Optimization of Concrete Duct Bank Power Cable using Self-Adaptive Differential Evolution

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Abstract. *Underground cable performance with the qualitative aspects of the maximum cable temperature and ampacity are functions of installation conditions. Thus, this work presents an efficient methodology to improve the thermal performance of power cable with respect to optimize structural sizing involving the variables design of concrete duct bank dimensions. The methodology integrates the powerful features of the finite elements method (FEM) technique and the self-adaptive Differential Evolution (jDE) for handle various geometrical parameters in the complex surrounding installation case. Simulation results obtained by jDE were compared with control algorithms of the Particle Swarm Optimization (PSO), momentum-type PSO (mPSO) and Genetic Algorithm (GA). To optimize structural sizing, it was found that the performance of the concrete duct bank could be improved by jDE method and be better when comparing with the results from the other methods. Moreover, jDE could reduce sizing of the concrete duct bank with 41.39% compared with the traditional design at the same ampacity of installation in noncomplex surrounding installation (normal case). This is important for reduce installation cost of the concrete duct bank.*

Keywords:

Underground power cables, concrete duct bank, cable ampacity, the temperature distribution, optimization

1. Introduction

Underground power systems are widely applied in urban areas because they are more secure, safe and reliable compared to overhead power systems. Although an underground power system can improve the appearance of city landscapes, the material costs for installation are very high [1-3]. Moreover, maintenance and time to repair are considered because it is difficult to find the cable fault locations in systems [1-3]. Therefore, installation conditions and proactive maintenance are important for prolonged life and performance of the power cable [1, 3, 4].

Power cable performance is a function of ampacity, which represents its maximum electrical current carrying capacity. This is limited by the critical insulation temperature [1-4]. The construction conditions and material properties are the reason for differences in cable current carrying capacity.

A concrete duct bank is one of the construction methods that can protect underground power cables from damage due to penetration and traffic above the duct [2, 5, 6]. Moreover, concrete can improve the thermal properties of the underground power system. Concrete has a low thermal resistivity and prevents soil from drying in the vicinity of power cables [7-9]. The approximate concrete price of USD 105 per cubic meter is strongly depends on the location of the installation and availability of raw materials, among other factors [8, 10]. Therefore, to design the system, the structural size of the concrete duct bank should be considered as a factor, which it impacts construction costs.

Numerical methods based on heat transfer theory were used to evaluate power cable ampacity [11-13]. The international electrotechnical commission (IEC) 62095 is based on the finite element method (FEM). It is preferred to conventional methods for solving comprehensive problems [7, 14-18]. Several researchers presented the combination of FEM and meta-heuristic method to find the optimal various designs of underground power cable installation [16-18]. The particle swarm optimization algorithm (PSO) [18] and momentum-type PSO (mPSO) [16, 17] were the effective methods for solving the optimal various designs of underground power cable installation. Recently, a new meta-heuristic method called self-adapting control parameters differential evolution algorithm (jDE) was proposed to solve optimization problems [19]. The jDE was presented by J. Brest for using simply method with adaptive control parameters. This is to reduce the difficulty of the setting parameter and maintainability to search for the best solution of differential evolution algorithm (DE). Furthermore, DE is one of most powerful optimization algorithms and has very strong global search capacity [20]. However, the jDE for considering the optimal sizing of cable duct bank has not applied.

The purpose of this paper is to present the optimal design variables of concrete duct bank dimensions by jDE for installation in normal case and complex surrounding (with drain pipe). The considered parameters indicate the algorithm performance with respects of the minimum concrete cross-section area, average minimum concrete cross-section area and the standard deviation. Simulation results obtained by jDE are compared with those of the PSO, mPSO and genetic algorithm (GA) methods.

2. Modeling and Problem Formulation

2.1 Thermal analysis

In urban and industrial estate areas, the vicinity of the power cable may adjoin other carry utility lines, such as steam, water and sewer pipes. The underground power cable ampacity was analyzed with the system voltage, U, of 115 kV and three-phase system frequency, f, of 50 Hz. The cross-section area of the underground power cable in a casing pipe is 800 mm^2. The cable is arranged in a rectangular fashion and covered by reinforced concrete in a concrete duct bank with drain pipe parallel. The power cable construction in industrial estate areas has found with a problem of thermal pipe, such as steam, and hot water pipes. For this study, the duct bank power cable was installed to parallel with the hot water drain pipe at 90^{o}C, as following the thermal model of El-Saud [18].

