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Optimal Network Reconfiguration Considering Weighted Sum Multiobjective Cuckoo Search Spring Algorithm

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Abstract – **Distribution network reconfiguration is to reconstruct the network at reasonable structure that can deliver the electrical energy efficiently by changing the topology switches between tie-line and sectionalizing switch. In this paper, Multiobjective Cuckoo Search Algorithm (MOCSSA) is presented to determine the optimal network reconfiguration based on weighted sum approached. Two objectives function power loss minimization P_{loss} and voltage profile improvement Vmin are considered simultaneously at various weightage ratio. The proposed algorithm is tested on IEEE 69-Bus test System. From the analysis, the proposed algorithm had yielded better optimal solution.**

Index Terms – **Multiobjective Cuckoo Search Spring Algorithm, Weighted Sum, Voltage Profile Improvement, Power Loss Minimization, Network Reconfiguration**

I. INTRODUCTION

THE electrical power system is an infrastructure modern society and having complex interconnected network. The generation, transmission and distribution networks are major components, that delivers electricity as requested to end users. These components are differentiated with potential voltage level. The complete circuit will allow current flows, and ratings are depending to potential voltage with considering fraction on the system, called resistance [1].

The electrical power system contributes 13% of power loss from total supply generated [2]. The 80% comes from distribution network [3]. Many factors affecting power losses, such technical and non-technical losses. The technical losses related with variability of load, voltage profile, length of system conductor, and performance of load.

The network reconfiguration is a process of changing topology switches between tie-line and sectionalizing switches by "closing" the "normally opened" switch and "opening" the "normally closed" switch, respectively [4]. With the large scale of distribution network, studying the problem of optimal swithes has important practical value and research significant [5]. Hence, the challenges is to select optimal switches whereas influene the minimum losses value and improve voltage profile in the distribution network. The network reconfiguration can be considered as single objective or multiobjective, minimize losses, maximize voltage profile.

There are many techniques has been proposed by previous researchers to determine the optimal network reconfiguration such as Quantum Genetic Algorithm [6], Cuckoo Search Algorithm [5], Gravitional Search Algorithm [7], and Hopfield Neural Network [9]. Obviously the optimization of switch for distribution network reconfiguration has different concerns and challenges. In those cases, more research is needed in order to improve the existing approaches.

The multiobjective is applied extensively not only to provide multiple solution by various of weights, but also reflects of single set of weights [13]. On top of that, there are many approaches to define the weight with different perspective and priorities. The weighted sum is often presented as a tools that focus on application while the problem tend to be limited to those with just two objective functions. Fixed weighted sum for multiobjective named comprehensive objective function is to normalize the objectives [14].

The spring concept is to design the displacement along upper and lower bound of switches as the variables whereby always conflicted with the optimal values [15]. It reflects between more than single variables communication impact the objective functions.

Therefore, this paper introduces the elastic concept of spring function to enhance the existing algorithm namely as Cuckoo Search Spring Algorithm (CSSA) to determine the optimal network reconfiguration based multiobjective function.

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II. Methodology

The methodology is discussed on four different topics to catch the scope of work within analysis not over the gap.

A. Network Reconfiguration

The network reconfiguration is defined as a process of changing the topology by accomplished changing open/close state of switches for a certain objective [11]. Vector of bus voltage source and magnitude of current flowing through the line, are the impact after network reconfiguration complete the process. Voltage source at selected buses is different between before and after activity of network reconfiguration. The selected buses are taking the source from existing feeders, due to the performance of network, these buses will change the voltage source to optimal adjacent feeders by the same process of network reconfiguration. The first objective function (F_1) is specified as,

$$minimize\ (F_1) = min(P_{loss}) = \sum_{i=1}^{n} P_{loss} \quad (1)$$

For power loss equation can be described as follows (2) and (3):

$$P_S = \left(\left(|A| \left| V_{S(L-L)} \right|^2 \right) / (|B|) \right) - \left(\left(\left| V_{S(L-L)} \right| \left| V_{R(L-L)} \right| \right) / (|B|) \right) \cos(\theta_B + \delta) \quad (2)$$

$$P_R = \left(\left(\left| V_{S(L-L)} \right| \left| V_{R(L-L)} \right| \right) / (|B|) \right) \cos(\theta_B - \delta) - \left(\left(|A| \left| V_{S(L-L)} \right|^2 \right) / (|B|) \right) \cos(\theta_B - \theta_A) \quad (3)$$

