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Optimal Allocation of the Electrical Structure Design using the Bats Approach

***Abstract**. In this paper we describe and use a meta-heuristic optimization method is the algorithm of bats to be able to solve the problem of optimizing redundancy. This problem is known because we will strive to reduce the investment cost of the serial-parallel power system configuration through the algorithm, not to mention to maximize reliability and this is one of the constraints. Redundant components are included to achieve the desired level of availability, and service continuity. The maintainability of the system is based on a multi-state availability function. The elements of the power system are characterized by their performance, reliability, and availability and cost. These elements are chosen from a list of products available on the market. The meta-heuristic proposed seeks the best solution for a better configuration for our structure, which composes the system to be able to minimize the cost with the desired maximum reliability. To estimate the availability of the serial-parallel power system, a fast method based on the universal moment generation (UMGF) function is suggested. The algorithm approach of bats is used as an optimization technique. One gives an example of a power supply system for present simulation.*

Streszczenie**. Opisano I zastosowano meta heurystyczną metodę optymalizacji problemu redundancji. Optymalizacja ma na celu redukcję kosztów szeregowo-równoległego systemu dystrybucyjnego. Elementy systemu były opisywane przez ich właściwości, niezawodność i dostępność. **Optymalne ulokowanie elementów struktury dystrybucji z wykorzystaniem Bat.

Keywords: bats, Optimization of redundancy, Multi-state systems, reliability, availability, Universal Generator Function (UMGF)
Słowa kluczowe: optymalizacja, redundancja, niezawodność

Introduction

One of the most important problems in many industrial applications is the redundancy optimization problem. This latter is well known combinatorial optimization problem where the design goal is achieved by discrete choices made from components available on the market. The natural objective function is to find the minimal cost configuration of a series-parallel power system under availability constraints. The system is considered to have a range of performance levels from perfect working to total failure. In this case the system is called a *multi-state* system (MSS). Let consider a multi-state system containing n subsystems C_i ($i = 1, 2, \ldots, n$) in series arrangement. For each subsystem C_i there are various versions, which are proposed by the suppliers on the market. Components are characterized by their cost, performance and availability according to their version. For example, these components can represent machines in a manufacturing system to accomplish a task on product in our case they represent the whole of electrical power system (generating units, transformers and electric carrying lines devices). Each subsystem C_i contains a number of components connected in parallel. Different versions of components may be chosen for any given subsystem. Each subsystem can contain components of different versions as sketched in figure 1.

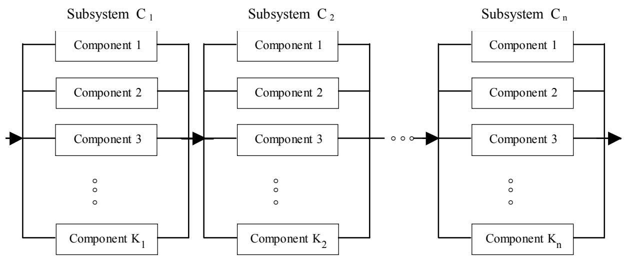

Fig. 1. Series-parallel power system structure

A limitation can be undesirable or even unacceptable, where only identical components are used in parallel (i.e. homogeneous system) for two reasons. First, by allowing different versions of the devices to be allocated in the same system, one can obtain a solution that provides the desired availability or reliability level with a lower cost than in the solution with identical parallel devices. Second, in practice the designer often has to include additional devices in the existing system. It may be necessary, for example, to modernize a system according to a new demand levels from customers or according to new reliability requirements.

