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An Efficient Harmony Search Optimization for Maintenance Planning to the Telecommunication Systems

Fouzi Harrou and Abdelkader Zeblah
[1]*University of Bourgogne, Institute of Automotive and Transport Engineering (ISAT), 49rue Mademoiselle Bourgeois, 58000 Nevers,*
[2]*University Of Sidi Bel Abbes, Engineering Faculty,*
[1]*France*
[2]*Algeria*

1. Introduction

A necessary precondition for high production is availability of the technical equipment. In addition, reliability engineers have to build a reliable and efficient production system. The system reliability affects essentially the reliability of its equipments. This characteristic is a function of equipment age on system's operation life. In this work, we consider series-parallel systems. To keep the desired levels of availability, strongly performs a preventive maintenance actions to components are best than breakdown maintenance. This suggestion is supported by a number of case studies demonstrating the benefits of PM in (Gude et al, 1993). In this case, the task is to specify how PM activity should be scheduled. One of the commonly used PM policies is called periodic PM, which specifies that systems are maintained at integer multiple of some fixed period. Another PM is called sequential PM, in which the system is maintained at a sequence of interval that have unequal lengths. The first kind of PM is more convenient to schedule. Contrary the second is more realistic when the system require more frequent maintenance at it age. A common assumption used in both these PM is that minimal repair is conducted on system if it fails between successive PM activities. In other words, minimal repairs do not change the hazard function or the effective age of the system.
Traditionally PM models assume that the system after PM is either as good as new state in this case is called perfect PM or simply replacement, as bad as old state the same as minimal repair, where he only restores the function of the system, this concept is well understood in the literature (Brown et al, 1983). The more realistic assumption is that the system after PM not return at zero age and remains between as good as new and as bed as old. This kind of PM is called imperfect PM. The case when equipment fails (damage), a corrective maintenance (CM) is performed which returns equipment to operating condition, in fact specially, the task of preventive maintenance actions served to adjust the virtual age of equipment. Our particular interest is under investigation to present an harmony search algorithm which determines the optimal intervals of PM actions to minimize maintenance-cost rate or maximize mission reliability.

1.1 Summuray of previous work

Several years ago, much work was reported on policy optimization of preliminary planned PM actions with minimal repair as in (Zhao, 2003), (Borgonovo et al, 2000). Most of these researches are based on two popular approaches to determine the optimal intervals for a PM sequence. The first is reliability-based method and the second is optimization method.
In the first one the PM is performed whenever the system availability or the hazard function of the system reaches a predetermined level and the optimal PM intervals will be selected. The second is finding the optimal intervals as a decision variable in the optimization problem. (Lin et al 2000) presents an algorithm to determine the optimal intervals based on the reliability-based method and in there models the effective age reduction and hazard function are combined. (Levitin et al, 2000) present a genetic algorithm which determine a minimal cost plan of the selecting PM actions which provides the required levels of power system reliability. A list of possible PM actions available for each MSS, are used. Each PM action is associated with cost and reduction age coefficient of its implementation.

1.2 Approach and outlines

The proposed approach is based on the optimization method using harmony search algorithm, which determines the intervals sequence of PM actions to minimize the maintenance-cost subject to availability or (reliability) constraints. The goal of the proposed approach is to know when, where, to which component and what kind of available PM actions among the set of available PM actions should be implemented. To evaluate the reliability and the effect of PM actions of series-parallel MSS, UGF method is applied. It's proved to be effective at solving problem of MSS redundancy and maintenance in (Monga et al, 1997), (Levitin et al, 1999) and (Ushakov et al, 2002).

2. Preventive maintenance

It has been shown that the incorporation of the preventive maintenance has a benefit and success. Also it was observed that the impact of the decrease of component failure rate and improvement of component reliability is vital to maintain efficiency of production. The

