International Journal of Technical Research (IJTR)
Vol. 8, Issue 1, Jan-Dec 2019

Designing of Power Distribution Network Using Simulated Annealing Algorithm

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Abstract — The rural communities located in remote locations are living in dark due to unavailability of power supply. Electrification of such communities can be done by installing an independent community based low voltage microgrid. In this research paper, the planning of ring distribution network is done with the objective of minimization of conductor length used in it. Simulated Annealing algorithm is implemented on the actual data of a village and the optimized ring distribution network is proposed for the same. This work can be useful for researchers and engineers involved in project of setting up microgrid in rural communities.

Keywords— Power distribution Planning, Simulated Annealing, rural electrification.

I. INTRODUCTION

In the modern era of electrification, 31 million homes are still living without electricity as reported by Forbes [1]. Though government is putting efforts to join such rural areas to the central grid, but the possibility of connecting remote rural areas to the central grid is low because of lack of supply of necessary infrastructures and supply needs. So, installation of independent community based microgrid is a viable solution for these areas and is being accepted around the globe. Many exemplary set-ups of independent microgrid like electrification in villages of Karnataka by Selco Company [2], electrification in Rajasthan villages as mentioned in [3] are capable of supplying the day to day electricity needs of the area satisfactorily. The planning of independent grid constitutes many important parts like location of solar power panel, layout of the grid and maintenance of the installed setup. In countries like India, where solar radiations are available for more than 200 days a year, solar energy is most easily available energy resource for generating electricity [4]. The installation of solar power plant at a suitable location in the village and supplying the electricity to all the houses in the community is an upcoming solution for such electricity starved rural areas. The investment cost involved in laying out the grid makes a large fraction of total investment cost of the setup. Therefore, the minimization of conductor length plays an important role not only in minimizing the investment cost but also in reducing the distribution losses. So, the main objective of this research paper is connecting all the houses in a rural community in a closed loop so that minimum conductor length is used. This objective problem is analogous to standard Travelling salesman problem (TSP). Now-a-days, the analogy of TSP with many other optimization problems makes it useful for solving many problems of logistics, vehicle routing, printing, soldering of PCB boards etc. As the complexity and size of the problem increases, the time taken for solving it increases extensively and in majority of cases, it is not feasible to solve them for most practical purposes. Different complex problems can be solved by computational techniques but still there are some problems which are fundamentally harder to solve. However, many intelligent algorithms have been developed that solve the complex problems rapidly. Algorithms like Nearest Neighbor algorithm, genetic algorithm, greedy heuristic algorithm, Simulated Annealing etc. can be used for solving TSP problem [5]. In this paper, Simulated Annealing algorithm (SA) is used for solving the problem. This algorithm is preferred over other available algorithms because of its useful property that it finds the global optima in presence of large number of local optima.

In this research paper, the objective of designing a microgrid which uses minimum possible conductor length is achieved by using simulated annealing algorithm. For the analytical study, the actual data of village Jaigarh, Madhya Pradesh has been taken through Google Earth. The reduction in conductor length reduces the installation cost and also, the distribution losses are reduced in the same proportion, which is an added advantage of the research work. This work can be useful for engineers involved in project of setting up microgrid in rural communities.

II. PROBLEM FORMULATION

Travelling salesman problem (TSP) was first proposed by Austrian mathematician Karl Menger [6].This computational problem is explained as, “Given a set of cities of different distances away from each other, and the objective of TSP is to find the shortest path for a salesperson to visit every city exactly once and return back to the origin city”.

Based on the distance and direction between two cities in a graph, TSP is classified as the following types:
(i) Symmetric,
(ii) Asymmetric

If distance between the two consecutive cities is same in all directions, it is symmetric TSP with undirected nature otherwise it is called asymmetric TSP . The analogy between TSP and objective problem can be used to find a solution for the problem which can be defined as “finding shortest closed path for a microgrid so that every house (node) is connected to it.” However, the best configuration can be found by Brute Force Method also, i.e. after evaluating all possible configurations for the grid. But for n number of nodes in a graph, (n - 1)! number of possible configurations are there and evaluating each one individually increases the time involved. So, instead of brute-force method, using dynamic programming approach, the solution can be obtained in lesser time.