Literature review

The vast majority of classical reliability or availability analysis and optimization assume that components and system are in either of *two* states (i.e., complete working state and total failure state). However, in many real life situations we are actually able to distinguish among various levels of performance for both system and components. For such situation, the existing dichotomous model is an oversimplification and so models assuming multi-state (degradable) systems and components are preferable since they are closer to reliability. Recently much works treat the more sophisticated and more realistic models in which systems and components may assume many states ranging from perfect functioning to complete failure. In this case, it is important to develop MSS reliability theory. In this paper, an MSS reliability theory will be used, where the binary state system theory is extending to the multi-state case. As is addresses in recent review of the literature for example in [1] or [2]. Generally, the methods of MSS reliability assessment are based on four different approaches:

1 The structure function approach.
2 The stochastic process (mainly Markov) approach.
3 The Monte-Carlo simulation technique.
4 The universal moment generating function (UMGF) approach.

In ref [1], a comparison between these four approaches highlights that the UMGF approach is fast enough to be used in the optimization problems where the search space is sizeable.

The problem of total investment-cost minimization, subject to reliability or availability constraints, is well known as the redundancy optimization problem (ROP). The ROP is studied in many different forms as summarized in [3], and more recently in [4]. The ROP for the multi-state reliability was introduced in [5]. In [6] and [7], genetic algorithms were used to find the optimal or nearly optimal power system structure.

This work uses an *bat algorithm* optimization approach to solve the ROP for multi-state power system. The idea of employing a colony of cooperating agents to solve combinatorial optimization problems was recently proposed in [8]. The bat algorithm approach has been successfully applied to the classical travelling salesman problem in [9], and to the quadratic assignment problem in [10]. Bat algorithm shows very good results in each applied area. It has been recently adapted for the reliability design of binary state systems in [11]. The bat algorithm has also been adapted with success to other combinatorial optimization problems such as the vehicle routing problem in [12]. The bat algorithmmethod has not yet been used for the redundancy optimization of multi-state systems.

Approach and Outlines

The problem formulated in this paper lead to a complicated combinatorial optimization problem. The total number of different solution to be examined is very large, even for rather small problems. An exhaustive examination of all possible solutions is not feasible given reasonable time limitations. Because of this, the BAT optimization (or simply BA) approach is adapted to find optimal or nearly optimal solutions to be obtained in a short time. The newer developed meta-heuristic method has the advantage to solve the ROP for MSS *without* the limitation on the diversity of versions of components in parallel.

During the optimization process, BAT will have to evaluate the availability of a given selected structure of the series-parallel system (electrical network). To do this, a fast procedure of availability estimation is developed. This procedure is based on a modern mathematical technique: the ***z***-transform or UMGF which was introduced in [13]. It was proven to be very effective for high dimension combinatorial problems: see e.g., in [2]. The universal moment generating function is an extension of the ordinary moment generating function (UGF) in [14]. The method developed in this paper allows the availability function of reparable series-parallel MSS to be obtained using a straightforward numerical procedure.

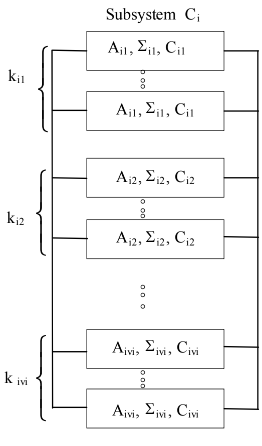

Fig. 2. Detailed structure of a given subsystem

Formulation of the redundancy optimization problem

Let consider a series-parallel power system containing n subsystems C_i ($i = 1, 2, \ldots, n$) in series arrangement as represented in figure 1. Every subsystem C_i contains a number of different components connected in parallel. For each subsystem i, there are a number of component versions available in the market. For any given system component, different versions and number of components may be chosen. For each subsystem i, components are characterized according to their version v by their cost (C_{iv}), availability (A_{iv}) and performance (G_{iv}). The structure of subsystem i can be defined by the numbers of parallel components (of each version) k_{iv} for $1 \le v \le V_i$, where V_i is a number of versions available for component of type i. Figure 2 illustrates these notations for a given subsystem i. The entire system structure is defined by the vectors $\boldsymbol{k_i} = \{k_{iv_i}\}$ $(1 \le i \le n, 1 \le v \le V_i)$. For a given set of vectors $\boldsymbol{k_1}, \boldsymbol{k_2}, \ldots, \boldsymbol{k_n}$ the total cost of the system can be calculated as:

(1)
$$C = \sum_{i=1}^{n} \sum_{v=1}^{V_i} k_{iv} C_{iv}$$

Optimal design problem formulation

The multi-state power system redundancy optimization problem of electrical power system can be formulated as follows: find the minimal cost system configuration $\boldsymbol{k_1}, \boldsymbol{k_2}, \ldots, \boldsymbol{k_n}$, such that the corresponding availability exceeds or equal the specified availability A_0. That is,

(2) Minimize
$$C = \sum_{i=1}^{n} \sum_{v=1}^{V_i} k_{iv} C_{iv}$$

(3) Subject to $A(\boldsymbol{k_1}, \boldsymbol{k_2}, \ldots, \boldsymbol{k_n}, \boldsymbol{D}, \boldsymbol{T}) \ge A_0$

The input of this problem is the specified availability, the outputs are the minimal investment-cost, and the corresponding configuration determined. To solve this combinatorial optimization problem, it is important to have an effective and fast procedure to evaluate the availability index for a series-parallel power system. Thus, a method is developed in the next section to estimate the value of $A(\boldsymbol{k_1}, \boldsymbol{k_2}, \ldots, \boldsymbol{k_n}, \boldsymbol{D}, \boldsymbol{T})$.

Multi-state system availability estimation method

The procedure used in this paper is based on the universal *z*-transform, which is a modern mathematical technique introduced in [13]. 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 universal moment generating function (UMGF) or simply *u*-function or *u*-transform. In this paper, we mainly use the acronym UMGF. The UMGF extends the widely known ordinary moment generating function in [14].

Parallel components

Let consider a subsystem m containing J_m components connected in parallel. As the performance measure is related to the system productivity, the total performance of the parallel subsystem is the *sum* of performances of all its components. In power systems engineering, the term capacity is usually used to indicate the quantitative performance measure of an component in [6]. It may have different physical nature. Examples of components capacities are: generating capacity for a generator, pipeline capacity for a water circulator, carrying capacity for an electric transmission line, etc. The capacity of a component can be measured as a percentage of nominal total system capacity. In an electrical network, components are generators, transformers and electrical lines. Therefore, the total performance of the parallel component is the sum of performances in [15].

The *u*-function of MSS subsystem m containing J_m parallel components can be calculated by using the Γ operator:

(4)
$$u_p(z) = \Gamma(u_1(z), u_2(z), \ldots, u_n(z)),$$

where $\Gamma(g_1,\ g_2,\ ...,\ g_n)=\sum_{i=1}^{n} g_i$.

Therefore, for a pair of components connected in parallel:

(5) $\Gamma(u_1(z),\ u_2(z))=\Gamma(\sum_{i=1}^{n} P_i z^{a_i},\ \sum_{j=1}^{m} Q_j z^{b_j})=\sum_{i=1}^{n}\sum_{j=1}^{m} P_i Q_j z^{a_i+b_j}$.

Parameters a_i and b_j are physically interpreted as the respective performances of the two components. *n* and *m* are numbers of possible performance levels for these components. P_i and Q_j are steady-state probabilities of possible performance levels for components.

One can see that the Γ operator is simply a product of the individual *u*-functions. Thus, the subsystem UMGF is:

$$u_p(z)=\prod_{j=1}^{J_m} u_j(z)\cdot$$

Given the individual UMGF of components defined in equation (11), we have:

$$u_p(z)=\prod_{j=1}^{J_m}(1-A_j+A_j z^{\Sigma_i})\cdot$$

Series components

When the components are connected in series, the component with the least performance becomes the bottleneck of the system. This component therefore defines the total system productivity. To calculate the *u*-function for system containing *n* subsystems connected in series, the operator η should be used: $u_s(z)=\eta(u_1(z),\ u_2(z),\ ...,\ u_m(z))$,

where $\eta(g_1,\ g_2,\ ...,g_m)=min\{g_1,\ g_2,\ ...,\ g_m\}$

so that

$$\eta(u_1(z),\ u_2(z))=\eta\left(\sum_{i=1}^{n} P_i z^{a_i},\ \sum_{j=1}^{m} Q_j z^{b_j}\right)=\sum_{i=1}^{n}\sum_{j=1}^{m} P_i Q_j z^{min\{a_i,\ b_j\}}$$

Applying composition operators Γ and η consecutively, one can obtain the UMGF of the entire series-parallel system. To do this we must first determine the individual UMGF of each component.

