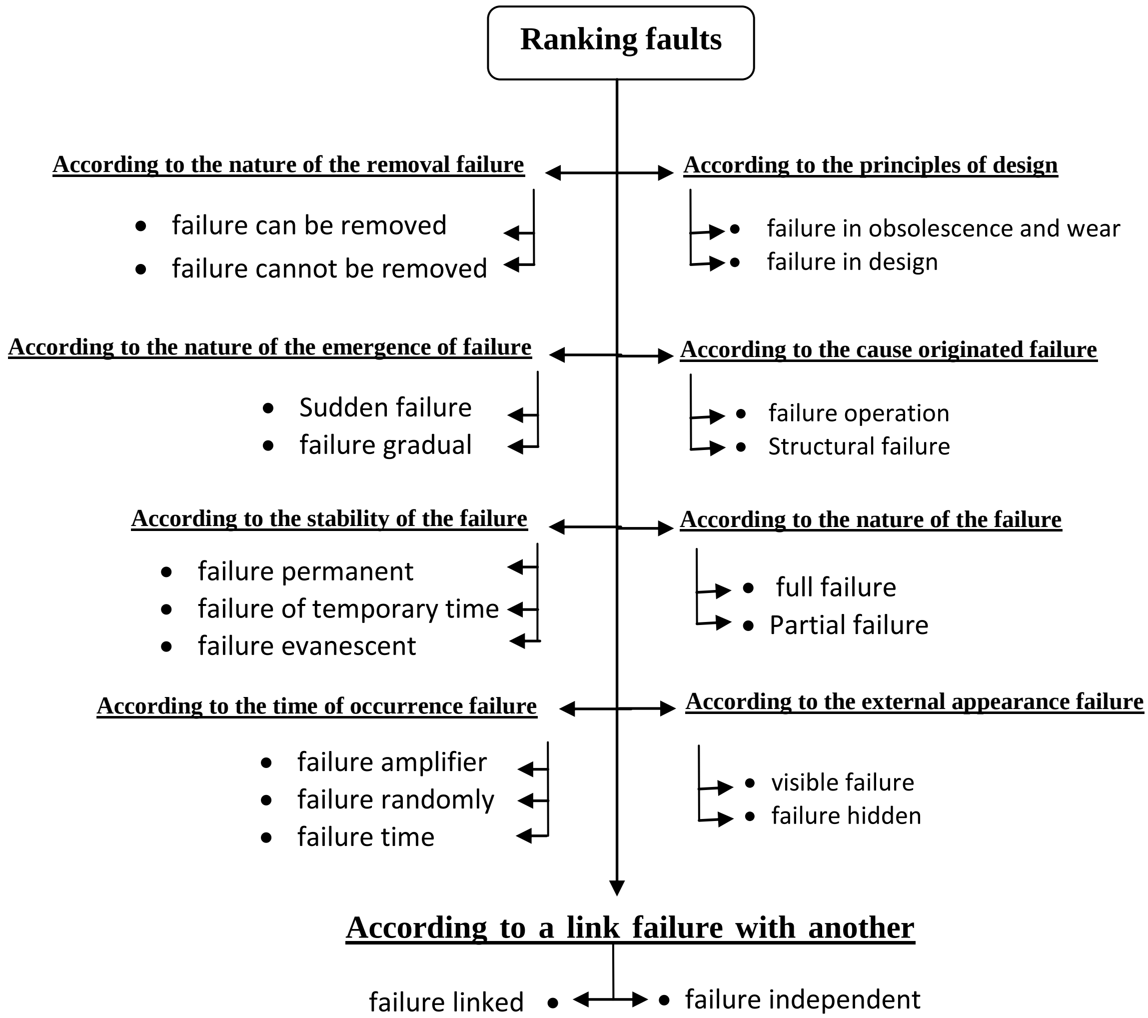


Figure 4. 3. Category indicators basic faults that appear using Inspection and Testing.

4.3 lubrication

The moving parts such as bearings, gears, and other bush animated parts. Need periodic lubrication to work well for so long. Must be using the correct type of oil with pest time and right amount. To accomplish these activities must prepare schedules. Which consist often accompanied with technical documentation by the manufacturer of the equipment and must adhere strictly to these documents, and timing. The lubrication programs can be applied within specific times (Daily, Quarterly, Weekly, Fortnightly, Monthly, Semi Annually, Annual and biennial).

4.4 Planning and Scheduling

Is to prepare detailed tables to plan preventive maintenance, based on the analysis of previous data must also be configured program scheduling. Because this program specifies in detail things and points that require attention daily, weekly, monthly, semi-annually or annually. For the purpose of achieving an effective plan for preventive maintenance must provide some basic requirements necessary to do so. These requirements are based on the effectiveness and efficiency of operating systems and the information available at the station.

There are three major partnerships that should be component in the planning and scheduling :

- ❖ Decrease maintenance cost.
- ❖ Boost benefit of the maintenance manpower by reducing delays and severance.
- ❖ Amelioration of maintenance works by credence the best methods and measures and commissioning the most qualified workers for the job.

It is other important issues in the maintenance schedule is the time period expected to hold maintenance by in order to prepare to stop the station from work and give orders to their employees non-essential not to come to work, and preparing a working group maintenance and give some training courses for them to revive their memories review steps and prepare equipment required.

Table 4.3.Example of Integrated Preventive Maintenance Scheme For the period of (/ /) until (/ /).