III. SIMULATED ANNEALING ALGORITHM

Simulated annealing (SA) is a probabilistic technique for solving NP hard problems. This technique is based on the process of annealing of metals. When the heat process of the metal is stopped, the temperature of the metal decreases as heat is lost to the environment. So, the molten metal starts solidifying as the energy of molecules decreases. The process of cooling continues till a thermal equilibrium between the energy state of the metal molecules and the molecules present on surrounding environment is attained. At this stage, the energy attained by the metal is at its minimum value. The simulated annealing process imitates this natural annealing process to find the optimum solution.

Simulated annealing is used for finding the global minimum of an objective function that may possess several local minima [7]. The artificial thermal noise is decreased with every step. The magnitude if change in energy function E(x) is controlled by parameter T, the computational temperature. The probability of change of state is estimated by the Boltzmann distribution of the energy difference between the two states and is given by equation (1).

$$P = e^{-\Delta E/T} \quad (1)$$

The algorithm takes step in arbitrary direction and if the selected step gives a better solution, then it is accepted. Otherwise, the algorithm takes the next step with a probability less than 1. The probability of accepting the bad step decreases exponentially as the temperature increases. the amount ΔE shows the energy is increased. The probability of accepting a step is given by equation (2).

$$P(Accepting\ a\ move) = 1 - e^{\Delta E/kT} \quad (2)$$

The efficiency of this algorithm is criticallt dependent on the parameter α, the temperature reduction rate. The result may converge to a local minima if α is too high. And the algorithm becomes very slow is we set too low value of α.The property which outstands the Simulated Annealing Algorithm out of other algorithms is that it find the global optima out of many local minima. This feature is possible due to its inherent property of recording the probability of poorer solution than the best solution. SA algorithm is suitable to real time problem because it find the solution in lesser number of iterations.

A simple implementation of Simulated Annealing Algorithm is carried out in MATLAB 2014 and the following parameters are decided:
Temperature reduction rate, α= 0.999
Initial temperature, T_{max}=0.025
Maximum no of iterations: 450

The algorithm of simulated annealing is given below [8]:

1. Set parameters of the system and the configuration. Set random value for x (0).
2. Set temperature T with a high value.
3. Repeat:
   i. Repeat:
   a. Apply changes in the state in steps, x = x + Δx
   b. Evaluate Change in energy
   $\Delta E(x) = E(x + \Delta x) - E(x)$
   if ΔE(x) < 0, remember the new state;
   Otherwise, remember the new state with probability
   $P = e^{-\Delta E/T}$
   til the maximum number of transitions is reached.
   ii. Set T = T − ΔT. Repeat until T is smaller than a prescribed value.

IV. CASE STUDY: JAIGARH VILLAGE, MADHYA PRADESH

A shortest ring distribution network is to be found using simulated annealing algorithm. The satellite view of locations of houses are shown in Figure 1.

Figure 1: Satellite view of Jaigarh village

Jaigarh is a small village in Silwani Tehsil in Raisen District of Madhya Pradesh State, India. It is located 93 km from state capital Bhopal. Jaitgarh village total population is 338 and number of houses are 65. [9] Reports that electricity is not available to this village and to other villages located near it. These East and North location obtained from Google Earth accessed on April 24th, 2019; are used as x and y coordinates of the house locations.

V. RESULTS AND DISCUSSION

When the simulated annealing algorithm is executed starting from the first random closed path. Fig. 2, Fig.3 and Fig. 4 shows the optimal configuration obtained at 50th, 100th and 200th iteration. The total length of conductor used in the microgrid is 4354.92, 3312.57 and 2354.57 meter respectively. Hence as the algorithm moves ahead with every step, the new routes are suggested which use smaller length of conductor.