The power cable in casing pipe consists of a cable conductor, cross-linked polyethylene (XLPE) insulation, metallic sheath and the non-metallic outer or jacket. There is a gap between outer cable at the inner pipe. High-density polyethylene (HDPE) casing pipe installs to parallel with the hot water drain pipe, as shown in Fig. 1. Table 1 presents the dimension and the thermal properties of power cable. Moreover, the power cable has a water blocking layer in each layer for continuous longitudinal watertight barrier throughout the cable length. This layer needs to be compatible with the outer cable materials and has no corrosive effect on adjacent metallic layers [21]. The parameters in Table 1 were used for estimating the cable ampacity. The metallic sheaths were bounded and earthed at the single-point end. Additionally, the gap in casing pipes was filled with a sand-bentonite mixture (SBM). The SBM can improve the cable ampacity by reducing its thermal resistivity in the vicinity of the cable [16, 17]. When the cable core temperature is higher than 90 ^{o}C, the XLPE cable insulation melts and the transmission line malfunctions.

The arrangement of a concrete duct bank in native soil with a deep cable duct bank at 2.5 m is shown in Fig. 2. The parameter for W_1 and W_2 represents the horizontal distance between the center of the casing pipe and the side edge of the concrete layer. The distance between the center of the casing pipe to the top and bottom concrete layers is defined by H_1 and H_2. The parameter for S_1 and S_2 is the spacing between the cable conductors.

The ambient temperature at ground level, T_g, is 30 ^{o}C and the native soil thermal resistivity, ρ_s, is 1 K·m/W [17]. The IEEE Standard 835 specifies a concrete thermal resistivity, ρ_c, of 0.6 K·m/W and a SBM thermal resistivity, ρ_{sbm}, of 1.0562 K·m/W [13, 16].

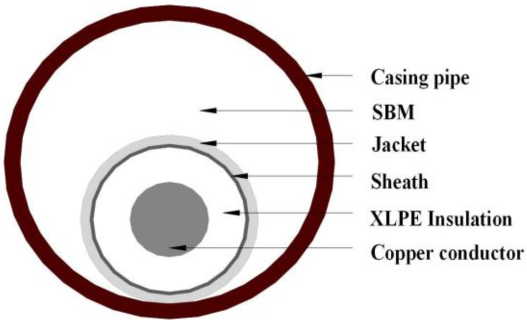

Fig. 1. Cross-sectional layout and arrangement of the power cable in a casing pipe

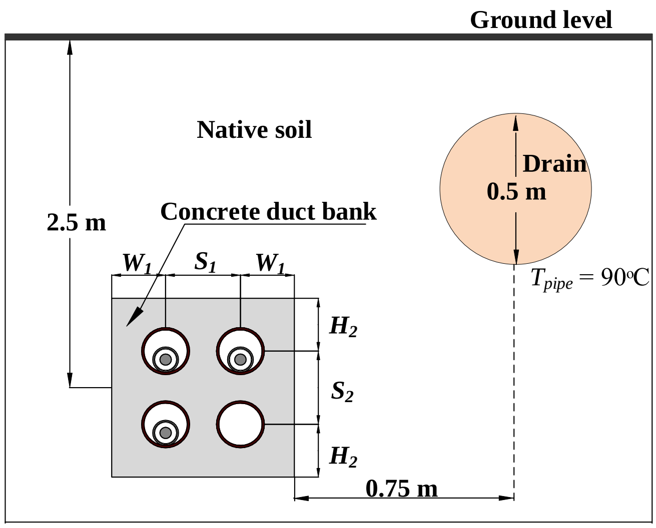

Fig. 2. The geometry of a concrete duct bank

Material	Radius (mm)	Thermal resistivity (K·m/W)
Copper conductor	190	2.5×10^3
XLPE Insulation	370	3.5
Copper sheath	385	2.5×10^3
PE jacket	430	3.5
HDPE casing pipe	800	3.5

Table 1. Dimension and thermal properties for an 800 mm^2 power cable in a casing pipe [16, 21, 22]

2.2 Determination of temperature distribution in underground power cable

To analyze the power cable temperature, T, the solution with using the heat transfer equation was defined as a functional relationship between the conductor current with the temperature in the cable and its surroundings. This is accomplished by assigning a conductor current and calculating the corresponding conductor temperature. In order to consider the cable ampacity, the conductor current, I, was increased with temperature increment to the critical temperature, T_{cc}, of the insulation at 90 ^{o}C for an XLPE insulator.