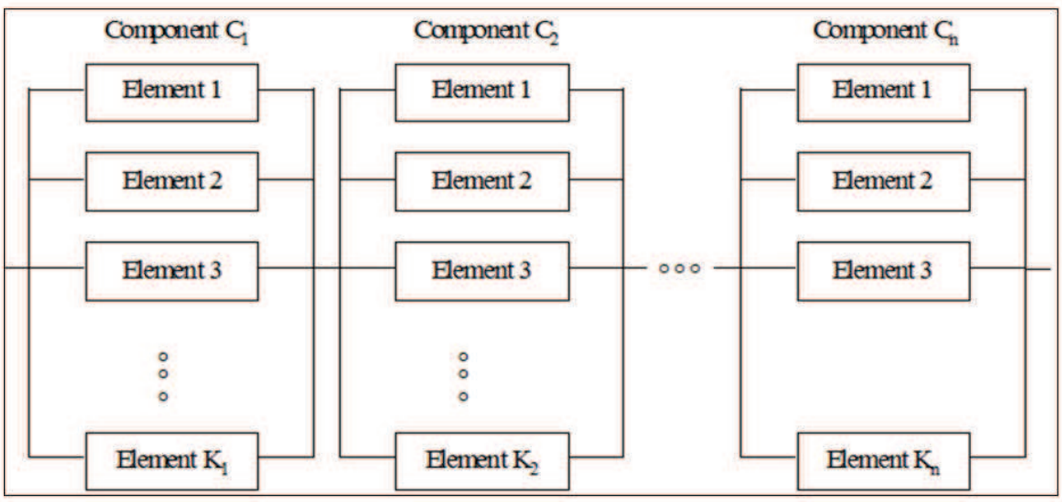


Fig. 1. Series-parallel Power System

major subject of maintenance is focused on the planning maintenance service of the power system. Such as cleaning, adjustment and inspection performed on operation's lifetime are classed as a preventive maintenance policy. However, all actions of PM not capable to reduce age component to zero age is imperfect. There are two main alternatives for modeling an imperfect PM activity. The first one assumes that PM is equivalent to minimal repair with probability p and $1-p$ is the equivalent to replacement in (Nakagawa, 1999). The second model where the imperfect PM directly analyzes how the hazard function or the effective age change after PM as in (Lin et al, 2000). The proposed model is based on reduction age concept. Let consider the series-parallel MSS system shown in figures 1.
If the component j undergoes on PM actions calendar at chronological times as follows:

$$(t_{j1},\ ...,\ t_{jn}) \tag{1}$$

Based on the second model description, the effective age after *i*-th PM actions may be written as:

$$\tau_j(t) = \tau_j^+(t) + (t - t_{ji}) \quad \text{for } t_{ji} < t < t_{ji+1}, (1 \le i \le n) \tag{2}$$

and $\tau_j^+(t_{ji}) = \varepsilon_i \tau_j(t_{ji}) = \varepsilon_i \left(\tau_j^+(t_{ji-1}) + (t_{ji} - t_{ji-1})\right)$ where $\tau_j^+(t_{ji})$ is the age of component immediately after the i–th PM action which ranges in the interval [0, 1]. By definition, we assume that $\tau_j(0) = 0$, $t_{j0} = 0$ and ε_i is the age reduction coefficient. Two limits for PM actions is, where $\varepsilon_i = 1$ and $\varepsilon_i = 0$. In the first case the component at least be restored to "as bed as old" state which assumes that PM does not affect the effective age. In the second case the model reduce the component age to "as good as new", which means that the component age reaches zero age (replacement). In fact, all PM actions which improve the component age are imperfect. As it be mentioned and demonstrated in (Lin et al, 2000), the hazard function of component j, as function of its actual age, can be calculated as

$$h_j^* = h_j\left(\tau_j(t)\right) + h_{j0} \tag{3}$$

where $h_j(t)$ is the hazard function is defined when equipment does not undergo PM actions and h_{j0} correspond to the initial age of equipment. The reliability of the equipment j in the interval between PM actions i and $i+1$ can be written as:

$$r_j(t) = \exp\left(- \int_{\tau_j^+(t_{ji})}^{\tau_j(t)} h_j^*(x)dx \right)$$

$$= \exp\left(H_j(\tau_j^+(t_{ji})) - H_j(\tau_j(t))\right) \tag{4}$$

$H_j(\tau)$ represents the accumulative hazard function. Clearly if $t = t_{ji}$ in equation (4) the reliability reaches the maximum and is equal to 1.
The Minimal repairs are performed if MSS equipment fails between PM actions, and there cost expected in interval [0, *t*] can be given as

$$C_{Mj} = c_j \int_0^t h_j(x)dx \tag{5}$$

Possible equipment j , undergoes PM actions at each chronological time $t_{j1}, ..., t_{jn_j}$, in this case, the total minimal repair cost is the sum of all cost can be written as :

$$C_{Mj} = c_j \sum_{i=0}^{n_j} \int_{\tau_j^+(t_{ji})}^{\tau_j(t_{ji+1})} h_j(x)dx = c_j \sum_{i=0}^{n_j} \left(H(\tau_j(t_{ji+1})) - H_j(\tau_j^+(t_{ji})) \right) \tag{6}$$

where $t_{j0} = 0$ and $t_{jn_j+1} = T$ where T represents the lifetime.