No. effective	**Name. effective**	**Executing Agency**	**Weight effective %**	**Duration of action (day)**	**Working Level**			**The actual percentage of completion %**	**Rate performance**	**Diffraction**	**Reasons of diffraction**	**Cost**				
					Engineer	Technician	Worker					spare materials	Consumables	Transport and Rental	Manufacturing / repair	Other
1	Stop the unit & make safe precautions															
2	Empting the unit & opening inspection door															
3	checking shaft seal& replace if necessary															
4	Checking runner															
5	visual inspection of draft tube &Repair any damage															
6	Checking the clearance between stationary parts and rotary parts & shaft seal clearance															
7	Checking upper & lower seals															
8	Filling the unit															
9	Oil filtration for governor															
10	Cleaning filters and tank with checking and greasing the system for governor															
11	checking non returning, reducing, loading & unloading valves for governor															
12	checking hydraulic, manual & air valves for governor															
13	Checking efficiency of pumps for governor															
14	Checking hydraulic piston for any leakage for governor															

4.5 Documentation (Data Recording)

Data retention is very important thing for document maintenance. Because it helps the maintenance teams to preparation the potential predictions maintenance. To have an integrated information system

1. The file system and coding such as classification and other equipment.
2. The main organization for individuals such as cards and levels of service and other supervision.
3. Planning and includes monthly forecasts and other equipment.

Through scheme below, can be identify the most important data that is stored

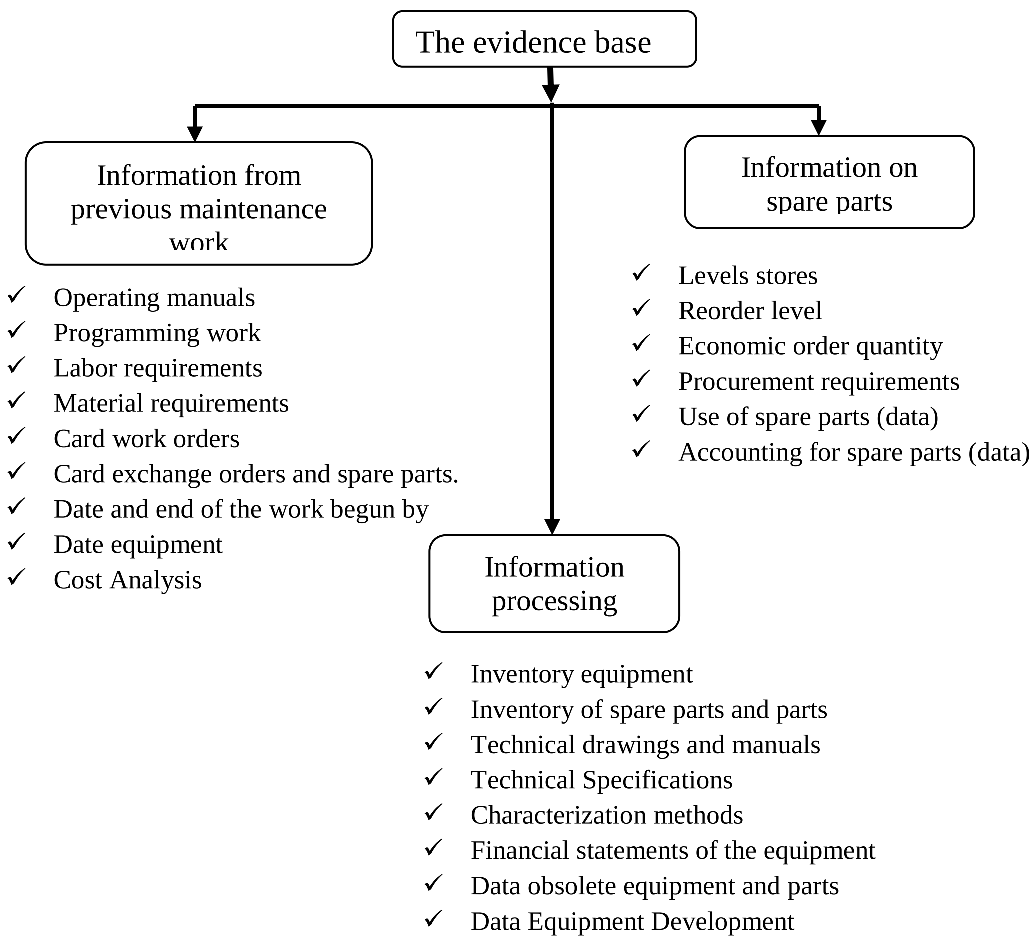


Figure 4.4. Information that can be included in the database.

There are a range of stages through which record data goes through (documentation process).

- ❖ Identify sections and units dealing with administrative information system.
- ❖ Determine the quality of the information.
- ❖ Select a worker to be undertaken this task and expertise.
- ❖ Identify the possibilities for and limitations of current systems
- ❖ Prepare a preliminary report includes reasons of design and development.

4.6 Maintenance Team Training

Training is one of the important and necessary things. For the purpose of preparing technical staff with a good level and accurate in their work .To follow this team and develop continuously through training methods.

There are some qualities that must be provided in the person who will work in the maintenance team:

- Good communication skills.
- High degree of skill oversight and auditing.
- The ability to Reception observations from people who are experts in their fields.
- Good physical structure.

With these attributes combined, a successful maintenance team can develop a special maintenance program.

4.7 Stimulation Methods

A system of incentives must be developed particularly for workers in the maintenance department .Include incentives to reward and increase in wages, and as well as moral incentives. There total of tactics behind this quest:

- Achievement a larger amount of work, but with the same number of workers.
- Achievement the same work, but with fewer workers.
- Achievement the same work, more quickly, although too much work.

