Optimizing Capacitor Placement in the IEEE 13-Bus Network Through Genetic Algorithm

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***Abstract*—This proposal aims to utilize capacitor banks to improve the voltage profile of the IEEE 13-Bus System without relying on voltage regulators. It also discusses the causes of such issues and the different approaches in solving or minimizing them. For the voltage profile, a margin of 0.05 is used to indicate a voltage violation. The simulation is done in OpenDSS: Distribution System Simulator.**

***Index Terms*—IEEE 13-Node, power flow, OpenDSS**

I. Introduction

The IEEE 13-Node Test Feeder is a highly loaded short feeder operating at 4.16 kV. Various phasing is exhibited in overhead and underground lines, feeding unbalanced spot and distributed loads. Also integrated into the network are an in-line transformer, a shunt capacitor bank, a switch, and a voltage regulator [1].

The initial simulation in OpenDSS shows that the integration of the voltage regulator in the network has already achieved an improved voltage profile, where all buses fall within the $\pm 5\%$ criterion. The simulation compared to the published result has a very slight difference. Hence, to illustrate the effects of other methods in addressing various issues in the network, the analysis will be done for the network that excludes the voltage regulator.

II. Identified Network Issues and Causes

A. Undervoltage

The initial analysis shows that all the bus voltages are below the nominal value of 1.0 pu. Excluding the source bus 650, the minimum and maximum voltage are 0.90727 and 0.99818, respectively. Considering a ± 5 voltage criterion, nine buses located farther from the source bus experienced undervoltage. This issue is primarily attributed to the heavy loading in the network.

B. Voltage Imbalance

The initial analysis shows a total power loss of 99.1929 kW, (3.019 %) and a total reactive loss of 295.353 kvar (18.75 %). This is due to the unbalanced load which caused voltage imbalance, increasing the line losses and decreasing the system efficiency.

III. Possible Solutions and Existing Practice

The issues in the network stem from a poor voltage profile. The following solutions offer to improve the voltages by improving the voltage regulation and reducing the voltage drop on distribution feeders [2].

A. Capacitor Bank

Installing capacitor banks can be in shunt or series configuration. A shunt capacitor can be costly in operation and maintenance if switched, although it offers good voltage regulation and reduction in voltage drop. With similar improvement, a series capacitor is best suited for longer and larger conductor lines and poses a challenge for varying loads.

B. Voltage Regulator

Integrating a voltage regulator offers excellent voltage regulation and voltage drop improvement. However, initial and operating costs are very high.

C. Load Balancing

At a low cost, load balancing is often the first option for poor-performing feeders. However, it may or may not work in improving the system.

D. Uprating Lines

Although uprating lines offers good improvement at a moderate cost, it is only best up to a certain wire size due to X/R characteristics.

E. Energy Storage Systems

If well-engineered, storage systems can greatly reduce voltage fluctuations. The problem with this method is its poor performance in reducing voltage drop and regulating voltage, in addition to increasing operating costs.

F. Network Reconfiguration

Network reconfiguration is a complex process that requires careful planning, analysis, and implementation. It is often performed periodically to adapt the distribution system to changing load patterns and operational requirements to improve the voltage profile.

G. Disributed Generation

Many DG systems come equipped with advanced power electronics and control systems. These systems can actively regulate the voltage at the point of interconnection with the distribution system, helping to mitigate voltage fluctuations and maintain a stable voltage profile.

IV. Proposed Methodology

To address the issue of poor voltage profile, the optimal placement of the capacitor bank in the network will be determined using Genetic Algorithm (GA). The network simulation will be done in OpenDSS while the GA will be implemented in Python. This involves modeling the network and implementing the GA.

A. IEEE 13 Modeling

The OpenDSS model for the IEEE 13-Bus System will be used. Once the optimal capacitor placements are determined, a comparison will be made before and after the optimization in terms of the voltage profile.

B. GA Implementation

The implementation of GA will have a limited scope of possible capacitor locations to the buses only and will exclude placement along the lines. The OpenDSSDirect Python package will be used to interface the GA with OpenDSS.

Gene space: All buses in the network.

Fitness function: a function of voltage difference among the buses with respect to the nominal voltage 1.0 pu

References

[1] K. P. Schneider, et.al, “Analytic Considerations and Design Basis for the IEEE Distribution Test Feeders,” IEEE Transactions on Power Systems, vol. PP, no. 99, pp. 1-1, 2017.

[2] Willis, H. Lee. Power Distribution Planning Reference Book. CRC Press, 2004.