3. Optimization problem

Let consider a power system organized with components connected in series arrangement. Each component contains different component put in parallel. Components are characterized by their nominal performance rate Ξ_j , hazard function $h_j(t)$ and associated minimal repair cost C_j . The system is composed of a number of failure prone components, such that the failure of some components leads only to a degradation of the system performance. This system is considered to have a range of performance levels from perfect working to complete failure. In fact, the system failure can lead to decreased capability to accomplish a given task, but not to complete failure. An important MSS measure is related to the ability of the system to satisfy a given demand.

When applied to electric power systems, reliability is considered as a measure of the ability of the system to meet the load demand (W), i.e., to provide an adequate supply of electrical energy (Ξ). This definition of the reliability index is widely used for power systems: see e.g., (Ross, 1993), (Murchland, 1975), (Levitin et al, 1996), (Levitin et al, 1997) and (Levitin et al, 1998). The Loss of Load Probability index (LOLP) is usually used to estimate the reliability index (Billinton et al, 1990). This index is the overall probability that the load demand will not be met. Thus, we can write R = Probab(ΞMSS≥ W) or R = 1-LOLP with LOLP = Probab(ΞMSS<W). This reliability index depends on consumer demand W.

For reparable MSS, a multi-state steady-state instantaneous availability A is used as Probab(ΞMSS ≥ W). While the multi-state instantaneous availability is formulated by equation (7):

$$A_{MSS}\{t, W\} = \sum_{\Sigma_j \geq D} P_j(t) \tag{7}$$

where ΞMSS (t) is the output performance of MSS at time t . To keep system reliability at desired level, preventive and curative maintenance can be realized on each MSS. PM actions modify components reliability and CM actions does not affect it. The effectiveness of each PM actions is defined by the age reduction coefficient ε ranging from 0 to 1. As in (Levitin et al, 2000), the structure of the system as defined by an available list of possible PM actions (v) for a given MSS. In this list each PM actions (v) is associated with the cost of its implementation $C_{p(v)}$, and $M(v)$ is the number of equipment affected corresponding to their age reduction $\varepsilon(v)$. Commonly the system lifetime T is divided into y unequal

lengths, and each interval have duration $\theta_y \quad 1 \le y \le Y$, at each end of this latter an PM action is performed. This action will be performed if the MSS reliability $R(t,w)$ becomes lower than the desirable level R_0.

Let us remark that the increase in the number of intervals increases solution precision. On the other hand, the number of intervals can be limited for technical reasons. All the PM actions performed to maintain the MSS reliability are arranged and presented by a vector V as they appear on the PM list. Each time the PM is necessary to improve the system reliability; the performed following action is defined by the next number from this vector. When the scheduled PM action v_i was insufficient to improve reliability, automatically the v_{i+1} action should be performed at the same time and so on. For a given vector V, the total number n_j and chronological times of PM action in equation (1) are determined for each component $j \quad 1 \le j \le J$. For all scheduled PM actions $v_i \in V$. The total cost of PM actions can be expressed as

$$C_p(V) = \sum_{i=1}^{N} C_p(v_i) \tag{8}$$

and the cost of minimal repair can be calculated as

$$C_M(V) = \sum_{j=1}^{J} c_j \sum_{i=0}^{n_j} \left(H(\tau_j(t_{ji+1})) - H(\tau_j^+(t_{ji})) \right) \tag{9}$$

The optimization problem can be formulated as follows: find the optimal sequence of the PM actions chosen from the list of available actions which minimizes the total maintenance cost while providing the desired MSS availability. That is,

Minimize:

$$f(V) \to C = C_p(V) + C_M(V) \tag{10}$$

Subject To:

$$A_\theta(\mathbf{V}, \mathbf{D}, \mathbf{t}) \ge R_0 \tag{11}$$

To solve this combinatorial optimization problem, it is important to have an effective and fast procedure to evaluate the availability index. Thus, a method is developed in the following section to estimate the system availability.