4.8 Control (Inventories) of Spare Parts

Spare parts of materials kept for the purposes of maintenance .The replacing the affected parts must know the upper and lower limits for the levels of inventories of these materials .The chart below shows the proposed program for the storage process by linking it with the maintenance process.

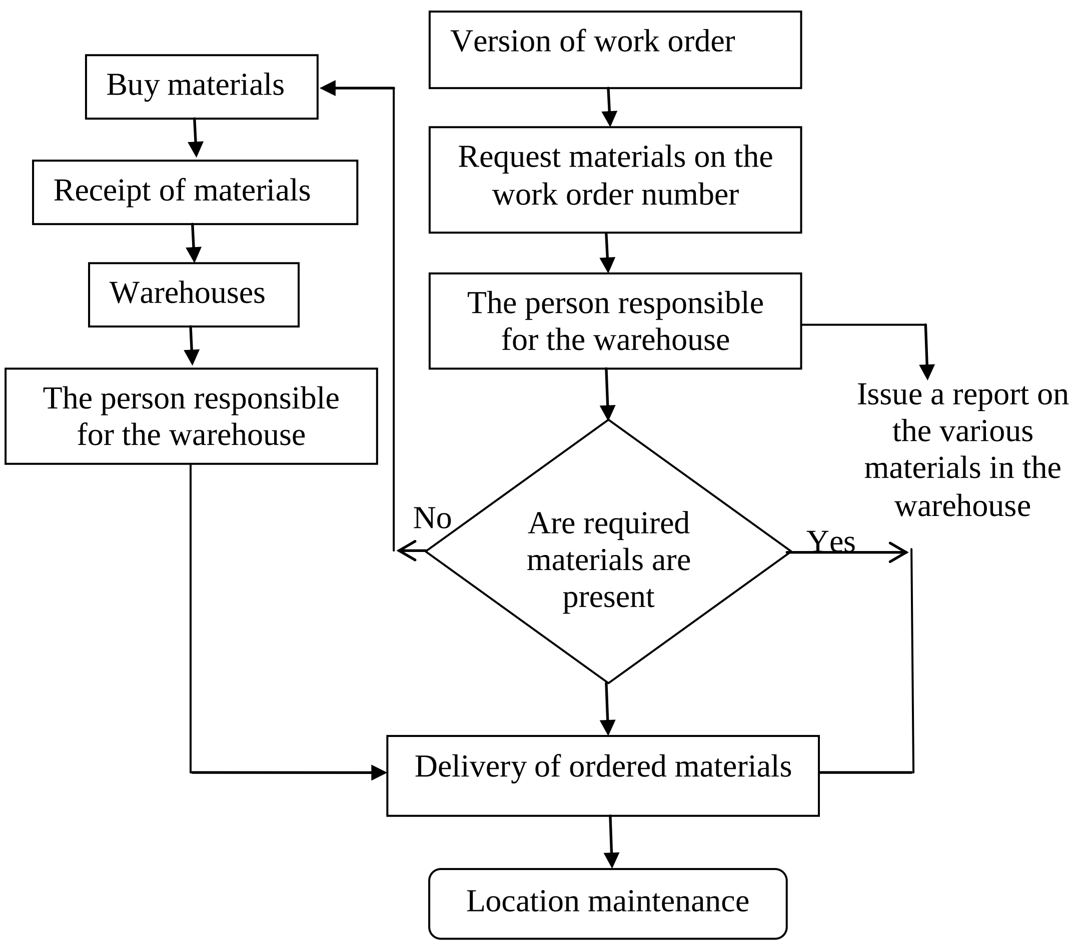


Figure 4.5. Control the movement of spare parts.

Chapter 5

EVALUATION OF MAINTENANCE PROGRAM

5.1 Performance Standards and Control

The purpose of application of the integrated preventative maintenance system is to find the best preset time within specific standards for maintenance there are many proposed standards. The manager of maintenance must know all the details of maintenance such as:

1- Report from maintenance team about all spent maintenance cost, these cost must be within planning cost as shown in figure 3.

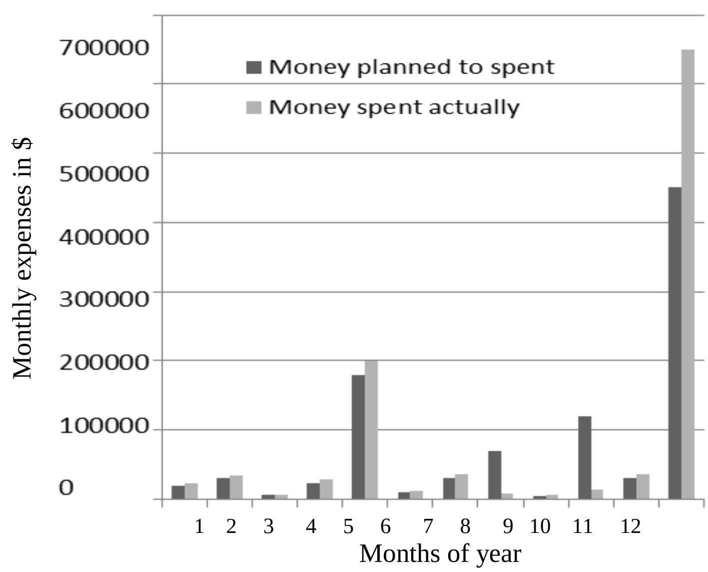


Figure 5.1. Average monthly costs.

