Optimization using Genetic Algorithm in a Low Voltage Distribution Network

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Abstract

Distribution utilities are under pressure to attain high efficiency and minimize system loss and because to the current trend in distribution regulation, distribution transformer relocation, network splitting, incorporating distributed generation and altering secondary line and service drop size, are some of the different ways to reduce secondary system loss (DG). The genetic algorithm is used in this study to properly position and size rooftop solar photovoltaic (PV) generation systems, minimizing secondary system loss (GA). The technique relies on a single, ideal installation to prevent voltage profile issues. This study uses thorough modeling to take into consideration various loads, client attributes, and solar PV generation systems. Power flow based forward and backward sweep methodology was employed because of the unique characteristics of low voltage secondary distribution network. To demonstrate the robustness of the suggested strategy, secondary line features were used.

Keywords
Distribution Network, Distribution Utilities, Genetic Algorithm, Optimization, System Loss

1. Introduction

The distribution network's power flow, voltage profile, efficiency, reliability, stability and protection, and are all significantly impacted by the existence of distributed generation (DG). The conventional distribution network is challenged, particularly if the DG is deployed at the low voltage secondary distribution network. Customers routinely request the interconnection of these systems from utilities and distribution firms as dispersed generating grows in popularity. Residential, commercial, and industrial power system users all heavily rely on distributed generation. A different source of power is offered by DG whereas a rooftop solar PV generation system is an example of DG that can be connected to the utility's service through its low voltage secondary distribution network. The influence on maintaining regular system operation could be negative when more solar PV generation systems are deployed.

Gibson et al., (2007) introduced a novel approach for characterizing the transformer secondary circuit archetypes and the load characterization based on customer use of the electric secondary distribution system. The results of the proposed method's implementation in a pilot region of the neighborhood electric utility confirm its efficacy. Waseem (2008) created a computer program using Microsoft Excel to calculate the energy losses in the service drops, secondary lines, and transformers for all transformer secondary circuits in the pilot region; as a result, the circuits with the highest losses are highlighted for more investigation. On the subject of the economic analysis and design of secondary circuits, the applications of the suggested secondary distribution model and load characterization presented are also covered. The effects of installing dispersed generation on distribution network functioning, including voltage profile, electrical losses, dependability, and harmonics, were studied in the literature (Alam et al. 2009), (Abdul Kadir et al. 2011), (Sun and Zhang 2009). The effects of distributed generating on voltage profile issues were examined. (Chen et al. 2012), (Conti et al. 2012), (Shalwala and Bleijs 2010), (Tan et al. 2010). To calculate the maximum quantity of DG in the secondary distribution network to take voltage profile issues into consideration, they suggested various load distribution models and a thorough investigation. To establish the maximum amount of power that may be injected into the distribution network without overvolting it, some of them developed analytical expressions. Others looked into the regulation of voltage on the residential distribution network.

The best location and size for distributed generation (DG) were suggested by Prabha et al., (2012); Al-Sabounchi et al. (2011) using, genetic algorithms (GA) and particle swarm optimization (PSO). They want to reduce overall real system loss and improve the system's voltage profile. They created a method for determining the best size and placement of a single PVDG unit on a three-phase unbalanced radial distribution feeder. They took into account the maximum discrepancy between the PVDG production curve and the feeder load curve. The technique has been successfully used on two 11kV feeders in the distribution network of Abu Dhabi. Several approaches were presented in the literature to optimize distribution generation (Song et al. 2019), (Zhang et al. 2016), (Reyes and Baeza 2018), (Ai et al. 2021), (Roy et al. 2020).

In terms of legislation, technology, and practices for connecting different kinds of distributed generation (DG) systems to the utility distribution network grids, Ving and Vaziri (2007) provided an update on the work currently being done by a variety of groups. They described a new project that the Massachusetts Technology Collaborative's (MTC) DG Collaborative is funding for an innovative architecture for the control and coordination of DG sources on secondary distribution network systems. Mukhopadhyay and Singh (2009) delivered a paper outlining the fundamental regulations, long-term goals, and advantages of distributed generation in India.

In this study, a rooftop solar PV generation system was suitably sized and placed in order to minimize secondary system loss using a genetic algorithm (GA). The technique relies on a single, ideal installation to prevent voltage profile issues.

