A Practical Approach for Designing Operationally Efficient Secondary Distribution Systems

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Introduction

Electric utilities in the US are faced with a unique and often conflicting set of challenges in their current operating environment. They are under increasing pressure to design "smarter" systems and improve operational efficiency, even as the integrity of their physical infrastructure declines, and human resources are more constrained. In order to meet these challenges, today's distribution designer must be equipped with tools that will help him/her do their job more efficiently. There is a wide range of applications and technologies focused on primary systems, substations and transmission grids, but the design of secondary systems is often overlooked. This paper presents a method and application for the optimal design of secondary systems to meet technical requirements while minimizing total owning costs, including the impact of losses.

In a typical U.S. distribution system, technical losses represent a significant portion of the overall cost of power delivery. While the major components that contribute to total losses are three-phase conductors and service transformers, secondary system losses are still a significant factor. In fact, a recent study completed by the DSTAR[1] utility research consortium shows that losses on secondaries and services are often higher than typically assumed, and may account for up to 15% of losses on urban and suburban systems. This study, along with increased industry focus on improving operational efficiency, initiated the development of a new approach to design and engineer more efficient secondary systems. The approach builds on previous work commissioned by DSTAR to develop a Secondary Electrical Design Software (SEDS) tool, and extends the core application to include optimization algorithms with a cost minimization objective.

The DSTAR Collaborative Software Approach

Distribution engineering is dominated by many routine functions, which must be accomplished quickly and efficiently. Often technicians or designers who are not analytically oriented perform these tasks. There are many power engineering software products on the market which are complicated and require significant training to use.

General-purpose software tools, such as spreadsheets, are often used to perform engineering calculations. Users have come to expect a user-friendly, highly intuitive interface for performing

[1] DSTAR (**D**istribution **S**ystems **T**esting **A**pplication and **R**esearch) is a consortium of North American utilities that fund pragmatic, near-term, distribution-related R&D projects of common interest. GE Energy acts as the Program Manager for DSTAR and conducts most of the research and software development on behalf of the DSTAR members. Information on DSTAR operation and products is available at www.dstar.org.

their tasks. However, easy-to-use software tools dedicated to routine distribution engineering tasks, using modern user interfaces, are not widely available. Much of the distribution engineering software used in the industry is “homegrown” and not developed for ease-of-use. Many have fallen into disuse because they do not meet the modern expectations of a software tool.

To meet the need for modern engineering software tools, DSTAR has developed over 15 applications that are designed to be used with minimal training. These applications can be easily customized to the equipment and practices used by each member utility, allowing the ultimate user (for example, a design technician with limited engineering expertise) to apply the program with maximum efficiency and minimum complexity. Most importantly, the development of these applications has been guided directly by the engineer and technicians, from several DSTAR member utilities, who use the software. Their experience and understanding of the technical issues is reflected in the design and layout of each software tool.

This unique collaborative structure has resulted in software applications that are used frequently and have undergone numerous changes to improve capability and usability. The DSTAR members who have participated in the development are vested in the process and, therefore, have taken an active role in maintaining the products as requirements have evolved. As we move forward into “smart” distribution system design and operation, a collaborative approach, exemplified by DSTAR, is nimble and flexible enough to develop new methods and software for planning the system of the future.

DSTAR Secondary Design Software (SEDS) Capability

Initially developed in 1998, the SEDS program enables users to quickly layout a secondary design and easily assess performance measures such as voltage drop, flicker, loading and short circuit current using a customized load flow algorithm. SEDS development benefited significantly from the testing, guidance, and input of the consortium member utilities. Development with such tight user integration resulted in a final product that provides significant flexibility and usability to the large number of utility planners all across the United States.

SEDS performs a variety of calculations for both single-phase and three-phase systems:

Single Phase Systems:

- Distribution transformer coincident loading
- Secondary cable loading coincident current
- Secondary service voltages
- Mutual and self flicker
- Service-entrance short circuit currents
- Cold load pickup guidelines
- Optimization based upon first cost or first order total owning cost

Three Phase Systems:

- Distribution transformer loading
- Secondary cable loading
- Secondary service voltages
- Voltage unbalance
- Mutual and self flicker
- Service-entrance short circuit currents

The recently developed optimization algorithm uses a member utility's existing SEDS database, and employs a unique method to improve overall computational time while always finding the best solution in a defined pragmatic space. The optimization objective function can be set for lowest first cost or lowest total owning cost taking into account overall secondary system losses. SEDS is the ideal software package for helping planners design the most efficient secondary systems using standard equipment (transformers and secondary conductors) while meeting technical service requirements.

Designing Secondary Systems Using SEDS

SEDS allows users to construct a secondary system design very quickly. However, there are some basic engineering questions that need to be addressed before SEDS can perform the calculations necessary to evaluate and optimize a design. Some of the key engineering questions related to secondary system design are:

- What is the steady-state and flicker characteristic of the connected loads?
- How long are the conductor runs?
- Is the service overhead or underground?
- What are the allowable limits for flicker, voltage drop, and short circuit current?
- What transformers and conductors do I have available?
- Are losses going to be considered?
- What is the first cost of each piece of equipment?
- What is the single-phase coincident factor for the connected loads?