The thermal field in the cable medium is governed by the differential equation of heat conduction:

$$\nabla \cdot (\frac{1}{\rho} \nabla T) + \mathrm{Q} = c \frac{\partial T}{\partial t} \quad (1)$$

where T denotes temperature at any point, ρ and c represent, respectively, the thermal resistivity and thermal capacity. Q is the heat generation per unit of volume and t denotes the time.

For steady-state thermal analysis of two-dimensional media, (1) can be modified to:

$$\frac{\partial}{\partial x}\left(\frac{1}{\rho}\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial x}\left(\frac{1}{\rho}\frac{\partial T}{\partial y}\right) + Q = 0 \quad (2)$$

$$Q = \frac{W}{A_{\mathrm{hs}}} \quad (3)$$

where A_{hs} is the cross-section area of the heat source. W denotes the cable heat losses per unit length (W/m) which is also called the Joule loss. The heat losses of the conductor, W_{c}, dielectric, W_{d}, and sheath, W_{s}, can be calculated by the equations and material electrical properties of IEC 60287-1-1 at the cable core temperature, T_{c}, increased to 90 °C [9].

The heat losses of the conductor per unit length of the power cable is given by:

$$W_{\mathrm{c}} = I^2 \cdot R_{\mathrm{c,ac}}(T_{\mathrm{cc}}) \quad (4)$$

where I is conductor current (A). It was varied to power cable ampacity (at $T_{\mathrm{c}} = T_{\mathrm{cc}}$), I_{90}. $R_{\mathrm{c,ac}}(T_{\mathrm{cc}})$ is the alternating current electrical resistance of the conductor at temperature T_{cc}.

The dielectric heat losses per unit length of the power cable are given by:

$$W_d = \omega \cdot C \cdot \left(\frac{U}{\sqrt{3}}\right)^2 \cdot \tan\delta \quad (5)$$

where ω is the angular frequency of a three-phase system (rad·s^{-1}) for an f value of 50 Hz. C is the operating capacitance per phase and unit length (F/m) and tan δ is the dielectric loss factor.

The heat losses of the sheath per unit length of the power cable are given by:

$$W_{\mathrm{s}} = \Delta Q_{\mathrm{c}} \cdot (\lambda_1^{'}(T_{\mathrm{sc}}) + \lambda_1^{''}(T_{\mathrm{sc}})) \quad (6)$$

where $\lambda'_1(T_{\mathrm{sc}})$ is the loss factor due to circulating currents at temperature, T_{sc}, and $\lambda''_1(T_{\mathrm{sc}})$ is loss factor by eddy currents at temperature T_{sc}.

For a single-point end, the losses due to the circulating currents in the sheaths are negligible [11]. For the two-dimensional thermal model, it can be assumed that the right and left boundaries extend to 10 m from the center of the cable duct bank. The height of the boundary from the top to bottom was 10 m. The right, left and bottom boundaries are assumed to be the thermal insulation. The mesh dimensions of the thermal model were used to analyze mesh sensitivity. This was to ensure that the cable ampacity value was stable (did not significantly change). The temperature at the top edge (the ground level) T_{g} and the initial ambient temperature is 30 °C [16, 21].

3. Overview of Self-Adaptive Differential Evolution (jDE) Algorithm

DE algorithm is a meta-heuristic optimization algorithm introduced by Storn and Price [23]. It was developed from a GA. The main advantage of DE is simple, very strong global searching capability and superior performance when compared with other meta-heuristic algorithms. Recently, a Self-adaptive Differential Evolution (jDE) (jDE) by J. Brest [19] was proposed with the aim to enhance the convergence characteristic of traditional DE by adjusted of evolution control parameters (F and CR). The jDE procedures were described in the following steps [19]. In this section, the DE scheme is classified by notation as DE/best/2/bin strategy. This strategy is one of the most powerful strategies in practice [20] and it can be described as follows.

The individual or dimensional vector of optimization parameters is represented by D. The population consists of N parameter vectors $\mathbf{x}_{i,G}$, $i = 1, 2,\ldots N$. The G is represented one generation. There is one population for each generation. N denotes the number of members in a population. It is not changed during the minimization process. The initial population is determined by randomly with uniform distribution.

The jDE operations are three operations to consist of mutation process, crossover process and selection process, which are explained below.

3.1 Mutation process

In the first step, each vector of the initial population is randomly generated within the minimum and maximum limits as shown in (7).