A and B are constant in polar form as $A = |A|\angle\theta_A$ and $B = |B|\angle\theta_B$. Where $B = jX'$, $\theta_A = 0$, $\theta_B = 90^o$ and $A = cos\beta\ell$, and the real receiving power is given by

$$P_R = \left(\left(\left| V_{S(L-L)} \right| \left| V_{R(L-L)} \right| \right) / (X'') \right) \sin\delta \quad (4)$$

Losses value is a different process between supplying and receiving real power as illustrated in (5).

$$P_{loss} = P_S - P_R \quad (5)$$

The distribution network is becoming viable solution and supported with improving the performance of networks. Voltage profile is the major consideration of doing network reconfiguration, either getting better or worse. The quality of voltage profile influences the reliability of supply, current value flowing through the lines, losses value and finally network security is taking place into consideration and improvement. The requirement of voltage tolerance must be always satisfied at ±10% of nominal voltage value [20].

The voltage magnitude deviation considers the limition of voltage magnitude imposed by utilities [16]. Therefore, the second objective function for cumulative voltage deviation as shown in (6) and (7).

$$minimum\ (F_2) = min(V_{min}) \quad (6)$$

$$CVD = \begin{cases} 0, if\ V_{min} \le V_i \le V_{max} \\ \sum_{i=1}^{N} |1 - V_i|, else \end{cases} \quad (7)$$

B. IEEE 69-Bus Test System

In this paper, IEEE 69-Bus distribution test system is utilized to evauate the effectiveness of the proposed algorithm. The total real and reactive loads in the test system are 3.802MW and 2.695MVAR respectively. It consists of 69 bus with 8 radial circuits at downstream level as shown in Fig. 1. The 68 switches are connected between individual and interconnected buses with numbering 1 to 68, respectively and it is called sectionalizing switch.

The five tie-line and area of sectionalizing switches are identified on this study as shown in Table 1. The tie-line represent as TL1, TL2, TL3, TL4 and TL5, respectively. Each of TL1, TL2 and TL3 have one area of sectionalizing switch, whereas TL4 and TL5 have two area of sectionalizing switch. Every tie-line will have switch number as 69, 70, 71, 72 and 73, there are located between bus 8 – 43, 16 – 46, 12 – 21, 50 – 59, and 27 – 65. When it relates to disconnection of sectionalizing switch and connection of tie-line switch, complete circuit is found with remaining number of feeders.

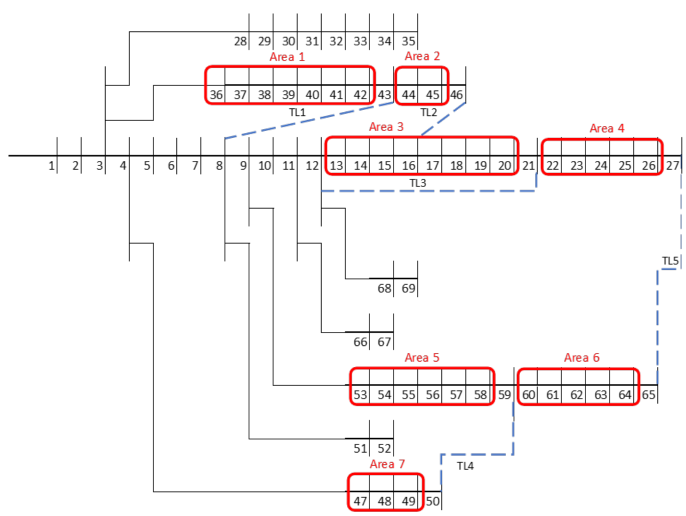

Fig. 1: Single line diagram 69-Bus IEEE Test System

TABLE I
Tie-Line And Sectionalizing Data

Switch No.	Tie-line	From Bus-to-bus	Area of section switch

69	TL1	8 - 43	S6: 36 - 42
70	TL2	16 - 46	S7: 44 - 45
71	TL3	12 - 21	S8: 13 - 20
72	TL4	50 - 59	S9: 47 - 49 S10: 53 - 58
73	TL5	27 - 65	S11: 22 - 26 S12: 60 - 64