The planning cost must be compare with the general budget, to control spend of the maintenance work.

2- Scheduling performance and effectiveness of the maintenance work: effectiveness of the maintenance work. This induces to which working to find the best design time for maintenance. The table 1 of scheduling and effectiveness has limitation (high and low) level if the program for maintenance is true or false. For example if the percentage is more than 60% the program is successful, if it is between 50% and 60% or less than the performance of the program is false and need to be develop. If it is false it may be because (delay at work, missing of spare parts, poor planning, etc.).While the percentage can be considered between 80% and 85% is considered as typical for the scheduling performance. When the percentage to be 100% as shown in figure 4, then incentives should be given to the maintenance team.

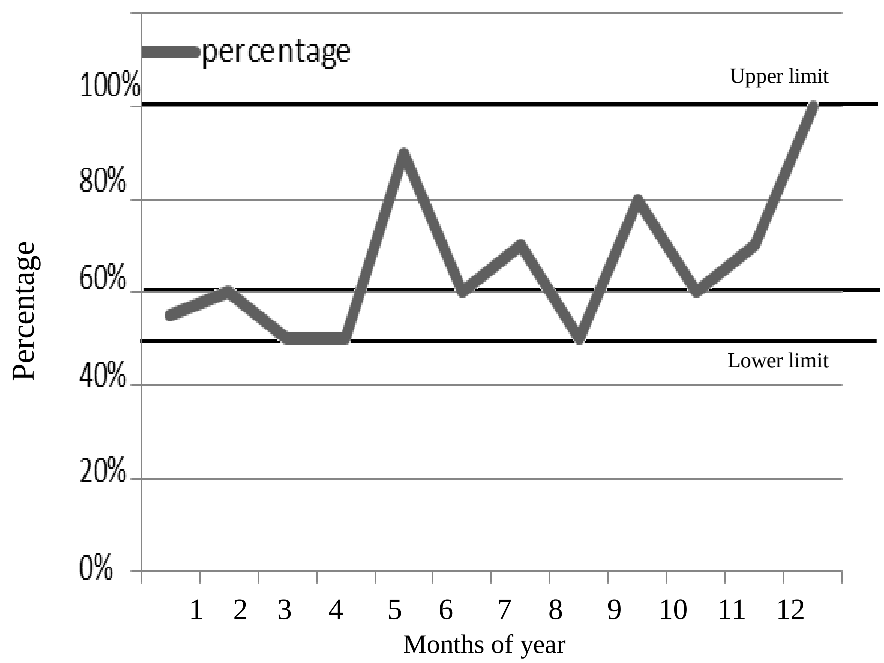


Figure 5.2. Scheduling performance.

Table 5.1.Scheduling and effectiveness table.

Month	Limitation				
	Low percentage			High Percentage	
	>50	50-60	< 60	80-85	< 85
Jan.	-	56	-	-	-
Feb.	-	60	-	-	-
Mar.	-	50	-	-	-
Apr.	-	50	-	-	-
May.	-	-	-	-	96
June.	-	60	-	-	-
July.	-	-	70	-	-
Aug.	-	50	-	-	-
Sept.	-	-	-	80	-
Oct.	-	60	-	-	-
Nov.	-	-	70	-	-
Dec.	-	-	-	-	100

3- Working table: is representing the limitation time table including extra time or lost time for maintenance work in one day and compares with the actual time planning for maintenance.

Table 5.2. Working table.

Month	Date of change	Part Name	Time of exchange			
			Planning Time (Hour)	Working Start Time (Hour)	Working End Time (Hour)	Extra Time (Hour)
Jan.	2	Guide Bearing	1:00	10:00 AM	11:15 AM	0:15
	6	Wicket Gate Arm	0:30	5:00 PM	5:45 PM	0:15
	8	Wicket Gate link	0:30	8:00 AM	8:30 AM	------
	8	Servo Motor connecting Rod	0:30	6:30 AM	7:10 AM	0:10
	10	Facing plates	0:15	5:00 AM	5:25 AM	0:10
	10	spiral case	0:15	12:00 PM	12:15 PM	-----
	10	Guide Bearing	0:30	3:30 PM	4:15 PM	0:15
	22	Wicket Gate Arm	0:15	8:00 AM	8:15 AM	-----
	22	Wicket Gate link	0:15	2:00 PM	2:30 PM	0:15
	24	Servo Motor connecting Rod	0:30	7:00 AM	7:30 AM	-----
	24	Facing plates	0:30	3:30 Am	4:00 AM	-----
	24	spiral case	1:00	3:30 AM	4:30 AM	-----
Total Time for this month			6 :00			0:45

This is considered standard as a type of maintenance measure unit. Also one can use the working table as a reference to compare the limit time for event if this event can be happen again. As shown in figure (5.3).

When designing the maintenance program and distribution of these tables, through which can be access to a range of information can be used to record information directly after the completion of the work.