For each target vector $\mathbf{x}_{i,G}$, a mutant vector $\mathbf{v}$ is generated according to (7) with randomly chosen indexes r1, r2, r3, r4 [1, N].

$$\mathbf{v}_{i,G+1} = \mathbf{x}_{best,\mathrm{G}} + F\left((\mathbf{x}_{r_1,G} - \mathbf{x}_{r_2,G}) + (\mathbf{x}_{r_3,G} - \mathbf{x}_{r_4,G})\right), \quad (7)$$
$$\text{When } r_1 \neq r_2 \neq r_3 \neq r_4 \neq i$$

The F is a real number that controls the amplification of the difference vector.

3.2 Crossover process

The target vector is mixed with the mutated vector by following scheme, to yield the trial vector.

$$\mathbf{u}_{i,G+1} = \left(u_{1i,G+1}, u_{2i,G+1}, \ldots, u_{Di,G+1}\right) \tag{8}$$

where

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & \text{if } r \le CR \text{ or } j = q \\ x_{ji,G} & \text{if } r > CR \text{ or } j \ne q \end{cases} \tag{9}$$

The CR is the crossover rate selected between [0,1], j and q are uniformly distributed random numbers in the range [1, D]. A random number, r, is generated between [0,1].

3.3 Selection process

In the last step, the fitness of trial vector is compared with the fitness of parent vector. In case the fitness of the trial vector is better than the fitness of the parent vector, the parameters of the next generation vector are selected to be equal to the parameters of the trial vector. Otherwise, the parameters of the next generation vector are selected to be equal to the parameters of the parent vector as shown in (10).

$$\mathbf{x}_{i,G+1} = \begin{cases} \mathbf{u}_{i,G+1} & \text{if } f(\mathbf{u}_{i,G+1}) > f(\mathbf{x}_{i,G}) \\ \mathbf{x}_{i,G} & \text{otherwise} \end{cases} \tag{10}$$

The trial vector, $\mathbf{u}_{i,G+1}$, yields a better fitness function value than $\mathbf{x}_{i,G}$, then $\mathbf{x}_{i,G+1}$ is set to $\mathbf{u}_{i,G+1}$; otherwise, the old value $\mathbf{x}_{i,G}$ is retained.

The setting control parameters for DE algorithm suggested by Storn et al. [23] and [24] are :

1) $F \in [0.8, 1]$;
2) $CR \in [0.8, 1]$.

As suggested by Storn [23], the proper values of control parameters frequently depend on the problem to solve. The control parameters are determined by the trial-and-error method with multiple optimizations for tuning parameters. Suitable control parameters are different for various function problems. To reduce the difficulty of setting parameter and maintainability for the best solution, the jDE algorithm presented by J. Brest has presented to use for simple method with analysis of the adaptive control parameters (F, CR).

New control parameter or $F_{i,G+1}$ and $CR_{i,G+1}$ are calculated by

$$F_{i,G+1} = \begin{cases} F_l + r_1 * Fu, & \text{if } r_2 < \tau_1 \\ F_{i,G} & \text{otherwise} \end{cases} \tag{11}$$

$$CR_{i,G+1} = \begin{cases} r_3 & \text{if } r_4 < \tau_2 \\ CR_{i,G} & \text{otherwise} \end{cases} \tag{12}$$

The produce factors F and CR in a new parent vector. r_1, r_2, r_3 and r_4 are uniform random between [0,1]. τ_1 and τ_2 represent probabilities to adjust factors F and CR, respectively. From suggestion of J. Brest, τ_1 and τ_2 are set to 0.1. Because F_l = 0.1 and F_u = 0.9, the new F takes a value form [0.1,1.0] in a random manner. The new CR takes a value from [0,1].

The rules for self-adapting control parameters F and CR are quite simple. Therefore, the jDE algorithm does not increase the time complexity in comparison to the original DE algorithm.

4. Algorithm development

This study applies the jDE for minimizing the cross-sectional area A_c of the concrete duct bank. Fig. 2 shows the design variables of a concrete duct bank dimension (W_1, W_2, H_1, H_2, S_1 and S_2).

$$\mathbf{x} = [W_1 \quad W_2 \quad H_1 \quad H_2 \quad S_1 \quad S_2] \tag{13}$$

The objective function for minimizing the cross-sectional area A_c of concrete duct bank by the permissible cable temperature will not be violated. The development based on FEM for power cable thermal analysis at the cable ampacity.