2. Problem Formulation

Installing a solar PV generation system in a distribution system can reduce secondary system losses while meeting electrical requirements. Losses from secondary line and service drops make up secondary system losses. The secondary system loss serves as the objective function *F* for the optimization problem. This study's goal is to reduce secondary system loss. The effectiveness of the secondary distribution network is gauged by the latter. The formulation of the optimization problem is:

$$\min F = re\left[\sum_{a=1}^{b} I_c (V_d - V_e)^*\right] \tag{1}$$

Where b is the total number of sections in the system, I_c is the line current along section a between nodes d and e, and V_d is the line voltage at node d. Section could be a service drop or a supplemental line.

The typical power flow solution may no longer be appropriate in the analysis of the secondary distribution network because of the unique characteristics of the secondary distribution network, including its radial topology and single-phase. Secondary system losses were computed using the backward/forward sweep power flow (Song et al., (2019)]. This power flow approach has been popular for radial distribution systems power flow analysis due to its minimal memory needs, computational efficiency, and fast convergence characteristic.

3. Secondary Distribution Network Modelling

A novel approach to modeling low voltage secondary distribution networks is presented in this section. It uses a process to determine the load model, secondary line and service drop model, secondary distribution circuit model, and solar PV generation system model.

Model for Secondary Distribution Circuits

In the Philippines, a typical secondary system comprises three wires, 240V, one phase, and a solidly grounded neutral that is connected to the primary neutral. Each transformer extends radially the specified number of pole spans to the left and right of the transformer in the secondary distribution circuit configuration. Transformers are typically positioned to offer two-, three-, or four-way feeds. As indicated in Figure 1, the typical preference is a two-way feed.

An example of a secondary distribution circuit diagram is illustrated in Figure 2, and Table 1 lists the associated circuit characteristics.

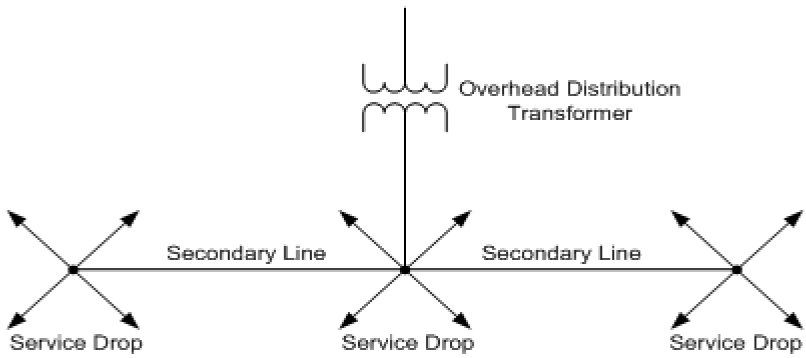

Figure 1. Two-way Secondary Feed

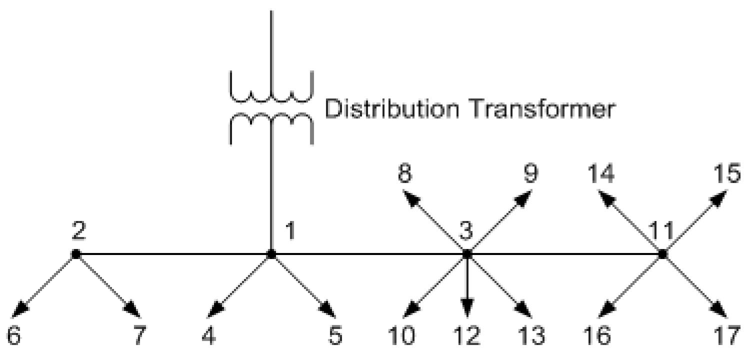

Figure 2. Example Secondary Distribution Circuit Diagram

Table 1. Circuit Characteristics

From	To	Length (m)	Wire Type
1	2	43	Secondary Line
1	3	59	Secondary Line
1	4	3	Service Drop
1	5	20	Service Drop
2	6	13	Service Drop
2	7	23	Service Drop
3	8	26	Service Drop
3	9	27	Service Drop
3	10	16	Service Drop
3	11	67	Secondary Line
3	12	16	Service Drop
3	13	17	Service Drop
11	14	13	Service Drop
11	15	5	Service Drop
11	16	23	Service Drop
11	17	30	Service Drop

Service Drop Model with Secondary Line

Actual distribution utility requirements for overhead secondary line and service drops are used to create the secondary line and service drop model. The secondary line is made up of 3/0 AWG black polyethylene (PE) insulated triplex cable, which has a current carrying capacity of 215A and an impedance of 0.4143+j0.0868 /km. The #6 AWG black PE-insulated triplex cable used in the service drop has a current carrying capacity of 70A and an impedance of 2.6488+j0.0999 /km. The bulk of single-phase loads are 240V systems linked, therefore the secondary line and service drop model is just twice the impedance.