4. Reliability estimation based on Ushakov's method

The last few years have seen the appearance of a number of works presenting various methods of quantitative estimation of systems consisting of devices that have a range of working levels in (Reinschke, 1985) and (El-Neweihi, 1984). Usually one considers reducible systems. In general forms the series connection, the level of working is determined by the worst state observed for any one of the devices, while for parallel connection is determined by the best state. However, such the approach is not applicable for the majority of real systems.

In this paper the procedure used is based on the universal z-transform, which is a modern mathematical technique introduced in (Ushakov, 1986). This method, convenient for numerical implementation, is proved to be very effective for high dimension combinatorial

problems. In the literature, the universal z-transform is also called UMGF or simply u-transform. The UMGF extends the widely known ordinary moment generating function (Ross, 1993). The UMGF of a discrete random variable Ξ is defined as a polynomial:

$$u(z) = \sum_{j=1}^{J} P_j z^{\Xi_j} \tag{12}$$

The probabilistic characteristics of the random variable Ξ can be found using the function u(z). In particular, if the discrete random variable Ξ is the MSS stationary output performance, the availability A is given by the probability $\text{Proba}(\Xi \geq W)$ which can be defined as follows:

$$\text{Proba}(\Xi \geq \text{W}) = \Phi\left(u(z)z^{-\text{W}}\right) \tag{13}$$

where Φ is a distributive operator defined by expressions (14) and (15):

$$\Phi(Pz^{\sigma-\text{W}}) = \begin{cases} P, \text{ if } \sigma \geq \text{W} \\ 0, \text{ if } \sigma < \text{W} \end{cases} \tag{14}$$

$$\Phi\left(\sum_{j=1}^{J} P_j z^{\Xi_j-\text{W}}\right) = \sum_{j=1}^{J} \Phi\left(P_j z^{\Xi_j-\text{W}}\right) \tag{15}$$

It can be easily shown that equations (14)–(15) meet condition $\text{Proba}(\Xi \geq \text{W}) = \sum_{\Xi_j \geq \text{W}} P_j$. By using the operator Φ, the coefficients of polynomial u(z) are summed for every term with $\Xi_j \geq W$, and the probability that Ξ is not less than some arbitrary value W is systematically obtained.

Consider single devices with total failures and each device i has nominal performance Ξ_i and reliability Ai. The UMGF of such an device has only two terms can be defined as:

$$u_i(z) = (1 - A_i)z^0 + A_i z^{\Xi_i} = (1 - A_i) + A_i z^{\Xi_i} \tag{16}$$

To evaluate the MSS availability of a series-parallel system, two basic composition operators are introduced. These operators determine the polynomial u(z) for a group of devices.

4.1 Parallel devices

Let consider a system device m containing Jm devices connected in parallel. The total performance of the parallel system is the sum of performances of all its devices. In power systems, the term capacity is usually used to indicate the quantitative performance measure of an device in (Chern, 1992). Examples: generating capacity for a generator, carrying capacity for an electric transmission line, etc. Therefore, the total performance of the parallel unit is the sum of capacity (performances) in (Ushakov, 1986). The u-function of MSS device m containing J_m parallel devices can be calculated by using the $\Im$ operator:

$$u_p(z) = \Im(u_1(z),\ u_2(z),\ \ldots,\ u_n(z)), \text{ where } \Im(\Xi_1,\ \Xi_2,\ \ldots,\ \Xi_n) = \sum_{i=1}^{n} \Xi_i$$

Therefore for a pair of devices connected in parallel:

$$\Im(u_1(z),u_2(z)=\Im(\sum_{i=1}^{n}P_iz^{a_i},\sum_{j=1}^{m}Q_jz^{b_j})=\sum_{i=1}^{n}\sum_{j=1}^{m}P_iQ_jz^{a_i+b_j}$$

The parameters ai and bj are physically interpreted as the performances of the two devices. n and m are numbers of possible performance levels for these devices. Pi and Q_j are steady-state probabilities of possible performance levels for devices. One can see that the $\Im$ operator is simply a product of the individual u-functions. Thus, the device UMGF is: $u_p(z)=\prod_{j=1}^{J_m}u_j(z)$. Given the individual UMGF of devices defined in equation (11), we have: $u_p(z)=\prod_{j=1}^{J_m}(1-A_j+A_jz^{\Xi_i})$.