The Bat optimization approach

The bats are flying mammals and which proceed of the wings, and they have also the ability to perceive sounds which emit one calls it “echolocation”. Whose most microchiroptères use this means which is echolocation for nourished because they are insectivorous, for protected from predatory and to locate to perch cracks in the dark darkness to them. It is estimated that there are approximately 1,000 various species of bat, which represents up to 20% of all the mammalian species. Their size varies the tiny ones bats bumblebee (from approximately 1.5 to 2 G) with the giant bats with a scale of approximately 2 m and weight going until approximately 1 kg. The microchiroptères generally have a front armlever length from approximately 2.2 to 11 cm.

These bats emit a very strong noise and to listen to the echo which rebounds starting from the surrounding objects. Their impulses vary in properties and can be in correlation with their strategies of hunting, according to the species Most bats use, of short signals modulated in frequency to sweep approximately an octave, others generally use signals at constant frequency for echolocation. Their signal with band-width varies according to the species and increases by using often more harmonics.

Studies show that microchiroptères uses time delay of the emission and the detection of the echo, time difference between their two ears, and the variations of sound intensity of the echoes to build a scenario in three dimensions of surrounding or they are. They can detect the distance and the orientation from the target, the type of prey, and even the rate of travel of the prey, such as the small insects. Indeed, studies suggest that the bats seem to be able to distinguish the targets by the variations from the Doppler effect induced by the rates of the target insects wing undulation.

Algorithm (BA) beats is a method méta-heuristics based on an algorithm of optimization which was initially inspired by the life of the bats to find their food [16]. The bald people mouse emit signals has place or they are and of écoûté the echo of recalls this process known as of echolocation to locate itself by report has the prey. BA is mainly built by the use of four principal ideas [16]:

1) Echolocation allows the bat of distinguished food the difference between the preys (prey and object)..

2) Each bat in position Xi steals at the speed of production of one V_i particular impulse with the frequency and the intensity of the f_i and Ai respectively.

3) the volume of Have exchange in various Ai ways such as the reduction of a great value to a low value.

4) the frequency r_i, f_i and laughed of rate of each impulse is controlled automatically.

Initially, all the bats fly randomly within the space of research producing of the random impulses. After each flight, the position of each bat is put up to date in the following way:

$$V_i^{new}=V_i^{old}+f_i(X_G-X_i);i=1,...,N_{Bat}$$

(6) $X_i^{new}=X_i^{old}+V_i^{new};i=1,...,N_{Bat}$

$$f_i=f_i^{\min}+Q_i(f_i^{\max}-f_i^{\min});i=1,...,N_{Bat}$$

where X_G has the best overall solution . The limit of the upper frequency and the lower frequency sounds of the nth bat are represented by $f_i^{\max}$ and $f_i^{\min}$. The population size is the total number of designated snowshoe N_B, ϕ_1 and is a number generated randomly between 0 and 1

The second position of the movement of the bat is simulated as follows:

(7) $X_i^{new}=X_i^{old}+\varepsilon A_{mean}^{old};i=1,...,N_{Bat}$

Epsilon “ε” is a random number in the beach of the segment [- 1.1] and for the improvement of the amplitude for all the bald people mouse. Once the position of the bald people mouse is improved by the adjustments above Xinew and the new random individual is produced if it the level of signal is larger than a random value β .