C. Cuckoo Search Spring Algorithm (CSSA)

The Cuckoo Search Spring Algorithm is a recently developed metaheuristic optimization based on nature-inspired to solve optimization problems in different fields of engineering [17]. It is a novel swarm intelligence optimization algorithm where it is proved to solve some optimization problems based in the brood parasitism of some cuckoo species, with enhanced Levy flights, rather than by simple isotropic random walks [18]. It is highly effective in solving global optimization by maintaining balance between local and global random walks using switching parameter, however it has disadvantages, as it is easily trapped in local optimal solution. Normally, the parameters are constantly for certain life span affecting the efficiency of algorithm. Cuckoo Search Algorithm is the cuckoo birds as parasitic nature during breeding process. The advantage of host birds is taken for cuckoo birds laying their eggs on the host birds' nest and the eggs were hatched by the host bird. The host birds will either abandon the foreign eggs or leave the nest entirely to build a new nest. It is based on the life span of a cuckoo bird. Cuckoos are interesting birds, not because of a good sound they can make but also because of reproductive and confrontational strategy. Moreover, for gaining access of feeding opportunity, the cuckoo chick can emulate the host chicks. The standard of Cuckoo Search Algorithm has three following ideal rules [19]. The current solution is discarded but the new solution is presented.

Rule 1: Each egg is produced by one cuckoo birds at a time, and one nest is randomly selected.
Rule 2: The next generation is retained from the best nest and high-quality eggs have been chosen.
Rule 3: The total number of available nests is fixed, and probability of host birds discovering foreign eggs is P_a ϵ[0,1].

Based on these three rules, it can be summarized as the pseudo code as shown in Fig. 2, illustrate the basic steps of the Cuckoo Search Algorithm.

Fig. 3 illustrates the flow chart process using Cuckoo Search Algorithm for multiobjective function to clarify the fitness function.

The parameters of n = 25, pa = 0.25 and number of iterations is 100 are set in simulation with lower bound (LB) and upper bound (UB) represent as tie-line and sectionalizing switches boundary.

The standard Cuckoo Search Algorithm realizes the simulation with the basis three ideal states and the produce the candidate populations to enhance the searching activity. Lévy Flights is commonly integrated. It can be expressed as follows (8) and (9) [20]:

$$X_i^{new} = Xbest_i + V_i^{new,Levy} \tag{8}$$

$$V_i^{new,Levy} = \alpha \times random[0,1] \times (Xbest_i - Gbest) \times Levy(\beta) \tag{9}$$

```
Cuckoo Search via Levy Flights
begin
    Objective function f(x), x = (x1,....,xd)^T
    Generate initial population of
        n host nests xi (I = 1,2,...,n)
    while (t<MaxGeneration) or (stop criterion)
        Get a cuckoo randomly by Levy flights
                1valuate its quality/fitness Fi
        Choose a nest among n (say, j) randomly
        if (Fi > Fj),
                replace j by the new solution;
        end
        A fraction (pa) of worse nests
                are abandoned and new ones are built;
        Keep the best solutions
                (or nests with quality solutions);
        Rank the solutions and find the current best
    end while
    Postprocess results and visualization
end
```

Fig. 2: Pseudo code of Cuckoo Search Algorithm

From the Lévy Flights, the next solution is almost like the previous solution, then the solution will not be recognized. In that case, it needs the different solutions.

The flexibility between equity and inequity of variables to select the optimal swithes using the spring element. This algorithm is presented in the design parameters vector:

$$x_i = x_{i,1}, x_{i,2} \dots \dots . x_{i,n} \tag{10}$$

$$x_j = x_{j,1}, x_{j,2} \dots \dots . x_{j,n} \tag{11}$$

$$y = f(x) = \begin{cases} x_i, & 0 \le x_i \le 1 \\ x_j, & 0 \le x_j \ge 68 \end{cases} \tag{12}$$

x_i is the tie-line switches until n^{th} number whereby "0" is open position and "1" is close position. While, x_j is represent the sectionalizing switches is between 0 and 68, whereby "0" is depicted as close position switch, 1 until 68 represent the line section when it is numbered dedicated as open position. The implementation of spring algorithm in traditional CSA namely Cuckoo Search Spring Algorithm (CSSA) is used in this paper to compete the optimal selected switches for network reconfiguration purposes for achieving the objective function.