4.2 Series devices

When the devices are connected in series, the device with the least performance becomes the bottleneck of the system. This device therefore defines the total system productivity. To calculate the u-function for system containing n devices connected in series, the operator δ should be used: $u_s(z)=\delta(u_1(z),\ u_2(z),\ ...,\ u_m(z))$,where $\delta(\Xi_1,\Xi_2\ldots,\Xi_m)=\min\{\Xi_1,\Xi_2\ldots,\Xi_m\}$ so that

$$\delta(u_1(z),u_2(z))=\delta\left(\sum_{i=1}^{n}P_iz^{a_i},\sum_{j=1}^{m}Q_jz^{b_j}\right)=\sum_{i=1}^{n}\sum_{j=1}^{m}P_iQ_jz^{\min\{a_i,\,b_j\}}$$

Applying composition operators $\Im$ and δ consecutively, one can obtain the UMGF of the entire series-parallel system. To do this we must first determine the individual UMGF of each device.

4.3 Devices with total failures

Let consider the usual case where only total failures are considered and each subsystem of type *i* and version v_i has nominal performance Ξ_{iv} and availability A_{iv}. In this case, we have: Proba($\Xi = \Xi_{iv}$) = A_{iv} and Proba(Ξ = W) = $1-A_{iv}$. The UMGF of such an device has only two terms can be defined as in equation (11) by $u^*_i(z)=(1-A_{iv})z^0+A_{iv}z^{\Xi_{iv}}=1-A_{iv}+A_{iv}z^{\Xi_{iv}}$. Using the $\Im$ operator, we can obtain the UMGF of the *i*-th system device containing k_i parallel devices $u_i(z)=\left(u^*_i(z)\right)^{k_i}=\left(A_{iv}z^{\Xi_{iv}}+(1-A_{iv})\right)^{k_i}$.

The UMGF of the entire system containing *n* devices connected in series is:

$$u_s(z)=\delta\begin{pmatrix}\left(A_{1v}z^{\Xi_{1v}}+(1-A_{1v})\right)^{k_1},\\ \left(A_{2v}z^{\Xi_{2v}}+(1-A_{2v})\right)^{k_2},\ldots,\\ \left(A_{nv}z^{\Xi_{nv}}+(1-A_{nv})\right)^{k_n}\end{pmatrix} \tag{17}$$

To evaluate the probability $\Pr oba(\Xi \geq W)$ for the entire system, the operator Φ is applied to equation (18):

$$\Pr oba(\Xi \geq W) = \Phi\left(u_s(z)z^{-W}\right) \tag{18}$$

5. The harmony search approach

The problem formulated is a complicated NP-hard complex problem. The total number of different solutions to be examined is very large. An exhaustive examination of the enormous number of possible solutions is not feasible given reasonable time limitations. Thus, because of the search- space size of the problem. Adopting the idea that existing evolutionary or meta-heuristic algorithms are found in the paradigm of natural processes, a new algorithm can be conceptualized from a musical performance process (say, a jazz trio) in (Geem et al, 2005) and (Mahdavi et al, 2007) involving searching for a better harmony. Musical performance seeks a best state (fantastic harmony) determined by aesthetic estimation, as the optimization process seeks a best state (global optimum: minimum cost; minimum error; maximum benefit; or maximum efficiency) determined by objective function evaluation. Aesthetic estimation is done by the set of the pitches sounded by joined instruments, as objective function evaluation is done by the set of the values produced by composed variables; the aesthetic sounds can be improved practice after practice, as the objective function values can be improved iteration by iteration in (Fesanghary et al, 2008).
Figure 2 shows the structure of the Harmony Memory (HM) that is the core part of the HS algorithm. Consider a jazz trio composed of saxophone, double bass, and guitar. There exist certain amount of preferable pitches in each musician's memory: saxophonist, {Do, Fa, Mi, Sol, Re}; double bassist, {Si, Do, Si, Re, Sol}; and guitarist, {La, Sol, Fa, Mi, Do}. If saxophonist randomly plays {Sol} out of its memory {Do, Fa, Mi, Sol, Re}, double bassist {Si} out of {Si, Do, Si, Re, Sol}, and guitarist {Do} out of {La, Sol, Fa, Mi, Do}, the new harmony (Sol, Si, Do) becomes another harmony (musically chord). And if this new harmony is better than existing worst harmony in the HM, the new harmony is included in the HM and the worst harmony is excluded from the HM (Omran, 2008). This procedure is repeated until fantastic harmony is found.