One insert the new solution found by the new member in the population has condition which one observes the constraint:

(8) $[\beta<A_i]\&[f(X_i)<f(Gbest)]$

As previously mentioned the value of the amplitudes of signal generated by the bats a progressive reduction formulated has by

(9) $A_{inew}=\alpha A_{iold}$

$$\Gamma_{iltrer} + 1 = \Gamma[1 - \exp(-\gamma . t)]$$

Constants α and β are the approachs important for the bald people mouse, and represent the iteration count in the algorithm

Step 1. Initialize the bat population or their position X_i^{old} and their velocities V_i^{old}. Define pulse frequency f_i at X_i^{old}. Initialize pulse rates r_i and the loudness A.

Step 2. Generate new solutions by adjusting frequency, and updating velocities and locations/solutions (Equation (10)).

Step 3. if (rand > r_i) Select a solution among the best solutions Generate a local solution around the selected best solution.

Step 4. Else generate a new solution by flying randomly.

Step 5. If ($[\beta < A_i] \& [f(X_I) < f(G_{best})]$) Accept the new solutions, increase r and reduce A.

Step 6. Rank the bats and find the current best X_i^{new}.

Step 7. while (iteration < Max number of iterations) Post process results and visualization. The algorithm stops with the total-best solution.

Power design example

Table 8-1 summarizes the different technology components

Table 8-2 parameters of the power demand curve, and design of our system as shown in

Figure 8-1, a numerical example is solved by the use of the data provided in tables 8-3. Every electrical component of the subsystem is considered a unit with total failures

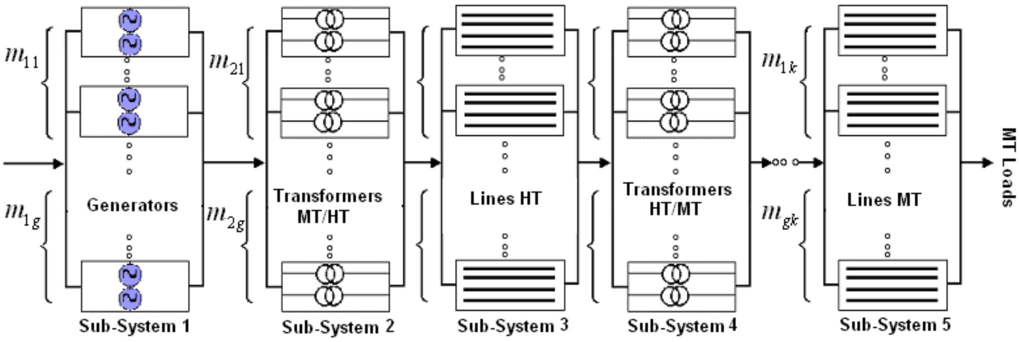

Fig. 8.1. Series- parallel power design

With a true simulation delivered by an example real of (G. Levitin), for each algorithm, knowing that the structure of the network is described with a number maximum, $g_{\max}$, for components which are placed parallel, one take account of the values and of the parameters of this one the results are compared for all these meta-heuristic we summarize in the table 5-3 which represents different meta-heuristic. this the configuration from the networks for the design, with lower costs and better a reliability.

Knowing that the data of the availability of different component technologies are listed in table

Optimal design solution and result discussion

Our natural objective function is to define the minimal cost power system configuration which provides the requested level of availability. The whole of the results obtained by the proposed ant algorithm for different given values of A_0 are illustrated in Table 3. This latter also shows the computed availability index *A*, the cost *C* of the system and their corresponding structures. Three different solutions for A_0 = 0.97, A_0 = 0.975,A_0 = 0.98, A_0 = 0.985, A_0 = 0.99, A_0 = 0.995 are represented. In these experiments the values parameters of the are the set of the following values: Loudness = 0.2 , Pulse rate =0.45 Q_{min}= 1, Q_{max} = 2,.The choice of these value affect strongly the solution. These value were obtained by a preliminary optimisation phase. The is tested well for quite a range of these values. In the 50 bat are used in each iteration. The stopping criterion is when the number of iterations attempt 500 cycles. The space search visited by the 50 bats is composed of 25000 solutions (50*500 cycles) and the huge space size of an exhaustive search (combinatorial algorithm) about 10^{45}. Indeed, a large comparison between the bat and an exhaustive one, clearly the goodness of the proposed bat meta- heuristic, which respect to the calculating time.it can be seen that the reliability is considerable in relation to the imposed threshold, and that the cost is optimized thanks to the different combination made by the approach of the .

