Network Topology Optimisation

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Abstract

Western Power's rural network has expanded in an ad-hoc manner over time as new customers requested connection to the grid. The primary objective of this project is to determine if the distribution network has expanded in an optimal manner through finding the shortest weighted path between customers in rural areas. Currently there are large portions of the distribution network assets in rural areas that are nearing the end of their life and will need to be replaced in the near future. This presents the opportunity to redesign the routing of the network through considering all customers, with the expectation that the length of the network and thus the level of investment will be reduced. A number of algorithms including the minimum spanning tree (MST) and genetic algorithm (GA), are used to compute the optimised path throughout a constraint weighted area. The results indicate that the optimised path of the network produces a reduction in length, and thus a reduction in costs.

1. Introduction

Western Power is responsible for the transmission and distribution of electricity within the South-West Interconnected System (SWIS). The transmission network has undergone a relatively high degree of planning using forecasts to determine optimum location of zone substations for load distribution. However the distribution network (specifically in rural areas) has grown organically in a more ad-hoc manner to facilitate the connection of new individual customers as requested. Hence the same level of detailed planning of circuit placement has not been applied for the rural distribution network as for the transmission network.

There was significant expansion of the South West Interconnected Network in rural areas approximately 40 years ago. As a result, over the next 20 years up to 80% of the Western Power distribution overhead network which was originally installed will be subject to renewal as assets reach end of life. This presents the opportunity to retrospectively redesign the routing of the network based upon knowledge of existing customer locations.

Metropolitan areas will not be considered in this project due to the lack of available pathing options as a result of physical and regulatory restrictions. Additionally, the high density of customers in metropolitan areas means that highly meshed networks are required and therefore little opportunity for additional optimisation is available.

Western Power's current approach to replacing elements of the distribution network that have reached end of life utilises a direct 'like for like' replacement program. Planners can optimise by visually identifying patterns in order to determine which areas of the distribution network are of primary concern, but due to limited engineering resources this will generally only happen if the planners are looking at the area for other reasons, such as capacity shortages.

1.1 Project Objectives

The main objective of the project is to determine the optimum network path for the distribution network and compare the costs of implementing the new system against the current 'like for like' replacement approach. If the total costs of the new approach are less than or equal to the current method then the new approach will be considered. Otherwise the old method will remain with the renewed confidence that it is the most optimised network topology.

1.2 Literature Review

A past study on optimising a power distribution network in Brazil has used a Minimum Spanning Tree (MST) algorithm to determine the initial population for a GA (Carrano, E., et al. 2006). The MST determines the minimum weighted path connecting all nodes given a finite set of nodes and edge weights (Nesetril, J., et al 2001). It was found that the GA performs better in combination with a local search operator such as the MST to generate the starting population. In order for a GA to be successful, the search must both converge towards an optimal solution as well as maintain a diverse population (Deb, K, 1999). Randomly generated solutions were used in combination with the MST to maintain diversity and avoid premature convergence.

Additionally, the study undertaken by Carrano determined that the Stochastic Tournament selection operator is an effective selection criteria. Therefore the Stochastic Tournament will be the primary selection method, while an MST will produce the starting population. The calculation of other parameters however, is largely dependent on the specific problem and thus will need to be investigated independently.

2. Process

Research into identifying the constraints and requirements of the distribution network topology determined that environmental zones, land subdivisions, cultural constraints, construction type, maintenance accessibility and fault finding are the key factors to achieve an accurate topological model. As all of the geographical data is based off Western Power's GIS system, it is crucial that these areas are able to be represented. Environmental zones, land subdivisions and cultural constraints are easily identifiable as separate layers in the GIS system. However construction type, accessibility and fault finding needed to be calculated. Construction type (either overhead or underground cabling) directly depends on the environmental and cultural zones and has been dealt with as such. Accessibility and fault finding were both linked to the position of the network, and can be incorporated through placing the network parallel to roadways. It should be noted that the algorithm is not considering power restrictions, therefore fault finding is only in regards to the topology of the network.