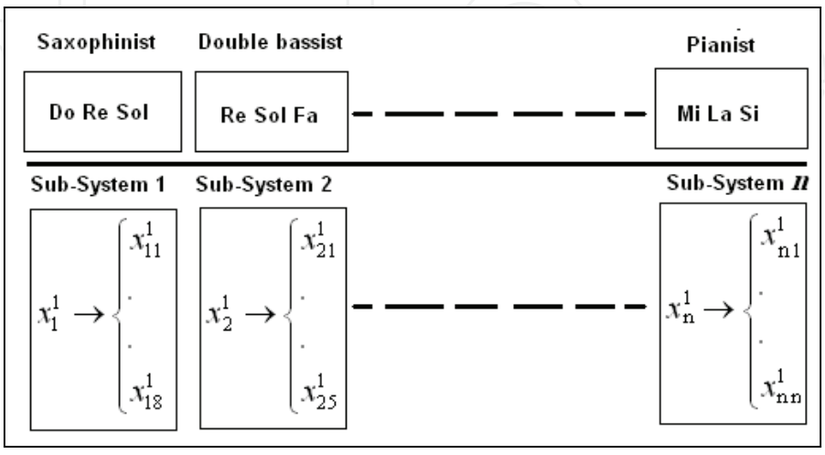


Fig. 2. Synoptic Modeling HS For Optimization

Step 1. Initialize:
Set N_istrument:=N_sybsystem {N is the integer number},
Set MHCR:=0.7{harmony memory considering rate},
Set PAR:=0.35{Pitch adjustment rate},
Set PAD {Pitch adjustment decision},
Set NI:=75{improvisation number},
Set t:=0 {t is the time counter},
Set Interval_t:=0 {θ is Interval time},
Set List PM_actions [L_{n1}]:= $\left[P_{n1}^{\upsilon} \right]$ {Available PM_actions},
Set PM_Action:=0 {m is the time counter},
For every Components (i,j) set an initial value $x_{ij}^{1} \to \left\{ x_{11}^{1},...,x_{n1}^{1} \right\}\ x_{ij}^{1}$,
Set For All components ($1 \le j \le J$):
Set Effectve_age:= τj
Set $H_j(\tau_j^{+}) = 0$
For i:=1 to n do
Mat$_k$ (HM):= i {starting component is the first element of the **Mat** list of the k-th instrument},
The HM matrix is filled with randomly generated as the HMS.

Step 2. Improvise a New list **Mat**$_k$ until is full {this step will be repeated (n-1) times}, $x^{n\upsilon} \to \left\{ x_{11}^{n\upsilon}, x_{12}^{n\upsilon},..., x_{nk}^{n\upsilon} \right\}$
2.0. y:=Interval_time+1
2.1 T:= Interval_time +t′
2.2 Effectve_age:=τj+t
2.3 New PM_action:= $x^{n\upsilon} \in \left[P_{n1}^{\upsilon} \right]$

Step 3.
Compute For j:=1 To J
$H_j(\tau_j)$ According equation (3)
End
Compute For j:=1 To J
$r_j(\tau_j)$ According equation (4)

Step 4.
Compute For j:=1 To n do {for every k-th instrument on Subsystem i }
Choose the PM_Action with probability

$$PAD\ for\ x_{ij}^{n\upsilon} \begin{cases} Yes\ If\ ran_1 \le PAR \\ No\ If\ ran_1 \succ (1 - PAR) \end{cases}$$

Then $x_{ij}^{n\upsilon} \leftarrow x_{gi}^{n\upsilon} \pm ran_i(\ ) * bw$
With Cost j, corresponding to Equation (8) and (9)
Increment to the k-th instrument on the i subsystems
Insert PM_Action and Cost j in **MAT**$_k$ (s).

Step 5.

If R (t,Ξ) < R_0 increment and define the new PM_Action to perform, add the new cost to total Cost.
Recalculate the reliability r
Else Goto Step 2.
If R (t,Ξ) >= evaluate the cost of minimal repair for all components ($1 \le j \le J$): and add these costs to the total cost.
Print minimal total cost to the corresponding reliability and
Stop.

