

An Improved Bat Algorithm for solving Series-parallel power system problem

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Abstract
Today's highly capitalized power societies require 'maximum benefit with minimum cost.' In order to achieve this goal, design engineers depend on cost optimization techniques. This work uses an improved bat algorithm (IBA) meta-heuristic optimization method to solve the problem of power optimization systems design. We consider the case where redundant electrical components are chosen to achieve a desirable level of reliability. The electrical power components of the system are characterized by their cost, capacity and reliability. The reliability is defined as the ability to satisfy the consumer demand which is represented as a piecewise cumulative load curve. The proposed meta-heuristic seeks for the optimal design of series-parallel power systems in which a multiple choice of generators, transformers and lines are allowed from a list of product available in the market. Our approach has the advantage to allow electrical power components with different parameters to be allocated in electrical power systems. To allow fast reliability estimation, a universal generating function (UGF) method is applied. A computer program has been developed to implement the UGF and the IBA algorithm. An illustrative example is presented.
Keywords: Improved Bat Algorithm (IBA), Optimization, Power system design, reliability, Universal moment generating Function (UMGF)

1. Introduction

To provide a requirement level of system reliability, redundant electrical components are included in system. Engineers try always to reach this level with minimal system cost. The problem in electrical power systems concerning a natural objective function is to minimize the total cost of the power system subject to reliability constraints. This problem is well known as redundancy optimization problem (ROP). It has addressed in many studies [1] [3]. These studies are usually concerned with the binary state case. However, electrical power components systems exhibit a multi-state behavior. In fact, when applied to power systems, reliability is considered as a measure of the ability that production systems meet the load demand, i.e. provide an adequate supply of electrical energy [5]. In this case, the effect of outage will be different for generators and different nominal generation of power capacity will also depend on consumer demand. In fact the capacities of power system component should be taken into account as well as the consumer load curve. The redundancy optimization problem for a system with different electrical components capacities may be considered as a problem of electrical power system optimization. The same problem is addressed in [6], where the basic approach optimization was formulated. In reference [4], a modification of the gradient method was applied for funding the minimal cost design of series-parallel electrical power system structure. Components of the system with different reliability, capacities and costs were considered, and demand was estimated using a load curve. The drawback of the approach adopted in [3] and [4] is that costs of components are defined as explicit analytical function of their capacities and the same reliability index values are assigned to all the components of given type, regardless of their capacity. In [7-8], a genetic algorithm and ant colony approaches are used as an optimization technique to solve the problem. In this paper, we suggest an Improved Bat algorithm to find the optimal power system structure by choosing the appropriate electrical components (technology of generators, transformers and electrical lines) from a list of available products in electrical power market for each type of electrical components. In practice, a variety of products are in fact available and each technology is characterized by its capacity, reliability and cost. Our objective is to select the optimal combination of generators, transformers and lines used in power system for all electrical components corresponding to the minimal total cost subject to the requirement of meeting the demand with the desirable level of reliability. To evaluate the reliability for arbitrary series-parallel power system structure, a fast procedure is developed which is based on universal generating function (UGF) [4] [9].The rest of the paper is organized as follows. Section 2 of the paper consists of a general description of model used and a formulation of problem. In section 3, we describe the reliability estimation method using the UGF technique.

Notations:
c_i: *Cost of electrical component i.*

M_i: Available electrical components technologies.
g_i: power components performance.
r_i: power components reliability.
r_i: power components reliability.
ROP: redundancy optimization problem.
IBA: Improved Bat Algorithm
AC: Ant colony algorithm.
GA: Genetic algorithm.
HS: Harmony Search algorithm.

2. Description of system model and problem formulation

Let us consider a power system containing n electrical power components connected in series- parallel as sketched in (Fig. 1).