The values associated with each constraint weighting were determined through discussions with Western Power personnel. The land subdivision weightings were split into three constraints based on the size of the subdivision. The environmental zones allocated weightings to conservation estate, high conservation estate, declared rare flora, multiple wetlands, threatened ecological communities and bushforever. The area selected for testing did not include all of the above constraints, thus they have not all been incorporated as of yet. The cultural constraints include aboriginal heritage sites. Again, the area selected for testing did not include any cultural constraints, thus they have not been incorporated.

The test area for optimisation has been hand picked to focus on an area that will provide multiple weighting constraints over a large area and thus increases the possibility of alternate, more optimised routes existing. The current network asset rating system selects areas of the distribution network where a high proportion of assets are nearing the end of life. This ensures the assets are replaced in an efficient manner, with minimal unnecessary replacements.

A Travelling Salesman Problem (TSP) GA was chosen as a starting GA to optimise the network as it is a similar problem and identifies issues with using a GA. Following the completion of the TSP GA and the MST, the problem specific GA can be applied to optimise the test area. The new GA uses the results from the MST to provide a starting solution for the algorithm as the initial population of a GA directly correlates to the quality of the solution found (Diaz-Gomez, P.A., et al. 2007). The selection of solutions will use the Stochastic Tournament as it has proven to be effective in past studies. The mutations used for the algorithm are problem specific and have been created for use in this project. The GA can then be applied to the test area to identify possible issues as well as determine the minimum weighted distance. An overview of the GA is shown below in Figure 1.

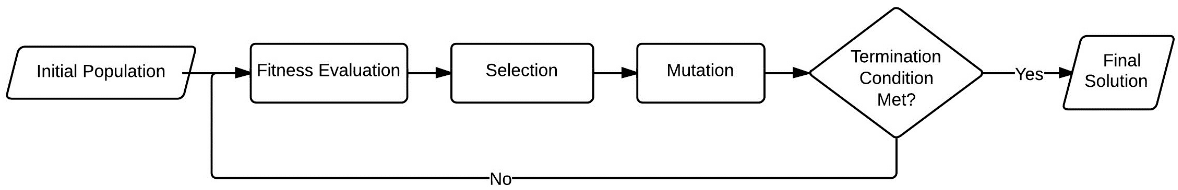

Figure 1 - Genetic algorithm procedure

3. Results and Discussion

The results for the genetic algorithm with all of the aforementioned constraints is still being processed and is not yet finalised, however preliminary results have been recorded. The MST was the first optimisation algorithm to be applied to the given test area. The MST significantly reduces the length of the given network, as shown in Table 1, with a decrease of approximately 55 kilometres in relation to the present network. Though this is a significant decrease in network length, the MST does not consider the different phases (single and three phase) associated with the network as well as additional nodes that are not customers. There will likely be substantial issues with the direct implementation of the MST as a result, however the purpose of this algorithm is to identify a good starting solution for the GA to proceed with. As the MST results significantly reduce the network length it will likely provide a good starting position for the GA.

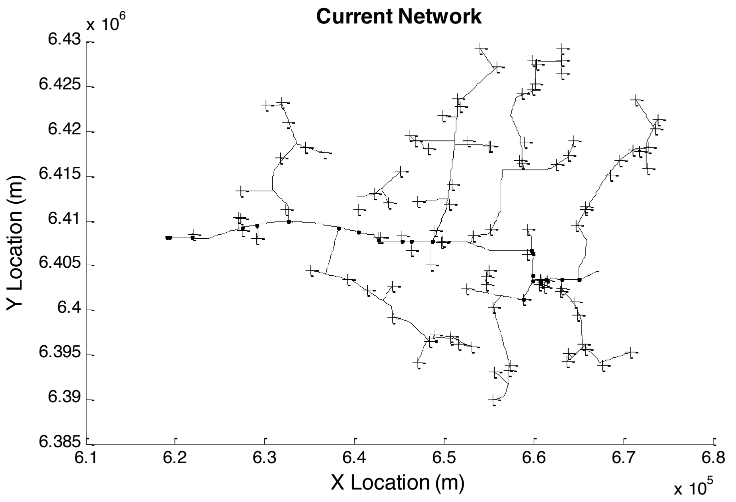

Figure 2 Current distribution network topology for the selected area. Crosses represent customer nodes.