6. Illustrative example

6.1 Description of the power system to be optimized

Let consider a series-parallel MSS (transmission system) consisting of three subsystem connected in series arrangment as depickted in figure.3 and 4. The system contains 13 equipments with different performance and reliabilty.
The transmission systems is composed by a emission and reception station where the signal is modeled to the analyzer series parallel components and emitted to orbital satellite. Concerning reception the series parallel system is composed by modelyzer RTID-2, 2 and 3 other amplifier TM-841, 842 and 843. Following the process and transmitted by telecom network (Linking with lines and without lines transmission). At the end the system supplies a graphique and TMAE station. The reliability of each component is defined by veibull function: $h(t) = \lambda^{\delta}\delta(\tau(t))^{\delta-1} + h_0$ MSS lifetime is 20 years. The time for possible PM_actions are spaced intervals of θ= 2.0 months. The problem is to guarantee a PM plan wich provide the system work during its lifetime with a performance, relaibility not less than Ξ0, R0 and the age reduction is the same of all components ε =0.56

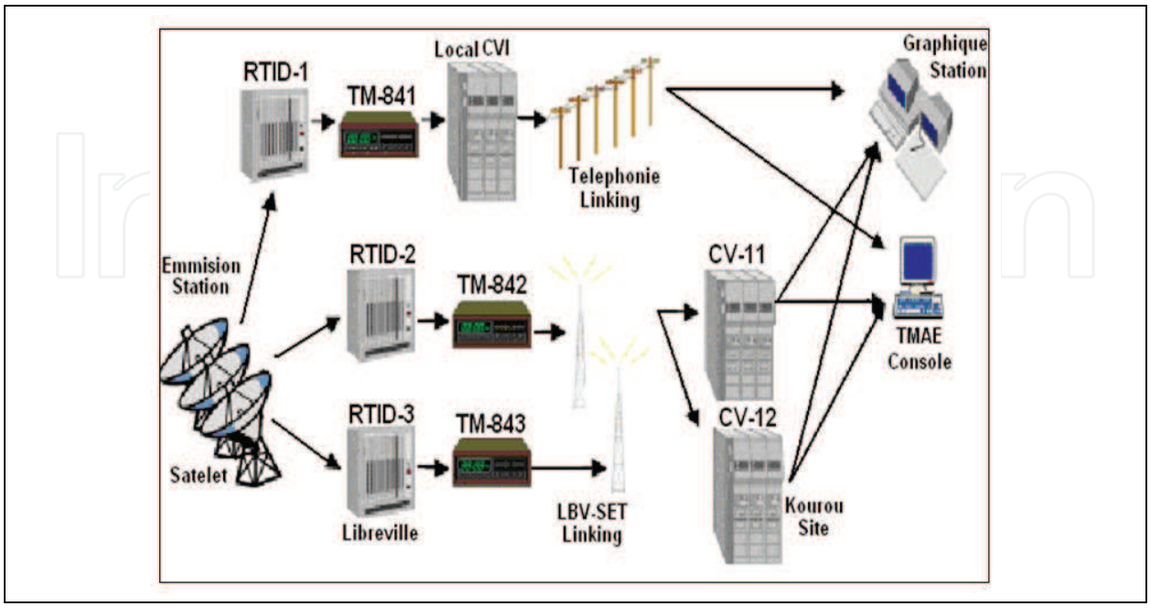


Fig. 3. Detailed Series-Parallel Transmission System

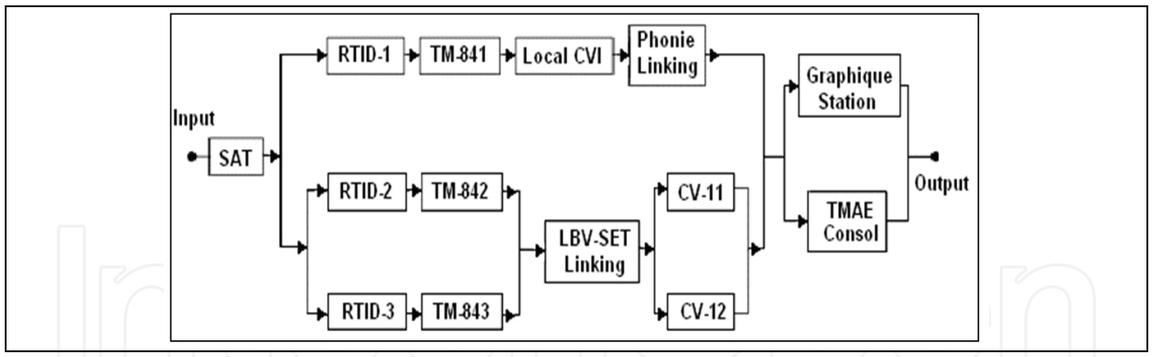


Fig. 4. Synoptic Series-Parallel Transmission System

	λ	δ	h_0	Min_Cost	Ξ %
			0.001	1.02	
1	0.05	1.8	0.003	0.9	40
2	0.05	1.8	0.003	0.9	80
3	0.05	1.8	0.003	0.9	80
4	0.05	1.8	0.002	0.7	80
5	0.02	1.3	0.002	0.7	70
6	0.02	1.3	0.002	0.7	70
7	0.02	1.3	0.006	0.8	70
8	0.08	1.6	0.005	0.6	85
9	0.07	1.8	0.003	0.8	89
10	0.05	1.8	0.002	0.8	90
11	0.08	1.7	0.001	0.9	90
12	0.03	1.6	0.001	0.8	95
13	0.004	1.5			87

Table 1. Parameter Of components

PM_Actions	Components	PM_Cost
1	1- SAT	10.2
2	2- RTID-1-2-3	2.9
3	2- RTID-1-2-3	4.1
4	2- RTID-1-2-3	2.2
5	3-TM-841-2-3	2.9
6	3-TM-841-2-3	4.1
7	3-TM-841-2-3	2.2
8	4-Tele-Linking	3.9
9	5-LBV-SET	4.1
10	5-LBV-SET	3.7
11	6-CV-11	5.5
12	6-CV-11	2.2
13	7- Graphique-S	3.5
14	8-TMAE	8.2

Table 2. Parameter Of Pm_Actions

t	PM_Actions	Affected Components	R (t,0.8)
12.250	2(6)	3	0.923
16.652	8	4	0.922
20.00	9	5	0.954
22.11	4	2	0.911
25.64	2	1	0.937

Table 3.The Best Pm plan By HS For R(t,0.8)>0.9