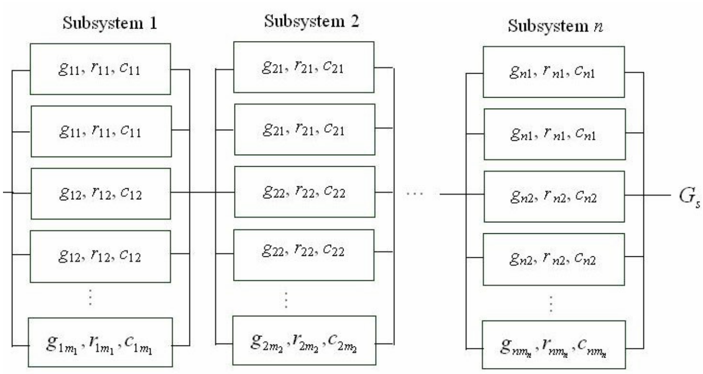

Figure 1. Series- Parallel Power System

Every component of type $i = 1, \ldots, n$ contains a number of electrical components. All the power components of type i belonging to different technologies are connected in mashed structure. A multi-choice of generators, transformers and lines will be adopted for each given system element. Each technology available in market has different costs, reliabilities and nominal capacities. A vector of parameters $c_{i m_i}$, $r_{i m_i}$, $g_{i m_i}$ can be specified for each technology m of element of type i. The electrical system component i is defined by the numbers of series and parallel components of each technology k_{iv} for $1 \le j \le m_i$ where M_i is the total number of technologies available of element of type i . The entire system structure is defined by a vector $k_i = \{k_{im_i}\}$ $(1 \le i \le n,\ 1 \le j \le m_i)$ and the total cost of the system for given set $k_1, k_2, \ldots, k_n$ is formulated as follows:

$$C = \sum_{i=1}^{n} \sum_{j=1}^{m_i} k_{im} c_{im} \qquad (1)$$

Usually in electrical power energy, the loss of load probability index (LOLP) and the expected energy not supplied (EENS) in operation period T are used for reliability estimation [5]

. This index measure the probability that the load demand will not be meet. Generally the load demand is represented by discrete random curve. If the time period of load is the set of M intervals, with duration T_j $(j = 1, \ldots, M)$, and each demand level d_j has T_j duration, the LOLP is calculated as follows:

$$LOLP = \frac{1}{\sum_{j=1}^{M} T_j} \sum_{j=1}^{M} P(g_s \succ d_j)\, T_j \qquad (2)$$

and

$$EENS = \frac{1}{\sum_{j=1}^{M} T_j} \sum_{j=1}^{M} P(d_j \geq g_s)\ T_j \quad (3)$$

Where $P(g_s \leq d_j)$ represents the probability that the total system capacity g_s is lower than the demand level d_j (EENS). All capacities production and demand are defined as a percentage of their total nominal value. The cumulative load curve is represented by vectors $d = \{d_i\}$ and $T = \{T_j\}$ who is known for every power system.
The measure of reliability system is defined by R index in reference [2], given by the expression $R = 1 - LOLP$. This index will be compared and must be not less than some preliminarily specified level R_0 .

The problem of electrical power system reliability optimization can be formulated as follow: find the electrical power system design $k_1, k_2, ..., k_n$ that provides the minimum total cost under reliability constraint. This problem can be started as below:

Minimize $$C = \sum_{i=1}^{n} \sum_{j=1}^{m_i} k_{im} c_{im} \quad (4)$$

Subject To $$R(d, t, k_1, k_2, ..., k_n) \geq R_0$$

3. Reliability estimation method

The problem defined above is one of combinatorial optimization problem, it is necessary to enumerate a huge number of possible system states. Thus, it is required to use an effective and fast procedure for structure reliability estimation. As shown above, the main problem is to evaluate the index R for arbitrary series and parallel system. The probability that the total capacity of the electrical power system is not less than a specific load demand level d must be calculated as:

$$R(d) = P\{g_s \succ d\} = 1 - P\{g_s \leq d\} \quad (5)$$

The procedure used to estimate this index is based on a modern mathematical technique: the UGF (or u-transform) technique in [10-11-12].This method was first applied to real power system reliability assessment and optimization in [13-14], and represent an extension of ordinary moment generating function [15]. The UGF, in our case, of a discrete variable E is defined as a polynomial

$$u(z) = \sum_{j=1}^{J} P_j z^{g_j} \quad (6)$$

where the discrete random variable g has J possible values and P_j is the probability that g is equal to g_j . Under consideration if only the components with total failures are considered. For instance for each element of type i and technology m has reliability R_{im_i} and nominal capacity g_{im_i} , then we denote by:
$P(g = g_s) = R_{im}$ and $P(g = 0) = 1 - R_{im}$. The UGF can be defined of such an element has only two terms as:

$$u_{im} = (1 - R_{im}) z^0 + R_{im} z^{g_{im}} \quad (7)$$

A brief overview on UGF method with respect to its applications for multi-states system (MSS) which has a finite number of states, there can be m different levels of output performance at each time t : $g(t) \in g = \{g_h, 1 \leq j \leq m\}$ and the system output performance can be defined by two finite vectors g and $p = \{p_h(t)\} = \Pr\{g(t) = g_h\}\ 1 \leq h \leq m$, here the UGF, represented by the polynomial $u(z)$ can define all the MSS output performance, i.e. it represent all the possible states of the system by relating the probability of each state to performance of MSS in that state in the form:

$$u_{MSS}(t,z)=\sum_{h=1}^{m}p_h(t)z^{g_h} \tag{8}$$

Having the MSS output performance, the system reliability for arbitrary time t and demand d can be obtained using the following operator Ω_A

$$\begin{aligned}R(t,d)&=\Omega_A(u_{MSS}(t,z),d)\\&=\Omega_A(\sum_{h=1}^{m}p_h(t)z^{g_h},d)\\&=\sum_{h=1}^{m}p_h(t)\alpha(g_h-d)\end{aligned} \tag{9}$$

where $\alpha(x)=\begin{cases}1, & x\geq 0\\ 0, & x<0\end{cases}$

More explicitly, the probability that the total capacity of the power system is not less than a specified load level demand, and can be written as follows:

$$P\{g\geq d\}=\Omega(u(z)z^{-d}) \tag{10}$$

where Ω is a distributive operator defined by the following expression:

$$\Omega(pz^{g-d})=\begin{cases}p, & if \quad g\geq d\\ 0, & if \quad g<d\end{cases} \tag{11}$$

and

$$\Omega(\sum_{j=1}^{J}pz^{g_j-d})=\sum_{j=1}^{J}\Omega(pz^{g_j-d}) \tag{12}$$

For the components of the fuel system containing components connected in different ways, in parallel case, the total capacity is equal to the sum of all components of capacity
Therefore, the u-function can be calculated by using the Γ operator:

$$u_s(z)=\Gamma(u_1(z),...,u_n(z))=\prod_{i=1}^{n}u_i(z) \tag{13}$$

where

$$\Gamma(g_1,...,g_n)=\sum_{i=1}^{n}g_i \quad \text{so that} \tag{14}$$

$$\begin{aligned}\Gamma(u_1(z),u_2(z))&=\Gamma(\sum_{i=1}^{n}p_iz^{a_i},\sum_{j=1}^{m}q_jz^{b_j})\\&=\sum_{i=1}^{n}\sum_{j=1}^{m}p_iq_jz^{a_i+b_j}\end{aligned} \tag{15}$$

We can see that the Γ operator is simply a polynomial product representing u - individual functions. Another case if the system contains components connected in series, the operating level is determined by the worst condition observed for any of its components, and the worst state becomes the system bottleneck . Therefore, this element defines the total capacity of the system. To calculate the function u- system containing m the component mounted in series, the operator β must be used :

$$u_s(z)=\beta(u_1(z),...,u_m(z)) \tag{16}$$

For which

$$\beta(g_1,...,g_m)=\min\{g_1,...,g_m\} \tag{17}$$

so that

$$\beta(u_1(z),u_2(z)) = \beta(\sum_{i=1}^{n} p_i z^{a_i}, \sum_{j=1}^{m} q_j z^{b_j}) \\ = \sum_{i=1}^{n}\sum_{j=1}^{m} p_i q_j z^{min(a_i,b_j)} \tag{18}$$

The MSS reliability was presented and $P\{g \geq d\}$after time has passed for this probability becomes constant.

4. Improved Bat optimization approach

Bats are extraordinary animals. Bat Algorithm (BA) is a new metaheuristic population based optimization algorithm utilized to solve our problem and Bats are the only mammals with wings [16], and they also have the advanced echolocation ability. It is estimated that there are about 1,000 different species of bats, representing up to 20% of all mammal species. Their size varies from small bumblebee bat (about 1.5 to 2 g) giant bat with a wingspan of about 2 m and weight up to about 1 kg . Microchiroptera type bats are generally have a length of the forearm from about 2.2 to 11 cm. Most bats use short signals, frequency modulated sweep about an octave; others use mostly constant frequency signals for echolocation. Their signal bandwidth varies with species and increases more often using harmonics. Studies show that micro bats use the delay between detection and the mission of the echo, the time difference between the two ears, and changes in the loudness of the echoes to build environment in which it is located three dimensions of the environment.