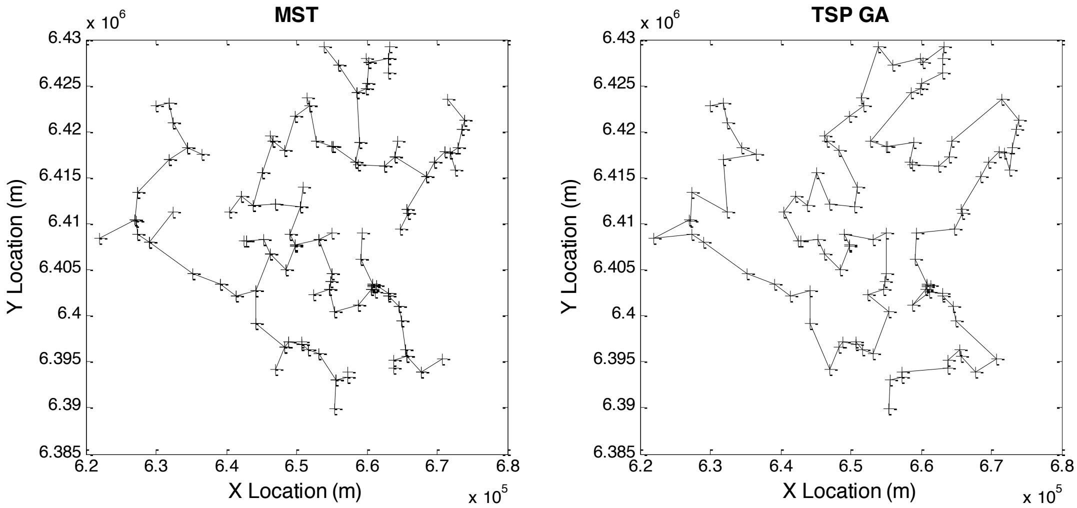

Figure 3 Left: Minimum spanning tree (MST) applied to the selected area. Crosses represent customer nodes. Right: TSP GA applied to the selected area. Crosses represent customer nodes.

The TSP GA results are shown in Table 1 and have been taken from the best solution from 20 simulations. Simulating for more than 20 simulations provides minimal improvement. The TSP GA results indicate that the length of the network can be reduced by approximately 18 km. This is far less than the length reduction of the MST, however the TSP GA only considers a single continuous line and thus does not utilise branching. The immediate disadvantage of using a single line to represent the distribution network is that the voltage drop across the network would be exceedingly high and impractical. The purpose of calculating the TSP GA is not to consider a direct implementation but rather to assist in identifying issues the coding of the GA.