Load Model

This study employs a load characterization technique based on the monthly load consumption of customers. For each customer, the average actual power was calculated by dividing the total number of hours by the sum of the energy consumed. The reactive power of each client is calculated in this study using a load power factor of 85%. End-use electrical devices and equipment used in homes and businesses for things like lighting, entertainment, cooking, drying, etc. make up residential and commercial loads. Finding the voltage dependencies for each of these appliances and pieces of equipment in a home or business establishment is necessary for modeling. Standard ZIP parameters, which represent the percentages of a particular load model's constant real and reactive power (PQ), constant current (I), and constant impedance (Z) types of loads, can be used to simulate the voltage dependency of loads. Each customer, whether residential or commercial, would experience various types of load changes. For residential customers, this study utilizes 8.3% constant PQ, 26.7% constant Z, and 65% constant I. For commercial customers, it uses 13% constant PQ, 34% constant Z, and 53% constant I.

Model of a Solar PV Generation System

Rooftop PV installations with solar PV modules and an inverter are the most common types of solar PV generation systems used by residential and commercial users. These systems are normally run at unity power factor, which means that only real power is generated. This study injected negative actual power into the solar PV production system (AC output power).

4. Optimization using Genetic Algorithm

Generating the initial population, which was done at random, is the GA's starting operator. A single-level string is used to represent an individual. As there are nodes in the system, the length of the chromosomal string is also an integer. The chromosomal string is 17 bases long in the sample secondary distribution circuit. The secondary riser of the distribution transformer's secondary node 1, also known as the root node or source node, is node 1. The sites where the service drops from the secondary lines are tapped into are Nodes 2, 3, and 11.

This study installs solar PV generation systems at each node in increments of 25 W up to the combined real power of all associated loads in order to get the best single installation. The ideal location for a single installation of a solar PV generation system, according to data from an example circuit, is node 15 and a capacity of 15.325 kW. Based on this, the first population is generated at random (see Figure 3). The chromosomal strings' encoding is demonstrated in example 3 here. By using this technique, source and tapping point nodes are not where solar PV installations are made (nodes 1, 2, 3, and 11). Optimal single installation capacity, in this example 15.325 kW, is equal to the total of numerous installations.

It will then call the power flow function after producing the initial population and pass the produced population as an input. The objective function is then calculated for each individual.

According to Misola and Navarro (2013), this paper's fitness function is as follows:

$$Fitness(x_i) = \frac{(Nind)(X^{(x_i - 1)})}{\sum_{i=1}^{Nind} (X^{(x_i - 1)})} \tag{2}$$

$$0 = (MAX - 1)X^{Nind-1} + \sum_{n=2}^{Nind} (MAX)X^{Nind-n} \tag{3}$$

Where MAX is the selection pressure or bias toward the fittest individual, N_{ind} is the total number of individuals, X is the computed real-numbered root of the polynomial in (3), x_i is the position of individual i in the ordered population, and so forth.

The process of selection involves figuring out how many times, or trials, a specific individual will be chosen for reproduction and, consequently, how many offspring that individual will have (Navarro and Navarro 2016). The roulette wheel selection was made for this based on secondary system loss; this process is utilized to probabilistically select individuals.

Crossover is the fundamental GA process for creating new chromosomes. In this study, single-point crossover was applied, as seen in Figure 3. The combined power of Children 1 and 2 is 13.625 kW and 17.025 kW, respectively. On average, they differ from the original figure by 1.700 kW. In order to prevent voltage profile issues in the system, the crossover methodology in this work proposes a corrective procedure that keeps the summation of many solar PV installations equal to the ideal single installation value. The disparity is added arbitrarily on any node besides the source and tapping point nodes if the sum is smaller than the initial value. With the exception of the source and tapping point nodes and nodes without solar PV installation, the disparity is randomly subtracted from any node if the sum is more than the original amount (See Figure 3). Not all strings in the population will necessarily undergo the crossover procedure. Rather, it is used with a probability, Px, when the breeding couples are selected.

Swap mutation, which is based on Misola and Navarro (2013) is the mutation approach used. Simply two random nodes with solar PV installations are chosen, and their contents are switched. Figure 4 displays a swap mutation example. Similar to crossover, not every string in the population will necessarily be subjected to the mutation process. Instead, a probability, Pm, is used to determine what proportion of the population will be modified.

The objective value will be determined when the children have been modified. This study coupled elitism with fitness-based reinsertion. The maximum number of generations determines the termination.