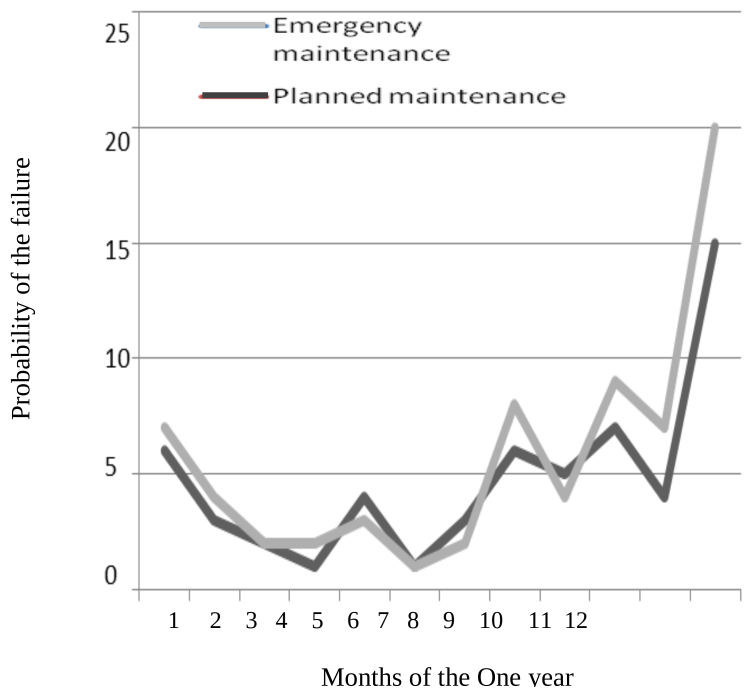


Figure 5.3. Time wasted in repairs or stop the machine.

4- Know the times the standard work orders for maintenance, what is known decide the extent of the improvement program and reduce costs. The more maintenance hours increased costs with especially wage workers there are likely accomplish the same work, but a few hours less and this all depends on the table prepared for maintenance if bypassed hours are planned That leads to failure of the program so he needs to continuous assessment by the supervisor of maintenance.

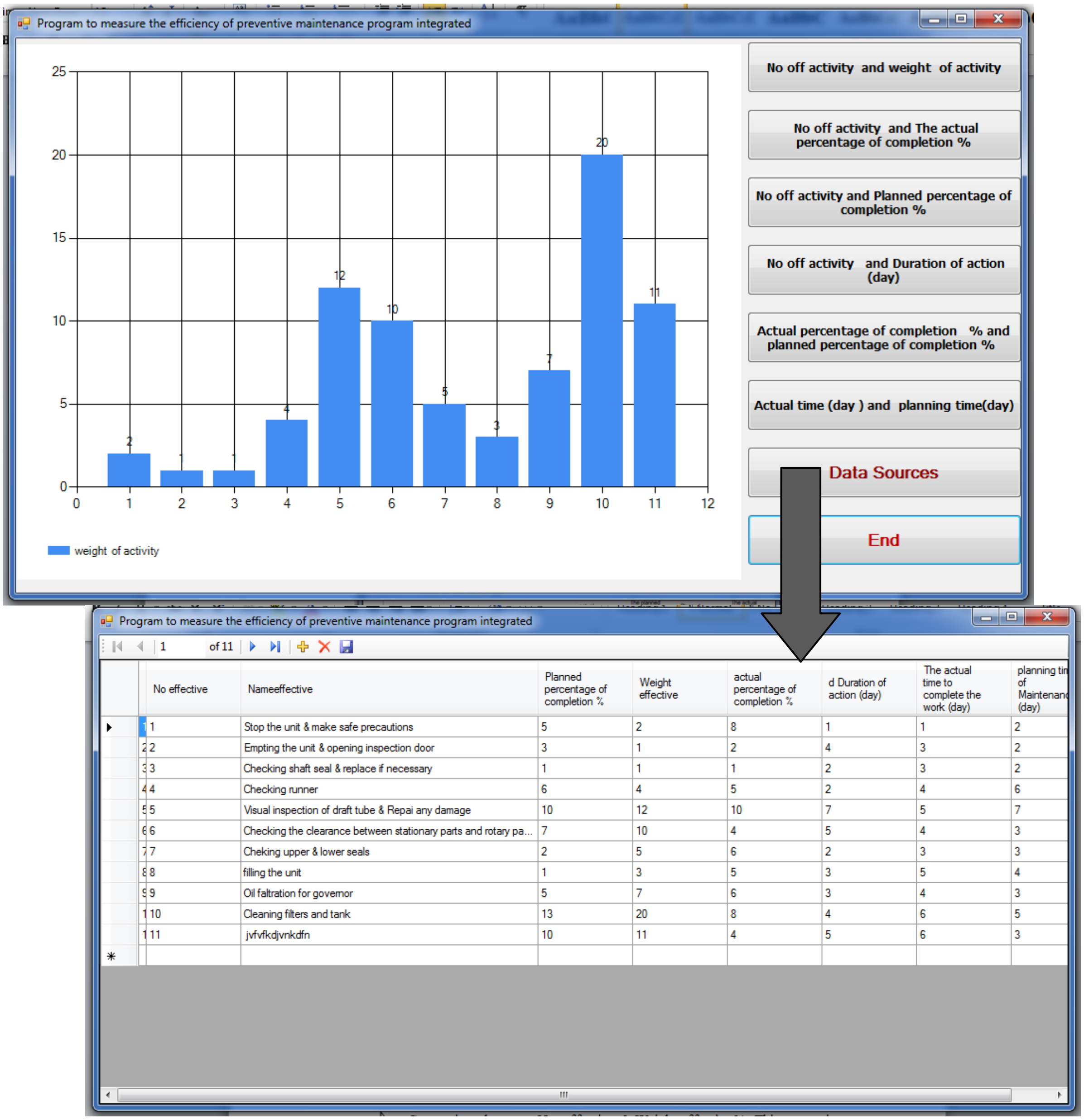
5.2 The New Evaluation Program

In this thesis, the proposed technique is designed to give evaluation with high accuracy result, this result based on four parameter compression between (number of activity and weight of activity percentage), (number of activity and the actual percentage of completion), (weight of activity percentage and actual percentage of completion) and (number of activity and duration of action) all these parameters are shown in figure 5, and 6. The procedure of program based on (Microsoft Office Access 2007 & Visual Basic 2008).