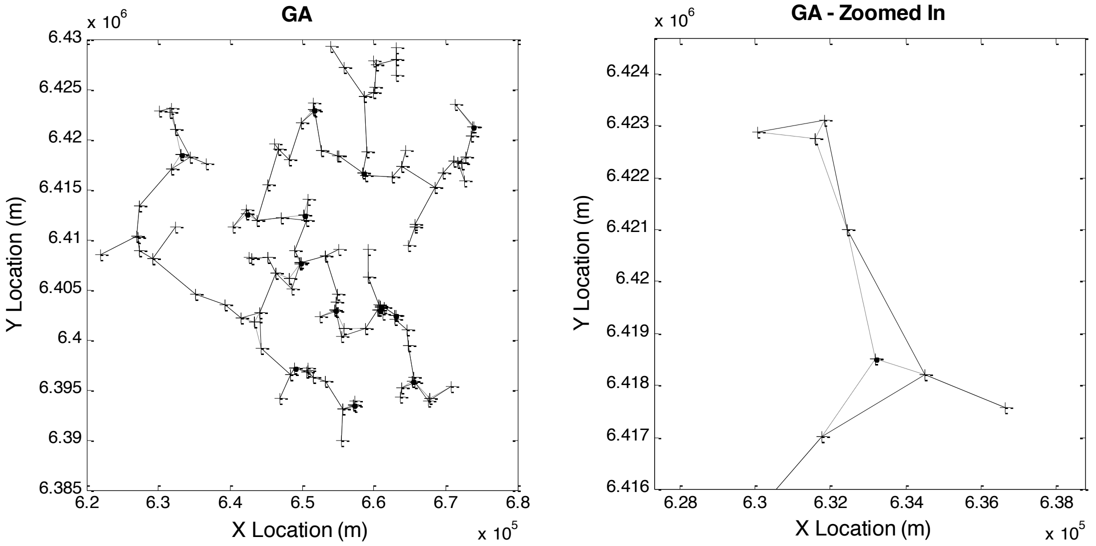

Figure 4 GA applied to the selected area. The solid line represents the MST while the dotted line represents the improvements made by the GA. Crosses represent both customer nodes and non-customer nodes.

The results for the GA are given in Table 1 and shown in Figure 4. The current version of the GA optimises the network through the use of a mutation that creates additional nodes known as Steiner points. Connecting to a Steiner point produces the minimum distance between any three points. From Figure 4 it is evident that there are several Steiner points for the given network, and thus the length of the network is minimised beyond that of the MST.

One of the major limitations with the current version of the GA is that there is little diversity, which is evident through the similarities between the MST and the GA shown in Figure 4. In order for the GA to consider a wider search space, additional mutations are required. These mutations are presently being worked on and include; removal of additional nodes, addition of boundary nodes that are of close proximity to customers and the addition and removal of nearby edges.

Algorithm	Total Network Distance	Simulation Time
(Current Network)	300.4 km	-
MST - Prim	245.6 km	0.70 s
MST - Kruskal	245.6 km	0.65 s
TSP GA*	282.0 km	141.9 s
GA*	243.5km	23m 10s

Table 1 Simulation Results

* The TSP GA and GA results were taken from the best solution over 20 simulations.

All calculations have been performed on an Intel(R) Core(TM) i5-3230M CPU @ 2.60 GHz

4. Conclusions and Future Work

At the time of writing the GA has not yet been finalised, however based on the preliminary results the length of the network, and thus the cost can be reduced. Importantly, the route of the optimised network has noticeable differences in comparison to the current network location, suggesting there are multiple routing options available. When the full constraint weighted GA is completed processing the route is expected to alter to a greater extent from the current network position. The present issue with the results established is the lack of options considered. These results do not consider additional pathing points which are present in the current network in Figure 2, thus are constrictive in the possible solutions calculated. The results from the GA will amend this issue.

The remaining work will largely focus on considering operator alterations of the GA. Alterations to the selection criteria and mutations will be dependent on the consistency and accuracy of the solutions calculated. Fixing the three phase component of the distribution network and optimising only the single phase lines will be performed to determine if it as advantageous to maintain the current three phase locations while altering the single phase components. This will hold a benefit for fault finding on the main back-bone supply as the three phase line can be kept in close proximity to existing roads and access trails. Lastly, the GA will be applied to additional test areas to ensure the algorithm performs well for different sets of data.

With the completion of the remaining work there will still remain areas to be explored in regards to the practicality of the algorithm. The power requirements of the distribution network have not been considered, thus a further study incorporating the power requirements of the network is recommended. Additionally, alternative optimisation algorithms, such as Colony Optimisation and Tabu Search, could also be investigated.

5. References

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