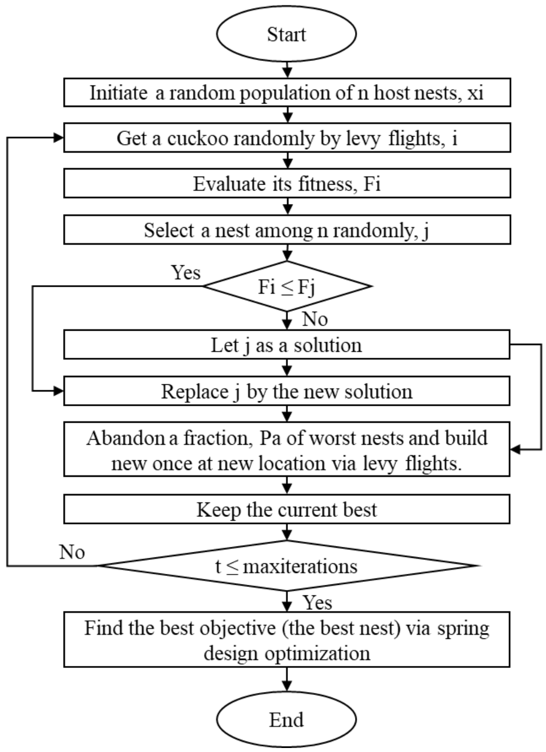

Fig. 3: Flow chart process for CSSA

D. Weighted Sum Implementation in Multiobjective Function

As discuss earlier, multiobjective function is the combination more than single objective function. In this study is focusing on losses and voltage profile considered as two objective functions. Equation 13 indicates the weighted sum equation with the weight can be set as (11).

$$F(x) = w_1\, F_1(x) + w_2 F_2(x) + \ldots + w_m F_m(x) \tag{13}$$

$$\sum_{i=1}^{k} w_i = 1, \qquad w \geq 0 \tag{14}$$

To consider the problem with two unconstraint objective function as shown below:

$$z = (w_1 . F_1) + (w_2 . (1 - F_1)) \tag{15}$$

Where:

- w_1 Weight of losses [0,1]
- w_2 Weight of voltage profile [0,1]
- F_1 P_{loss} as the objective function
- F_2 V_{min} as the objective function
- $F(x)$ Combination between more than single objective function

The weight represents in percentage value and this paper will present three different percentage ratios to evaluate the optimal percentage considering to convergence time and minimum fitness value. In this paper, the ratio is representing as:

1) *R1 = w1(25%).w2(75%),*
2) *R2 = w1(50%).w2(50%), and*
3) *R3 = w1(75%).w2(25%).*

III. Result And Discussion

In this paper, MOCSSA is utilized to determine the optimal network reconfiguration for power loss minimization and voltage profile improvement.

Table II illustrates the changes operating of topology switch between sectionalizing and tie-line switches using MOCSA. Each of ratio shows there are 6 switches involve in changes of position from initial condition in a way of improving distribution network performance. The tie-lines at S3, S4 and S5 are in close position whereas S1 and S2 stay in open position of switch. The opposite of tie-line switches, S8 represent the line 17, S10 represent the line 55 and S12 represent the line 61 are change from close position switch to open position switch, respectively. These three-ratio resulting the same sectionalizing and tie-line switches operated in a such way to get the optimal network reconfiguration.

TABLE II
The Switching Involves For Mocssa

Ratio	Tie-line Switch				
	TL1	TL2	TL3	TL4	TL5
R1	0	0	1	1	1
R2	0	0	1	1	1
R3	0	0	1	1	1

Ratio	Sectionalizing Switch						
	S6	S7	S8	S9	S10	S11	S12
R1	0	0	17	0	55	0	61
R2	0	0	17	0	55	0	61
R3	0	0	17	0	55	0	61

TABLE III
The Improvement Of Voltage Profile And Losses

Ratio	Initial		MOCSSA		Percentage Improvement	
	V_{min} (p.u)	P_{loss} (MW)	V_{min} (p.u)	P_{loss} (MW)	V_{min}	P_{loss}
R1	0.9093	0.2246	0.9428	0.1119	3.68%	50.17%
R2	0.9093	0.2246	0.9428	0.1119	3.68%	50.17%
R3	0.9093	0.2246	0.9428	0.1119	3.68%	50.17%

In terms of voltage profile performance and reduction of losses, these three ratios show the same improvement for voltage and losses as shown in Table III. There is no different result value after complete network reconfiguration since the same operating optimal switch involves. As a result, each of ratio contribute the improvement of distribution network performance through this algorithm without differences to the other ratios.