❖ The main interface of the program: After installation of program it is easy to start with the main screen as it shown in figure 5.4. Start icon can be used the program.

Figure 5.4. Main interface of technique program.

Operational interface: From the next screen (Data sources icon) can start to enter your data in simple table and save it such as shown in the figure 5.5.



No effective	Nameeffective	Planned percentage of completion %	Weight effective	actual percentage of completion %	d Duration of action (day)	The actual time to complete the work (day)	planning ti of Maintenan (day)
1	Stop the unit & make safe precautions	5	2	8	1	1	2
2	Empting the unit & opening inspection door	3	1	2	4	3	2
3	Checking shaft seal & replace if necessary	1	1	1	2	3	2
4	Checking runner	6	4	5	2	4	6
5	Visual inspection of draft tube & Repai any damage	10	12	10	7	5	7
6	Checking the clearance between stationary parts and rotary pa...	7	10	4	5	4	3
7	Cheking upper & lower seals	2	5	6	2	3	3
8	filling the unit	1	3	5	3	5	4
9	Oil faltration for governor	5	7	6	3	4	3
10	Cleaning filters and tank	13	20	8	4	6	5
11	jvfvfkdjvnkdfn	10	11	4	5	6	3

Figure 5.5. Data source window for technique program.

The feature of this program:

- Easy to use
- The ability to use for all hydraulic power plant maintenance.
- Large capacity to save database.
- Prevent the personal mistakes.
- Ability to show related windows in same main page.

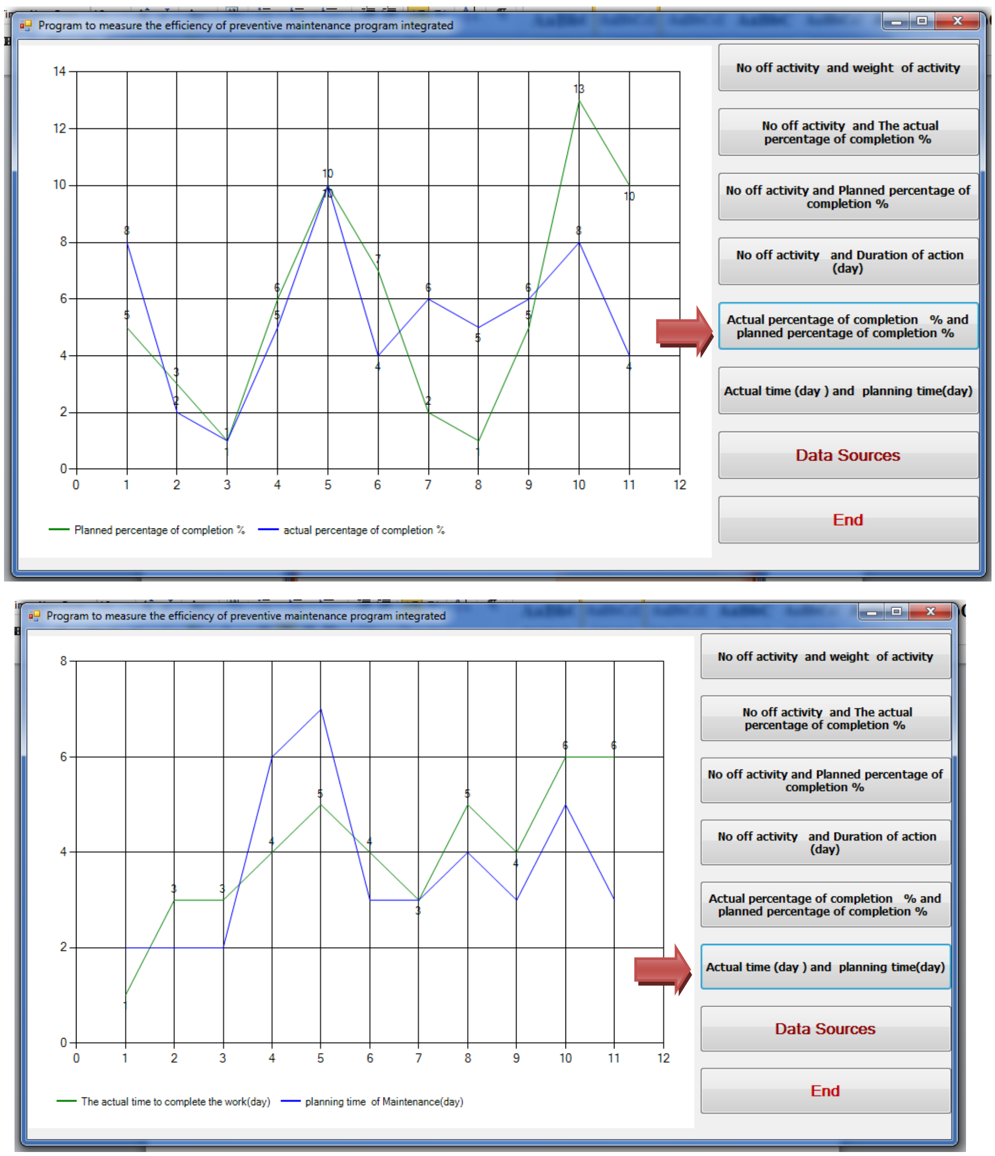


Figure 5.6.Charts window for technique program.