$$Minimize\ F(\mathbf{x}) = \begin{cases} A_c(\mathbf{x}) & \text{if} \quad T_c(\mathbf{x}) \le T_{cc} \\ A_c(\mathbf{x}) + P(\mathbf{x}) & \text{otherwise} \end{cases} \tag{14}$$

$$P(\mathbf{x}) = c*(T_c(\mathbf{x}) - T_{cc}) \tag{15}$$

The T_{cc} is the critical temperature of the insulation at 90 ^{o}C for an XLPE insulator and T_c denotes the maximum cable conductor temperature for FEM simulation with the $\mathbf{x}$ vector of design variables. It should be noted that the constant number of penalty factor, c, is equal to 10000, since the constraint is only that the T_c temperature shall not exceed the T_{cc} value. Therefore, the current conductor has determined the maximum capacity of power cable.

The values of the design variable fell between the lower bounds, which depend on the dimensions of casing pipe, concrete cover and the upper bounds, as identified by Ocłoń et al. [16, 17]. The values for H and W are 0.09 – 0.4 m with an S value of 0.16 – 0.6 m.

Then, the jDE optimization procedure was applied to solve the constrained optimization problem given by Eqs. (14), (15). The detailed application of jDE algorithm combined the FEM for the analyzed underground power cables system was shown in Fig.3.