1) Each bat utilizes the echolocation technique to search for food.

2) Each bat flies in the individual position Xi and at its own speed V_i to produce a particular pulse with frequency and intensity of f_i and Ai respectively.

3) In different ways The intensity of Ai evolution is such that the reduction of the high value to a very low value.

4) r_i , f_i rate and frequency of each pulse is initially controlled automatically , steals all the bats at random in the search space and producing random sounds . After each flies, the position of each bat is updated as follows:

$$V_i^{new} = V_i^{old} + f_i(X_G - X_i); i = 1,..., N_{Bat} \\ X_i^{new} = X_i^{old} + V_i^{new}; i = 1,..., N_{Bat} \\ f_i = f_i^{\min} + Q_i(f_i^{\max} - f_i^{\min}); i = 1,..., N_{Bat} \tag{19}$$

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:

$$X_i^{new} = X_i^{old} + \varepsilon A_{mean}^{old}; i = 1,..., N_{Bat} \tag{20}$$

Where ε is a random number in the range [-1,1] and to improve the average value of the amplitude for all bats. Once the position of the bat is improved by the above adjustments Xinew a new random individue is generated in the case where the signal r_i level is greater than a random value β .

This solution is new and will be inserted to the population if the constraint is respected:

$$[\beta < A_i] \& [f(X_i) < f(Gbest)] \tag{21}$$

As mentioned formerly the value of signal amplitudes generated by bats has a gradual decrease formulated by:

$$A_{inew} = \alpha A_{iold} \tag{22}$$

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

Where t is the number that represents the iteration. α and β which is the main constants in the steps of the algorithm.

Improved Bat algorithm (IBA) for solving our problem

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 (19)).

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.

5. Power Design Example

In order to illustrate the proposed metahrutistic's PSO, HS and IS to built the power design as in Fig.2, a numerical example is solved by use of the data given in Table 1. Each electrical component of the sub-system is considered as a unit with total failures. Table 2 contains the data of cumulative power demand.

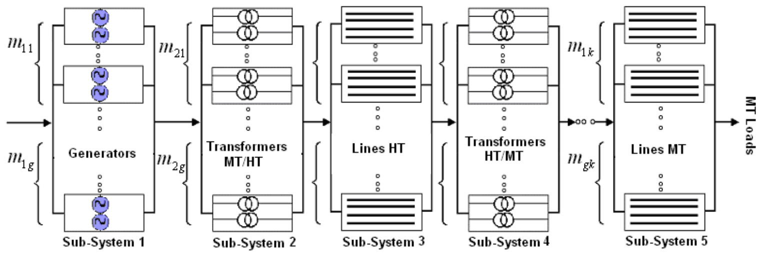

Figure 2. Series- Parallel Power Design

The maximum numbers of electrical components g_{max} in parallel are set to (7,5,4,9,4). The simulation results depend greatly on each algorithm's parameters values. The simulation was implemented to a real example taken from (G. Levitin) and the results are compared between these three meta-heuristics. Table 3 presents the obtained configuration.

Table 1. Data of Available Different Power Components Technologies

Sub-System #	Components #	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9
Generators 1	Reliability (%)	0.890	0.977	0.982	0.978	0.983	0.920	0.984	/	/
	Cost (%)	0.590	0.535	0.470	0.420	0.400	0.180	0.220	/	/
	Performance (%)	120	100	85	85	48	31	26	/	/
MT/HT Transformers 2	Reliability (%)	0.995	0.996	0.997	0.997	0.998	/	/	/	/
	Cost (%)	0.205	0.189	0.091	0.056	0.042	/	/	/	/
	Performance (%)	100	92	53	28	21	/	/	/	/
Lignes HT 3	Reliability (%)	0.971	0.973	0.971	0.976	/	/	/	/	/
	Cost (%)	7.525	4.720	3.590	2.420	/	/	/	/	/
	Performance (%)	100	60	40	20	/	/	/	/	/
HT/MT Transformers 4	Reliability (%)	0.977	0.978	0.978	0.983	0.981	0.971	0.983	0.982	0.977
	Cost (%)	0.180	0.160	0.150	0.121	0.102	0.096	0.071	0.049	0.044
	Performance (%)	115	100	91	72	72	72	55	25	25
Lignes MT 5	Reliability (%)	0.984	0.983	0.987	0.981	/	/	/	/	/
	Cost (%)	0.986	0.825	0.490	0.475	/	/	/	/	/
	Performance (%)	128	100	60	51	/	/	/	/	/