The advantages from the proposed program appear in the final diagram. This diagram represent the comparison between (planned percentage % & the actual percentage of completion %). From this comparison can know the different between the planned percentage and actual planning, for stand on the errors and limitation the causes that led to found the gap between them. From all above can say the proposed program very helpful to evaluate the preventive maintenance and this is confirmed by our study.

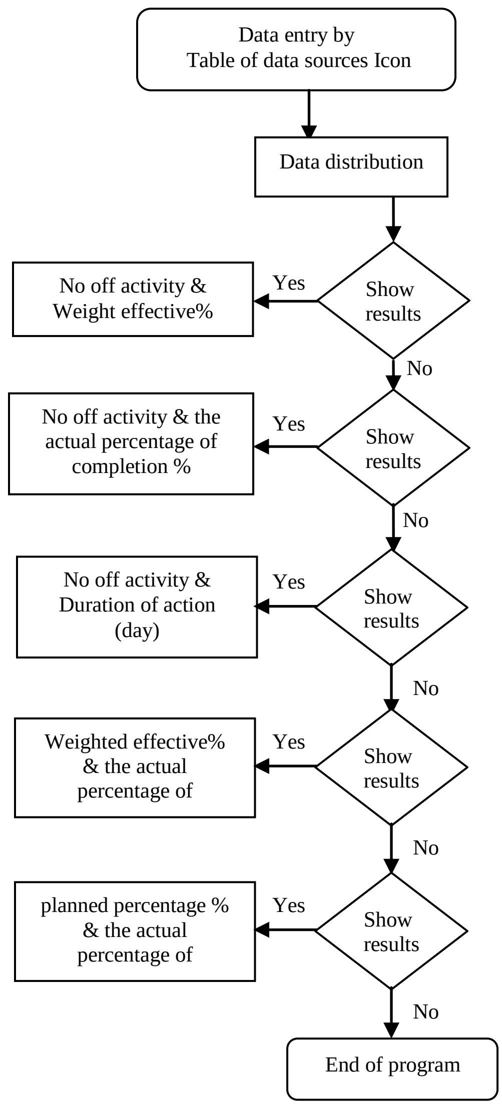


Figure 5.7. Flow chart for the technique program.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From all above can concluted that the integrated system of preventive maintenance is the best kind of maintenance that can be applied on hydropower plant. That's because of the following reasons:

1- Provides integrated system of preventive maintenance time for the completion of maintenance work within the pre-set specific plan based on clear minimize trauma of the likelihood of failure and improve the parts that undergoing maintenance.

2- To adopt a policy of singles replacement, that mean only 20% of the fault is important, the rate 80% is not important of the failure.

3- Advance planning is the main feature of this type of maintenance, help us avoid a lot of mistakes that could occur during a maintenance (ie, in a time when the station outside of work) and thus underestimate the stops and be confined lowest possible period.

4- By calculating total costs (planned them and actual) and then a comparison among them . Find that using the principle of preventive maintenance integrated can be reduce the cost of the actual work better than what was planned,   before the time allotted for maintenance and thereby giving an appropriate time to get cheaper prices and lower maintenance costs than it in the rest of the species.

6.2 Recommendations

1- Integrated prevantive maintenance program must be use in all the project of hdropower plant, because of the profit from it. And can be used the report from it as a giude to make the planing of maintenance.
2- The proposed cycle of integrated prevantive maintenance have a feature that can be used for all the opration machine maintenance system.
3- For the futre work can be to devlop the teqnic program for the evalution of prevative maintenance to cover mor criteria.
4- Apply the propsed schadule of spare part as a referance to use for all location work.

REFERENCES

[1] DEAC, V., CÂRSTEA, G., BÂGU, C & PÂRVU, F. (2010).The Modern Approach to Industrial Maintenance Management. *Journal of Informatica Economică .14*, 133-144.

[2] Mobley, R.K. (2002). *An Introduction to Predictive Maintenance*. United States of America: Elsevier Science.

[3] McKone, K.E., Schroeder, R.G & Cua, K.O. (2001). The impact of total productive maintenance practices on manufacturing performance. *Journal of Operations Management .19*, 39-58.

[4] Alkhamis,T.M & Yellen , J.(1995). Refinery unit's maintenance scheduling using integer programming.*Journal of butter worth heinemann,19*,544-549.

[5] Chaichan Chareonsuk ,C., Nagen Nagarur.N &Tabucanon,M.T.(1997). A multicriteria approach to the selection of preventive maintenance intervals.*Journal of Production Economics,49*,55-64.

[6] Gertsbakh & Kordonsky , Kh .B.(1997).Choice of the best time scale for preventive maintenance in heterogeneous environments. *Journal of Operational Research, 98,* 64-74.

[7] Percya, D.F., Kobbacy, K. A.H & Fawzib, B.B. (1997). Setting preventive maintenance schedules when data are sparse. *Journal of Production Economics*, *51*, 223-234.

[8] Sanmartf, E., Espufia, A & Puigjaner,L.(1997). Batch production and preventive maintenance scheduling under equipment failure uncertainty. *Journal of Computers chem. Engng , 21*,1157-1168.

[9] Duffuaa, S .O & Al-Sultan, K. S. (1999).A stochastic programming model for scheduling maintenance personnel. *Journal of Applied Mathematical Modeling, 25,* 358-397.