Table 1 summarizes the different technology components

Subsystm		Ver	Ava A	Cost C	Capacity Σ
Power Units	1	1	0.980	0.590	120
		2	0.977	0.535	100
		3	0.982	0.470	85
		4	0.978	0.420	85
HT Transformer	2	1	0.995	0.205	100
		2	0.996	0.189	92
		3	0.997	0.091	53
		4	0.997	0.056	28
		5	0.998	0.042	21
HT lines	3	1	0.971	7.525	100
		2	0.973	4.720	60
		3	0.971	3.590	40
		4	0.976	2.420	20
HT/MT Transformers	4	1	0.977	0.180	115
		2	0.978	0.160	100
		3	0.978	0.150	91
		4	0.983	0.121	72
		5	0.981	0.102	72
		6	0.971	0.096	72
MT Lines	5	1	0.984	7.525	100
		2	0.983	4.720	60
		3	0.987	3.590	40
		4	0.981	2.420	20

Table 2. Parameters of the power demand curve

Power Demand level (%)	100	80	50	20
Duration (h)	4203	788	1228	2536
Probability	0.479	0.089	0.140	0.289

Table 3. Optimal solutions obtained by

A_0	Optimal Structure	itération	Computed Availability **A**	Computed Cost **C**
0,97	Sous-Système :1 components 4-4-4-4 Sous-Système :2 components 3-4-5-2-5 Sous-Système :3 components 5-5-1-5 Sous-Système :4 components 6-2-5-6-3 Sous-Système :5 components 4-4-3-4	74	0.970	12.246
0,975	Sous-Système :1 components 3-4-1-2 Sous-Système :2 components 1-3-4-2-5 Sous-Système :3 components 3-2-4-3 Sous-Système :4 components 3-4-5-6-1-2 Sous-Système :5 components 3-4-3-4	323	0.996	19.656
0,98	Sous-Système :1 components 3-4-1-2 Sous-Système :2 components 5-3-4-2-5 Sous-Système :3 components 3-4-2-3 Sous-Système :4 components 3-4-5-6-1-2 Sous-Système :5 components 3-4-3-4	369	0.996	19.493
0,985	Sous-Système :1 components 3-4-1-2 Sous-Système :2 components 1-3-4-2-5 Sous-Système :3 components 3-4-2-3 Sous-Système :4 components 3-4-5-6-1-2 Sous-Système :5 components 3-4-3-4	446	0.996	19.656
0,99	Sous-Système :1 components 3-4-1-2 Sous-Système :2 components 5-3-4-2-5 Sous-Système :3 components 3-4-2-3 Sous-Système :4 components 3-4-5-6-1-2 Sous-Système :5 components 3-4-3-4	50	0.996	19.493
0,995	Sous-Système :1 components 3-4-1-2 Sous-Système :2 components 3-1-4-2-5 Sous-Système :3 components 3-4-2-3 Sous-Système :4 components 3-4-5-6-1-2 Sous-Système :5 components 3-4-3-4	414	0.996	19.656

Conclusion

Bat new algorithm for choosing an optimal series-parallel power structure configuration is proposed which minimizes total investment cost subject to availability constraints. This algorithm seek and selects components among a list of available products according to their availability, nominal capacity (performance) and cost. Also defines the number and the kind of parallel components in each subsystem. The proposed method allows a practical way to solve wide instances of reliability optimization problem of multi-state power systems without limitation on the diversity of versions of components put in parallel. A combination is used in this algorithm is based on the universal moment generating function and bat optimization algorithm.

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