Action times	Kind of PM_Actions	Affected Components	Levels R (t,0.8)
09	4	2	0.920
07.20	2(7)	3	0.987
05.85	8	4	0.985
06.03	10	5	0.960
25.60	11	7	0.983

Table 4.The Best Pm plan By Ant Colony For R(t,0.8)>0.9

7. Conclusion

In this paper we formulated the problem of imperfect maintenance optimization for series-parallel transmission system structure. This work focused on selecting the optimal sequence of intervals to perform PM actions to improve the availability. The model analyzes cost and reliability, to construct a strategy to select the optimal maintenance intervals, formulating a complex problem. An exhaustive examination of all possible solution is not realistic, considering reasonable time limitations. Because of this, an efficient meta-heuristic can be applied (Harmony Search Algorithm) to solve the formulated problem. More specifically, the harmony search approach is a good solution for such a combinatorial problem.

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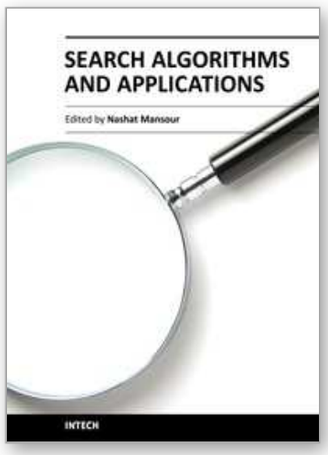
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Search algorithms aim to find solutions or objects with specified properties and constraints in a large solution search space or among a collection of objects. A solution can be a set of value assignments to variables that will satisfy the constraints or a sub-structure of a given discrete structure. In addition, there are search algorithms, mostly probabilistic, that are designed for the prospective quantum computer. This book demonstrates the wide applicability of search algorithms for the purpose of developing useful and practical solutions to problems that arise in a variety of problem domains. Although it is targeted to a wide group of readers: researchers, graduate students, and practitioners, it does not offer an exhaustive coverage of search algorithms and applications. The chapters are organized into three parts: Population-based and quantum search algorithms, Search algorithms for image and video processing, and Search algorithms for engineering applications.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
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Phone: +86-21-62489820
Fax: +86-21-62489821

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