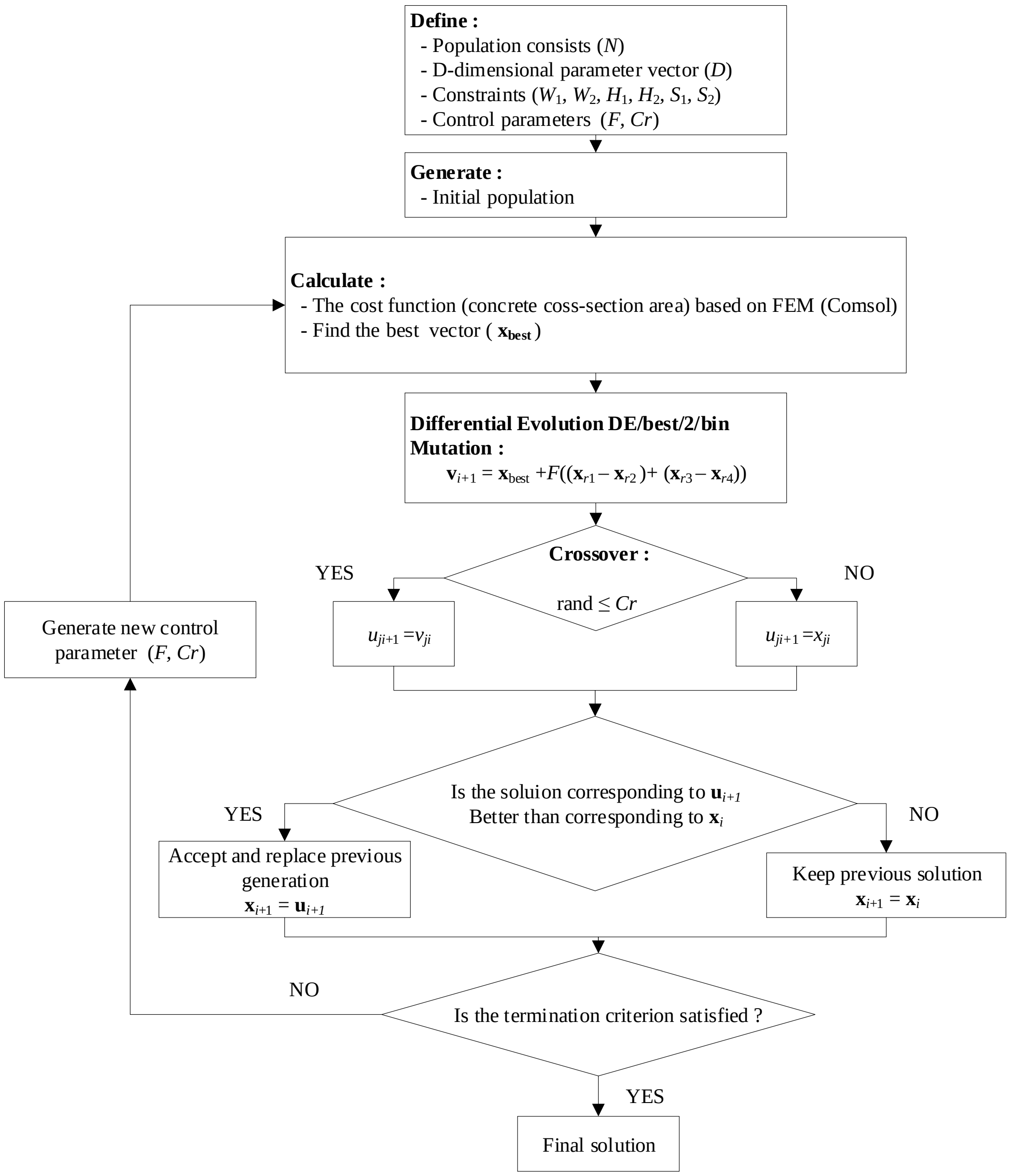

Fig. 3. Flowchart of the jDE for optimal design variables of concrete duct bank dimensions.

5. Results and discussions

From the economic reasons, the concrete duct bank cross-sectional area shall be minimized while ensuring the conductor temperature close to 90 ^{o}C. Therefore, the jDE with FEM combination is applied to optimization for the concrete area cross-sectional area the problem.

This section presents the performance of a concrete duct bank cross-sectional area optimization by jDE. Consideration has presented with installation of underground power cable in normal case and in case with drain pipe (hot water). These algorithms can be programmed by COMSOL and MATLAB software to run on a computer with Intel Core i7-7700-3.60 GHz and 8 GB DDR4 RAM. Moreover, this comparative study by PSO, mPSO and GA. All of the optimization methods for this study have set the parameters as population, N, of 10 and the number of iterations of 100. The control parameters of each algorithm are defined as follows:

For jDE $\tau_1 = \tau_2 = 0.1$ suggested by J. Brest et al [19].

For PSO the inertia weight, the cognitive learning factor, and social learning factor are assigned as 0.4-0.9, 0.2 and 0.2 respectively [18].

For mPSO the inertia weight, the cognitive learning factor, and social learning factor are assigned as 0.1, 2 and 2 respectively [16, 17].

For GA, the crossover rate is 0.50 and the mutation rate is 0.03.

5.1 Optimization for underground installation in normal case

First of all, for optimization concrete duct bank, the cross-sectional area of power cable have to identify the value power cable of traditional design. Based on the analysis of power cable ampacity by FEM with the heat transfer module of COMSOL Multiphysics [25], the conductor current, I, was increased until the conductor temperature reached the critical temperature, T_C, of XLPE insulation, at 90 ^oC.

For analysis of the traditional design of concrete duct bank as shown Fig.2, the system does not include drain pipe with a W of 0.180 m, H of 0.180 m and S of 0.250 m [21]. The analysis of ampacity by FEM was considered with a cross-sectional area, A_c, of concrete corresponding to the traditional design and using a concrete resistivity, ρ_c, of 0.6 K·m/W, an I_{90} of 904 A and A_c of 0.352 m^2. The thermal model was presented with mesh elements of about 29,700. The result of cable ampacity by IEC 60287 using a commercial program CYMCAP [26] was 950 A. The difference between the cable ampacity of FEM and IEC 60287 was 4.84%. Fig. 4 shows the FEM mesh in a duct bank power cable and thermal distribution.

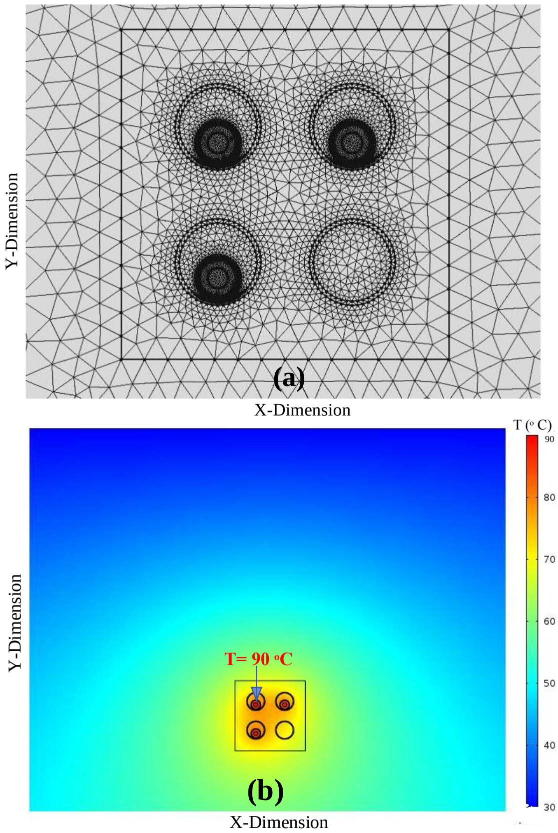

Fig. 4. Thermal simulation for a duct bank power cable with (a) FEM mesh and (b) thermal distribution in a duct bank power cable in case of traditional design