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Parent 1	0	0	0	225	500	0	0	1875	0	1650	0	200	2125	525	1625	4525	2075
Parent 2	0	0	0	275	2700	200	675	275	175	1500	0	325	1725	4550	1975	125	825

Single point swapped Crossover

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Child 1	0	0	0	225	500	0	0	1875	0	1500	0	325	1725	4550	1975	125	825
Child 2	0	0	0	275	2700	200	675	275	175	1650	0	200	2125	525	1625	4525	2075

Figure 3. Single point swapped Crossover

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
New Child 1	0	0	0	225	1500	0	0	1875	0	500	0	325	1725	4550	1975	1825	825
New Child 2	0	0	0	525	2700	200	0	275	175	625	0	200	2125	275	1625	4525	2075

Figure 4. Swap Mutation

5. Results and Discussion

Twenty test examples that are generated based on real secondary distribution network features show how effective the suggested strategy is. The entire simulation was programmed using Matlab. 10 residential and ten commercial customers make up the test cases (combination of residential and commercial customers). The number of generations and people is 500, the crossover and mutation probabilities are assumed to be 0.5 and 0.8, respectively, and a reinsertion rate of 0.5 was employed in all simulations.

The initial and improved results for the 20 test cases are displayed in Figures 5-8. The simulation's outcome demonstrates that by dividing the system's overall capacity among its nodes, the best single installation may be made even better. Secondary system loss and voltage profile improvement are also noted and are displayed in Figures 5-8. Secondary system loss and voltage profile improvement are also indicated as a percent reduction from 25–50% in a single installation to 38–64% in multiple installations.