Figure 2: Optimal configuration of 50th iteration

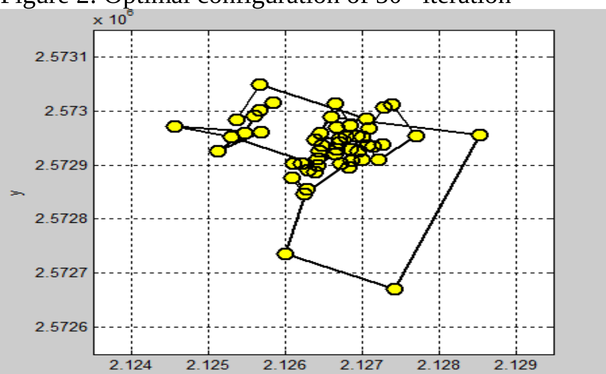


Figure 3: Optimal configuration of 100th iteration

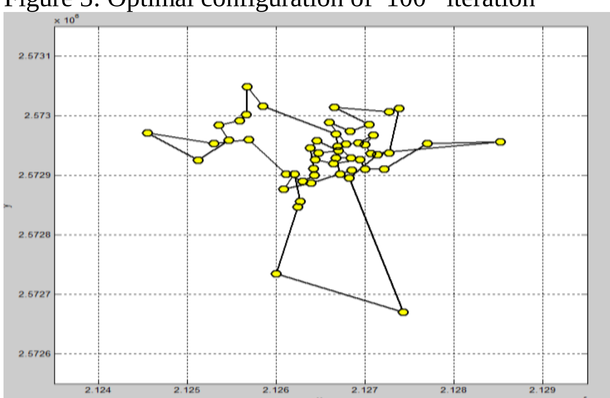


Figure 4: Optimal configuration of 200th iteration

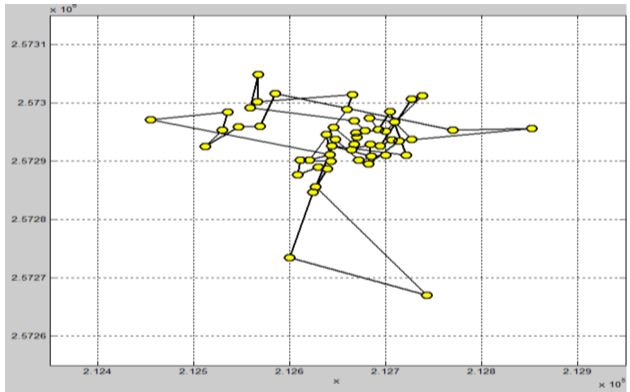
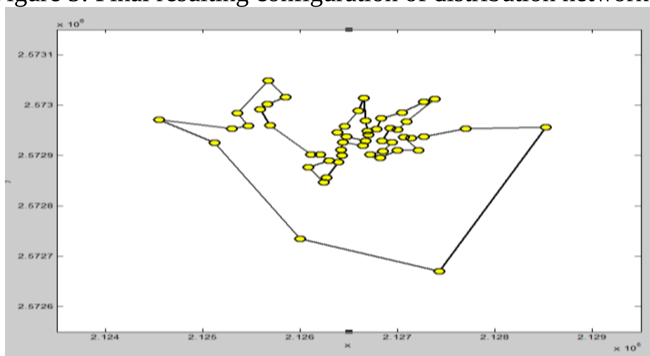


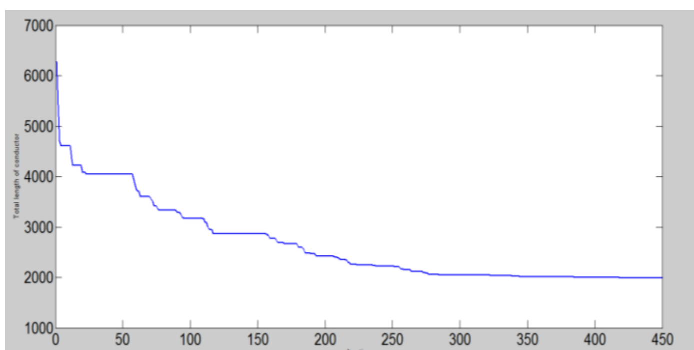
Fig.5 shows the final configuration obtained by the algorithm which uses 1955.52 meter of conductor length. Fig. 6 shows the variation of total length of conductor used with iteration numbers.

Figure 5: Final resulting configuration of distribution network



The optimal solution after final iterations represent a 65.38 % improvement compared to the initial configuration, in 14.45 seconds. Also it is visible that the configuration found after final iteration is less complicated than the intermediate configurations.

Figure 6: Total length of conductor v/s No. of iterations



VI. CONCLUSION

The length of conductor used in laying out the microgrid is minimized using the Simulated Annealing Algorithm. Importance of using the optimization process in designing power distribution network is emphasized by the results obtained from SA algorithm The results of the research work make a significant contribution for the planning stage of power distribution network. The minimization of conductor length gives the following benefits:

- The investment cost is reduced as the cost is directly dependent on length of conductor used.
- Reduced copper losses as the reduction in length reduces the total resistance of the line.
- Reduced maintenance and replacement cost as the shortest length faulty connection between two houses will only be replaced.

So, the research work can act as a useful tool for planning of electrification of rural areas for meeting the basic electricity needs of the residents and hence, uplifting the economy of rural communities.

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