The optimizations are carried out in order to find the best combination of the design variables W_1, W_2, H_1, H_2, S_1 and S_2. The following cable ampacity is taken into consideration, which is 904 A at same the traditional design. The results of minimum concrete cross-section area and average optimal value by jDE, PSO, momentum-type PSO and GA among the 10 independent runs are shown in Table 2. The standard deviation and percentage reduction from the traditional design are also indicated.

From simulation results shown in Table 2, it is observed that the best of the concrete duct bank cross-sectional area obtained by jDE is slightly less than that obtained by PSO, and mPSO. However, GA does not find the optimal value. As a result, the optimize structural sizing the concrete duct bank by jDE indicates better minimize cross-sectional area of concrete than that of the others, which yields the best percentage of cross-section area reduction. In addition, the average optimal value and standard deviation accomplished by jDE are significantly less than those of PSO and mPSO. Then, it is concluded that the overall performance of the optimize structural sizing of the concrete duct bank by jDE is remarkably better that those of PSO, mPSO and GA. In addition, the convergence characteristic of the optimize structural sizing of the concrete duct bank for each algorithm is illustrated in Fig. 5.

5.2 Optimization for underground installation with drain pipe

In urban and industrial estate areas, the surrounding of the underground power cable may close to other utility pipelines such as oil, water, sewer and steam pipes. However, the IEC 60287 is not efficient to analyze with an irregular configuration due to the complexity of the surroundings power cable problem. In this study, the for considering the cable thermal circuit, the cable route is complex and parallel surround with a hot water pipe. Therefore, the thermal field solution of the cable system was carried out by IEC 62095 (FEM) in order to determine the cable ampacity.

The traditional design of concrete duct bank use dimensions as following Fig.2. For analysis of ampacity by FEM considered with a cross-sectional area, A_c, of concrete corresponding to the traditional design and using a concrete resistivity, ρ_c, of 0.6 K·m/W, the result of cable ampacity, $I_{90,}$ is 711 A. Fig. 6 shows the FEM thermal distribution in a duct bank power cable with drain pipe (hot water) of 90 ^oC. However, the maximum loading of the transmission line of the provincial electricity authority (PEA) 115kV system is 803 A.

For following the thermal model of duct bank power cable with drain pipe parameters, the cable ampacity is taken into consideration: 803 A form the maximum loading of the transmission line of PEA. The results of minimum concrete cross-section area and average optimal value by jDE, PSO, momentum-type PSO and GA among the 10 independent runs are shown in Table 3. The standard deviation and percentage reduction from the traditional design are also indicated.

Methods	Design variables (mm)							Objective function			
	W_1	W_2	H_1	H_2	S_1	S_2	T_c	Minimum A_c (mm^2)	ΔA_c (%)	Average A_c (mm^2)	SD
jDE	90.00	90.00	90.00	90.00	174.61	401.79	90.00	206307.01	-41.39	209292.87	6280.64
PSO	90.00	90.00	90.00	90.00	166.00	416.48	90.00	206384.25	-41.37	230264.02	35486.15
mPSO	90.00	90.00	90.00	90.00	165.00	418.27	90.00	206405.64	-41.36	214858.33	11173.34
GA	96.06	90.00	90.00	93.03	176.06	396.74	89.97	211000.19	-40.06	233541.64	19851.39

Table 2 Optimal values of variables obtained by the minimum concrete cross-section area in the normal case of the cable ampacity for I = 904 A by jDE, PSO, mPSO and GA over 10 independent runs.

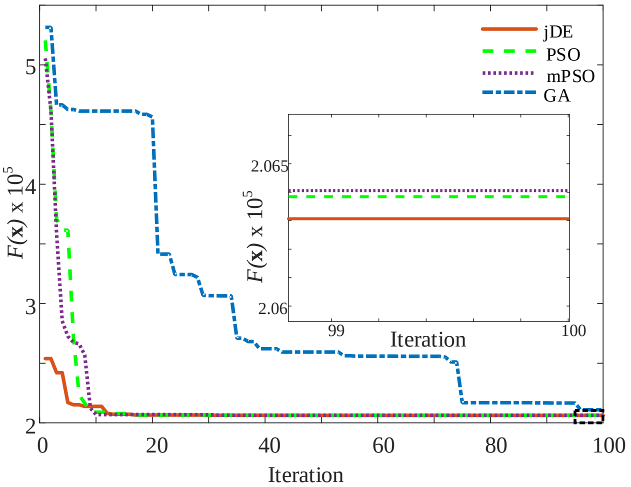

Fig. 5 Convergence profile of jDE, PSO, mPSO and GA in the normal case of the cable ampacity for I = 904 A.