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 Solution Obtained By Harmony Search Algorithm, Ant Colony and Genetic Algorithm and Improved Bat Algorithm

Reliability Constraint R_0	Sub-System	Optimal Power Design	Corresponding Availability R	Corresponding Cost C	Optimization Method
0.97÷0.990	Sub-System: 1 Sub-System: 2 Sub-System: 3 Sub-System: 4 Sub-System: 5	6 6 6 6 6 6 6 4 3 1 5 4 5 5 1 5 6 8 9 7 9 8 2 4 9 3 4 4 4	0.970	11.828	Improved Bat Algorithm
0.97÷0.990	Sub-System: 1 Sub-System: 2 Sub-System: 3 Sub-System: 4 Sub-System: 5	4-4-6-7 4-4-4-4-4-4-4 1-4 7-7-7-9 4-4-4	0.992	13.175	Harmony Search
0.97÷0.990	Sub-System: 1 Sub-System: 2 Sub-System: 3 Sub-System: 4 Sub-System: 5	3-4-4-6-7 5-5-5-5-5-5-4 1-4 7-7-7-8-8-9 3-4-4-4	0.9906	14.302	Ant Colony
0.97÷0.990	Sub-System: 1 Sub-System: 2 Sub-System: 3 Sub-System: 4 Sub-System: 5	4-4-6 3-3 2-2-3 7-7-7 4-4-4	0.992	15.870	Genetic Algorithm

6. **Discussion of Results**

The above table 3 shows the best optimal power design obtained by the suggested meta heuristic's (Improved Bat, Harmony Search, Ant Colony and Genetic Algorithms) for one desired reliability levels R_0 (0.97-0.990). This latter illustrate the computed cost and availability index to the corresponding power design. In the bat algorithm a set of parameter values are tested. When the demand varies the best values corresponding to the merit power design are: The population size = 500; iteration number = 500; loudness = 0.02; and the pulse rate at = 0.45. The choice of these values affects strongly the solution.

To compare the efficacy between theses algorithms an quality coefficient solution measure is proposed, this latter taken from NN method (Nakagawa and Nakachima) the best solution are selected from the lower NN coefficient $\lambda = \dfrac{Optimal\_Cost}{reliability}$

The results shows that the NN coefficient of optimal design given by bat algorithm is (λ=11.82/0.97) is very low than HS, ACO and GA.

Hence it is a meta- heuristic method only near optimal solutions can be obtained. To compare this meta-heuristic to the combinatorial one, the space searching is about Sub-Variables Number of bats and / or harmonies or ants or antigens (BA, HS, ACO and GA)*NI, but in combinatorial very exhaustive. The Program was run on PC Intel IV with 2.4 GHz. The time to find the best solution is 1'.01". Not realistic in combinatorial method.

An important difference between these meta-heuristics applied to the same problem. The advantage of IBA among HS, AC and GA is the quality of solution. The IBA gives the optimal power design among the HS, ACO and GA.

7. Conclusion

In this paper, we solve the electrical power design optimization which is a very interesting problem often reencountered in energy industry. It is formulated as redundancy optimization problem. The resolution of this problem uses a developing harmony search algorithm. This new algorithm for choosing an optimal series-parallel electrical power system design is proposed which minimizes total investment cost subject to availability constraints. This algorithm seeks and selects electrical components technologies among a list of available products according to their availability, nominal capacity (performance) and cost. Also defines the number and the kind of series-parallel electrical power components to put in each subsystem when consumers' demand changes. Proposed Improved Bat algorithm (IBA) has been compared to (SH), (ACO) and (GA) and simulations results reveal about the better performance of the proposed IBA algorithm.

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