The voltage result performance at individual bus is organized as shown in Fig. 4, where the same operating switch influencing the same voltage performance at every bus contribute 5 buses reduce of voltage level after performing network reconfiguration by optimal changes switch, whereas 23 buses unchange, and 41 buses increase the bus voltage level.

Fig. 5, 6 and Fig. 7, present the convergence curve of MOCSSA for ratio (w1 = 25% w2 = 75%), (w1 = 50% w2 = 50%), and (w1 = 75% w2 = 25%), respectively. Fig. 5 shows the algorithm converge at 45th iteration to the very minimum fitness value of 0.0710. Meanwhile, Fig. 6 shows at the respective ratio resulting the algorithm converge at 2nd iteration with the minimum fitness value, 0.0846. End of it, Fig. 7 shows by the selected ratio given in this paper, the algorithm converges at 47th iteration with the value of 0.0982.

Furthermore, as compared between three ratios in simulation, the ratio of w1 = 50% and w2 = 50% contribute 96% the fastest convergence curve. But the fitness value is in between performance of two comparative ratios, and it results the moderate fitness value, not too low and not too high differences.

The optimal network reconfiguration not only counting the performance of voltage profile and losses, but it is also evaluating the convergence of iteration number for achieving the minimum fitness value. Time taken for making decision is very important to find the optimal switches for reconfiguration distribution network protecting the receivable voltage and influence the losses injected by unnecessary current value.

From the result, it shows that, the percentage ratio between two objective functions, P_{loss} and V_{min} in Weighted Sum simulated with CSSA has the ability of influencing the performance of the algorithm to access the minimum fitness value. On top of that, the optimal network reconfiguration using MOCSSA and application of Weighted Sum for three different ratios having the differentiation in iteration number to achieve the performance of distribution network.