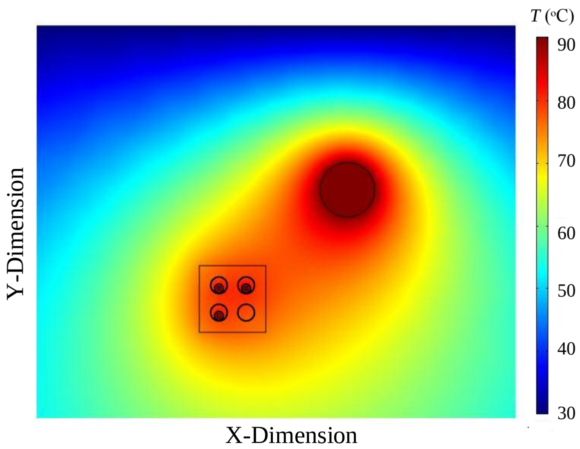

Fig. 6. Thermal distribution in a duct bank power cable with drain pipe (hot water)

Methods	Design variables (mm)							Objective function		
	W_1	W_2	H_1	H_2	S_1	S_2	T_c	Minimum A_c (mm^2)	Average A_c (mm^2)	SD
jDE	269.94	90.00	90.00	90.00	600.00	165.00	90.00	331180.76	331215.91	73.25
PSO	269.96	90.00	90.00	90.00	600.00	165.00	90.00	331185.05	344489.24	24015.76
mPSO	269.91	90.00	90.00	90.00	600.00	165.02	90.00	331185.51	332085.63	1913.62
GA	304.55	109.39	92.73	90.00	600.00	214.33	88.93	380045.60	441163.82	53861.73

Table 3 Optimal values of variables obtained by the minimum concrete cross-section area install with a drain pipe 90 °C of the cable ampacity for I = 803 A by jDE, PSO, mPSO and GA over 10 independent runs.

From simulation results shown in Table 3, it is observed that the best of the concrete duct bank cross-sectional area installs with a drain pipe 90 °C of the cable ampacity for I of 803 A obtained by jDE is slightly less than that obtained by PSO, and mPSO. However, GA does not find the optimal value. As a result, the average optimal value and standard deviation accomplished by jDE are significantly less than those of PSO and mPSO. Then, it is concluded that the overall performance of the optimize structural sizing the concrete duct bank by jDE is remarkably better than those of PSO, mPSO and GA.

From the above simulation results, it is shown that both cases of the optimize structural sizing for the concrete duct bank by jDE method have better performance than that of the PSO, mPSO and GA methods. The reason why the jDE is quite effective in solving the optimization problem is that the jDE includes the self-adapting control parameters. The jDE algorithm does not increase the time complexity, in comparison to the original DE algorithm, then the leader always explores and exploit the space of solution.

6. Conclusions

In this research, the optimal design variables of concrete duct bank dimensions installation in the normal case and complex surrounding (with drain pipe) by using the combination of Finite Element Method (FEM) and self-adaptive Differential Evolution (jDE) were reported. The simulation results obtained from the proposed jDE were compared with other algorithms of Particle Swarm Optimization (PSO), momentum-type PSO (mPSO) and Genetic Algorithm (GA). It was found that the minimization concrete cross-section area of the duct bank power cable, the optimizing by jDE, PSO and mPSO were practical to dimension the duct bank power cable for both normal and complex surrounding installations. The jDE, PSO, mPSO and GA were used to find the optimal value slightly different. However, the optimizing by jDE is higher global searching capability than PSO and mPSO. Since, the optimal value and average of optimum value were less than other algorithms.

Moreover, the standard deviation value by jDE is less than other algorithms for both normal and complex surrounding installations. This represents that the dislocation density results are also less. From the results, it can be concluded that the performance of the jDE algorithm for the optimal design variables of concrete duct bank dimensions is better than the PSO, mPSO and GA algorithms. Then, the combination of FEM and jDE becomes the best choice to reduce the optimal design variables of concrete duct bank dimensions under this research.

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