[10] Deris,S., Omatu, S., Ohta , H., Kutar , Lt. Cdr.S & Samat, P. A.(1999). Theory and Methodology Ship Maintenance Scheduling by Genetic Algorithm and Constraint Based Reasoning. Journal *of Operational Research, 112*, 489-502.

[11] Wang, Y & Handschin, E.(2000). A new Genetic Algorithm for Preventive unit Maintenance Scheduling of Power Systems. *Journal of Electrical Power and Energy Systems*, *22*, 343–348.

[12] Gopalakrishnana, M., Mohana, S & Heb, Z. (2001). A Tabu search Heuristic for Preventive Maintenance Scheduling. *Journal of Computers & Industrial Engineering*, *40*, 149-160.

[13] Dohi, T., Okamura, H & Osaki, S. (2001). Optimal Control of Preventive Maintenance Schedule and safety Stocks in an Unreliable Manufacturing Environment. Journal *of Production Economics, 74*, 147-155.

[14] Haghani, A & Shafahi, Y. (2002). Bus maintenance systems and maintenance scheduling: model formulations and solutions. *Journal of Transportation Research Part A, 36*, 453–482.

[15] El-Sharkh, M.Y & El-Keib, A.A. (2003). An Evolutionary Programming based Solution Methodology for Power Generation and Transmission Maintenance Scheduling. *Journal of Electric Power Systems Research, 65*, 35-40.

[16] Mohanta, D.K., Sadhu, P.K & Chakrabarti, R.(2004). Fuzzy Reliability Evaluation of Captive Power Plant Maintenance Scheduling Incorporating Uncertain Forced Outage Rate and Load Representation. *Journal of Electric Power Systems Research*, *72*, 73–84.

[17] Sortrakul, N., Nachtmann, H.L & Cassady, C.R. (2005). Genetic Algorithms for integrated preventive Maintenance planning and Production Scheduling for a single machine. *Journal of Computers in Industry, 56, 161*–168.

[18] Limbourg, Ph & Kochs, H. (2006). Preventive Maintenance Scheduling by variable dimension evolutionary algorithms. *International Journal of Pressure Vessels and Piping, 83*, 262–269.

[19] GuoaY., Limb, A. ,Rodriguesc, B& Yud ,S.(2007). Machine Scheduling performance with maintenance and failure. *Journal of Mathematical and Computer Modelling, 45,* 1067–1080.

[20] Radhakrishnan, V.R., Ramasamy, M., Zabiri, H., Do Thanh, V., Tahir, N.M., Mukhtar, H., Hamdi, M.R & Ramli, N. (2007). heat exchanger fouling model and Preventive Maintenance Scheduling tool. *Journal of Applied Thermal Engineering*, *27*, 2791–2802.

[21] Lamptey, G., Labi, A.S & Li, Z. (2008). Decision support for optimal scheduling of highway pavement preventive Maintenance within resurfacing cycle. *Journal of Decision Support Systems, 46*, 376–387.

[22] Zhou, X., Xi, L & Lee, J. (2009). Opportunistic preventive maintenance scheduling for a multi-unit series system based on dynamic programming. *Journal of Production Economics, 118*, 361–366.

[23] Joo, J.S. (2009). Scheduling Preventive Maintenance for Modular designed components: A dynamic approach. *European Journal of Operational Research, 192*, 512–520.

[24] Wanga, S & Yu, J. (2010). An Effective Heuristic for flexible job-shop Scheduling problem with Maintenance Activities. Journal *of Computers & Industrial Engineering, 59*, 436–447.

[25] Sun, K & Li, H. (2010). Scheduling problems with multiple maintenance activities and non-preemptive jobs on two identical parallel machines. *Journal of ProductionEconomics, 124*, 151–158.

[26] Moghaddam, K.S & Usher, J.S. (2011). Sensitivity analysis and comparison of algorithms in preventive maintenance and replacement scheduling optimization models. *Journal of Computers & Industrial Engineering, 61*, 64–75.

[27] Dehayem Nodema, F.I. ., Kenne´, J.P & Gharbi, A. (2011). Simultaneous control of production, repair/replacement and preventive maintenance of deteriorating manufacturing systems. *Journal of Production Economics, 134*, 271–282.

[28] Zhou, X., Lu, Z & Xi, L. (2012). Preventive maintenance optimization for a multi-component system under changing jobs hop schedule. *Journal of Reliability Engineering and System Safety, 101*, 4–20.

[29] Suliman , S. M.A & Jawad , S.H.(2012). Optimization of preventive maintenance schedule and production lot size. *Journal of Production Economics*,*137*,19–28.

[30] http://en.wikipedia.org/wiki/Hydroelectricity .

[31] Mack, R., Drtina , P.(1999). Numerical prediction of erosion on guide vanes and in labyrinth seals in hydraulic turbines, *International journal of Wear ,233* 685-691.

[32] Gebraeel, N., Lawley, M., Liu, R. & Parmeshwaran, V. (2004). Residual Life Predictions from vibration-based degradation signals: a neural network approach. *Journal of IEEE Transactions on industrial Electronics*, *51*, 694-700.

[33] http://www.hydroworld.com/articles/print/volume-18/issue-1/Articles/pumped-storage/designing pump-turbines-for-tongbai-in-china.html.

[34] Cassad, C.R & Kutanoglu , E.(2005). Integrating Preventive Maintenance Planning and Production Scheduling for a Single Machine. *Journal of IEEE TRANSACTIONS ON RELIABILITY*, *54*,120-124.