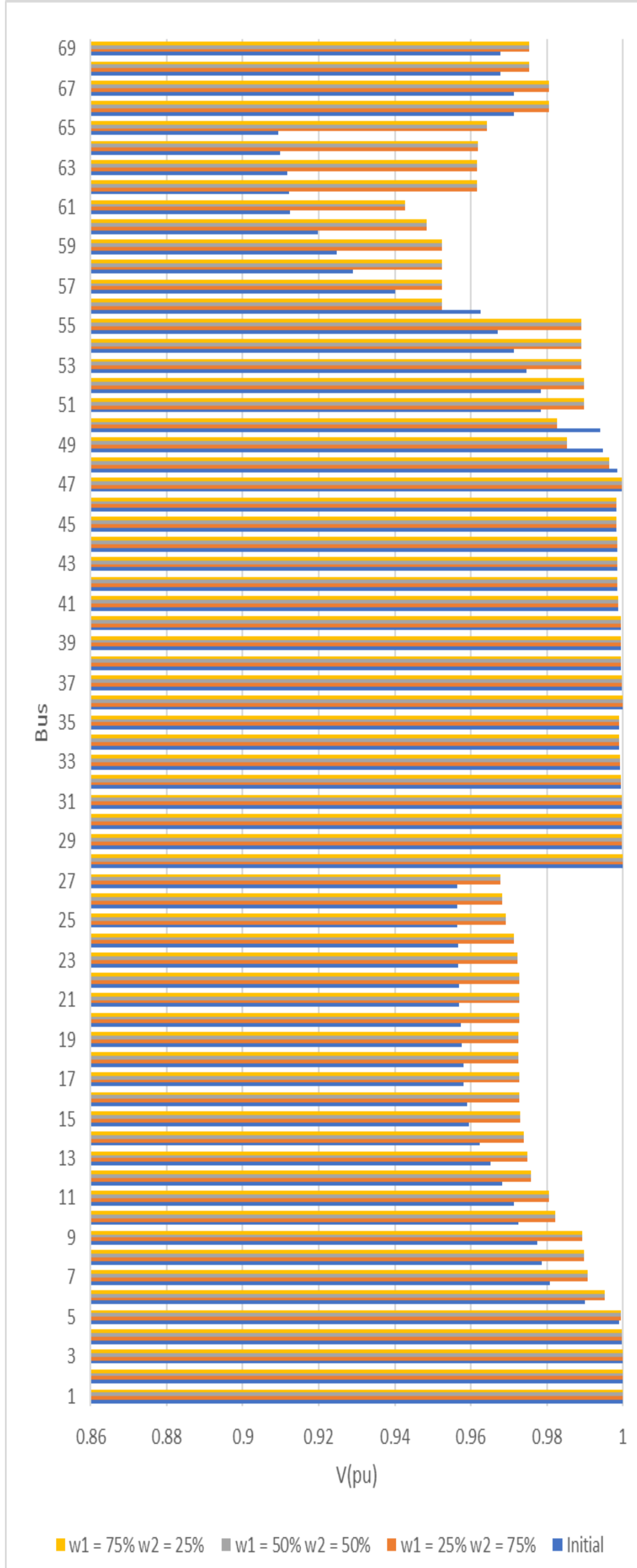

Fig. 4: The 69-bus voltage performance

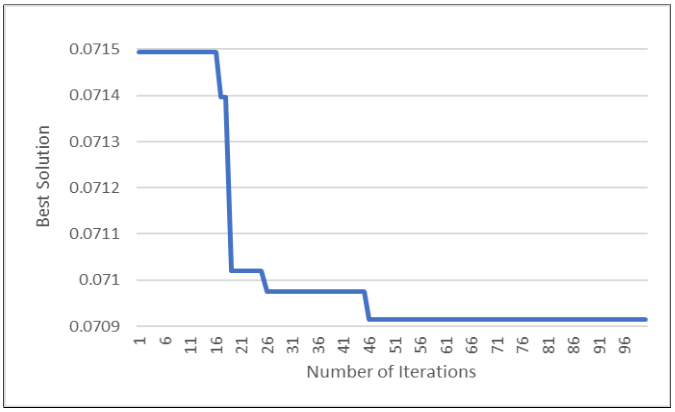

Fig. 5: The minimum fitness and convergence curve for ratio of w1 = 25% w2 = 75%

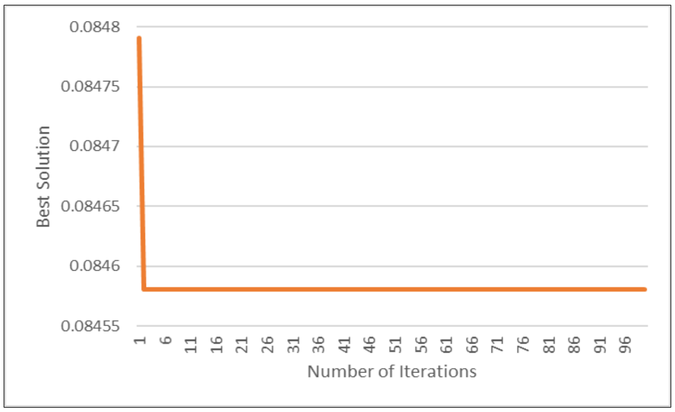

Fig. 6: The minimum fitness and convergence curve for ratio of w1 = 50% w2 = 50%

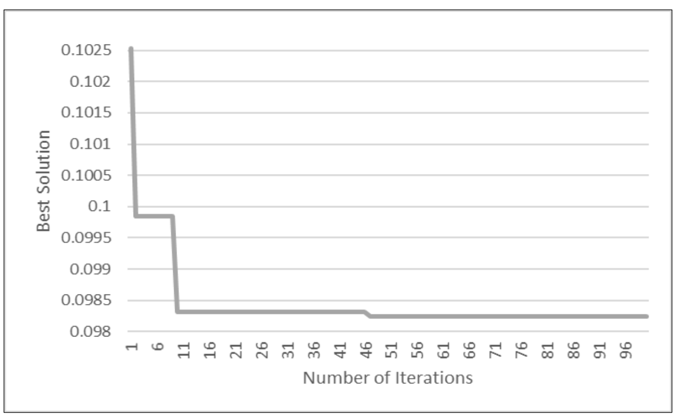

Fig. 7: The minimum fitness and convergence curve for ratio of w1 = 75% w2 = 25%

IV. Conclusion

This paper had presented Multiobjective Cuckoo Search Spring Algorithm (MOCSSA) for determining the network reconfiguration using IEEE 69-Bus Test System. Network reconfiguration is a process of changing topology switches between tie-line and sectionalizing switches. The objective function considered voltage profile improvement and minimize losses. Both objective functions are simulated simultaneously using various weighted sum ratio. The result showed that, the optimal switches during reconfiguration using MOCSSA produced best result in terms of voltage profile improvement and minimum power losses.

The recommendation for the next is to enhance the scale of boundary area between tie-line and sectionalizing switches where it can provide the minimum voltage is between acceptable limits of the nominal voltage.

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