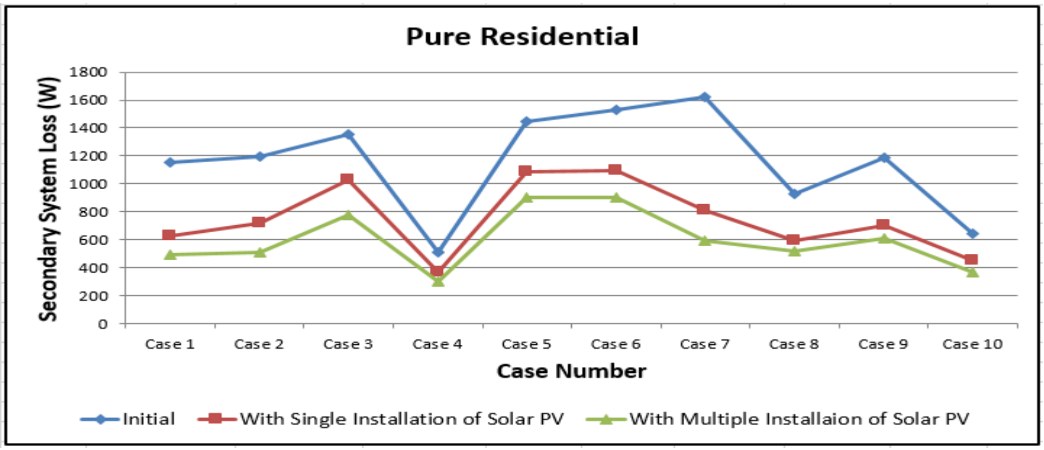

Figure 5. Secondary System Loss: Residential

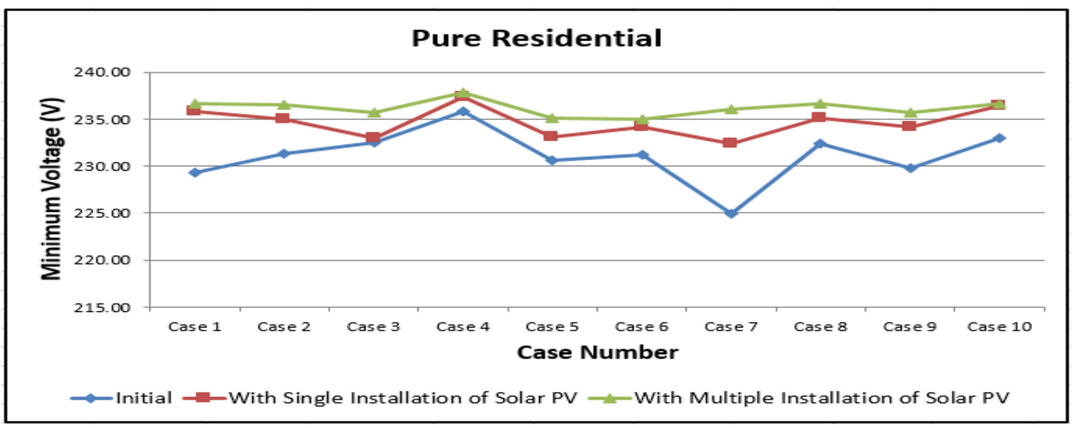

Figure 6. Minimum Voltage: Residential

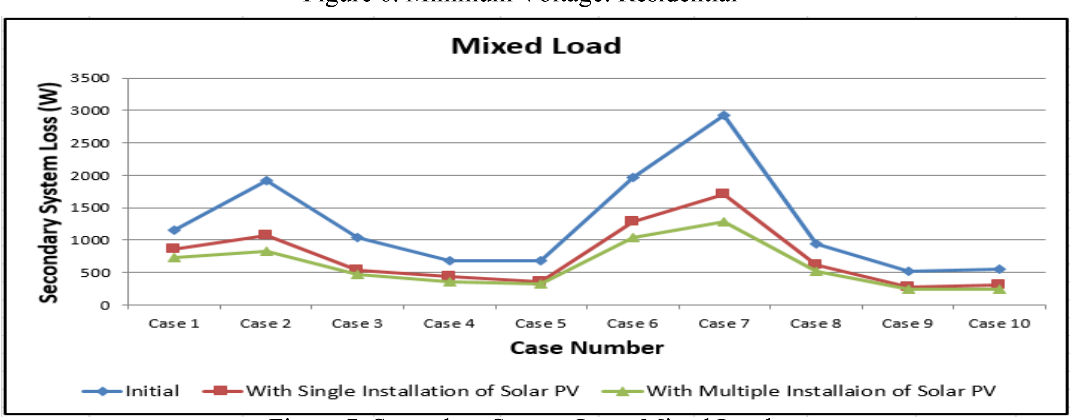

Figure 7. Secondary System Loss: Mixed Load

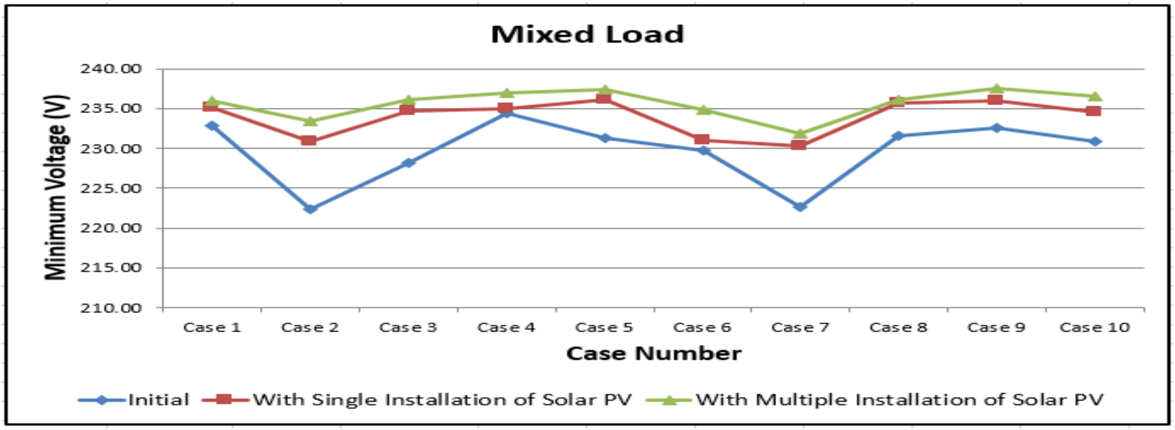

Figure 8. Minimum Voltage: Mixed Load

6. Conclusion and Future works

Using a genetic algorithm, we created a way in this paper to reduce secondary system loss (GA). To prevent voltage profile issues, the procedure is based on optimal single installation. Test examples based on actual secondary distribution network features are used to show how resilient the suggested solution is. The answer demonstrates that by dispersing the ideal single installation capacity to various system nodes, it is possible to achieve a considerably more optimal reduction of secondary system loss and voltage profile. Future research may use the approach outlined in this paper by accurately modeling the solar PV inverter based on real-world geographic characteristics, considering factors like temperature, irradiance, shading, position, tilt angle, etc. To reduce annual energy loss, time-varying loads may be adopted.

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Bryan B. Navarro is an Assistant Professor in the Department of Electrical Engineering at the Technological Institute of the Philippines and is currently a Staff Engineer at Manila Electric Company (MERALCO). He earned B.S. in Electrical Engineering from the Technological Institute of the Philippines, Quezon City, Master of Science in Electrical Engineering major in Power Systems from the University of the Philippines, Diliman, Quezon City. He has published journal and conference papers. He is an active member of the Institute of Integrated Electrical Engineers of the Philippines (IIEE).

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