After careful consideration of these key questions and populating the database with the relevant equipment data, users are ready to build a secondary system design. Users can build a base secondary design, similar to the example shown in Figure 1, by selecting components shown in the toolbar and dropping them on the screen in the desired location. Double-clicking the component and either selecting pre-populated data or entering user specified data specifies the attributes of the components. Each DSTAR utility has developed their own set of pre-populated data for transformers, loads, and conductors.

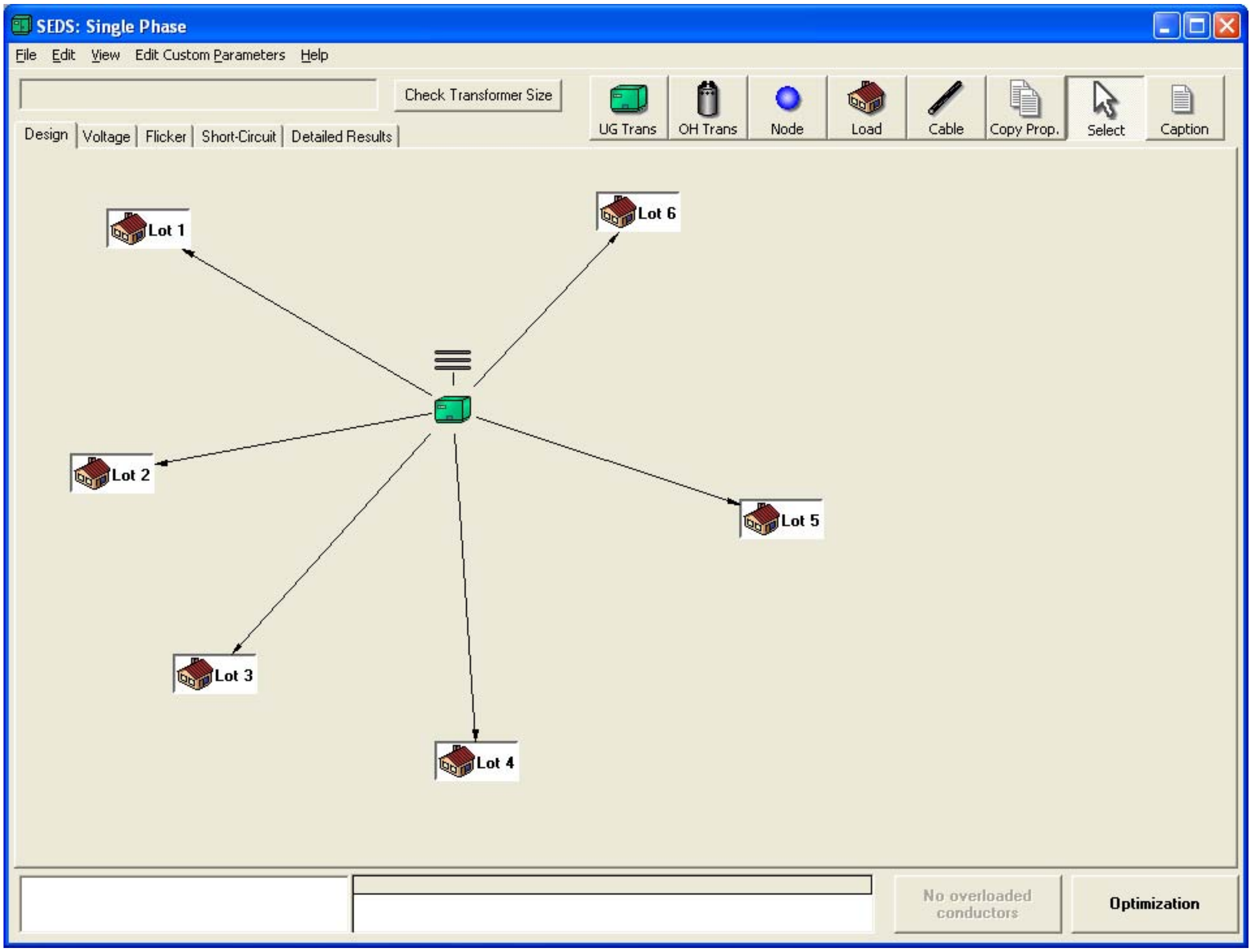

Figure 1 – SEDS Sample Layout

Figure 2 shows an example of a secondary design with calculation results. In this example, there are no voltage drop or flicker violations. The voltage drop and flicker results are shown next to each of the loads in the design. SEDS shows color-coded results to indicate whether or not the user defined voltage drop or flicker warning criteria has been violated. Additionally, the user will be warned if the transformer or conductor is overloaded. If there are violations, the user can make adjustments to the design to remove violations. Alternatively, the user can use the optimization feature in SEDS to remove violations while minimizing cost.

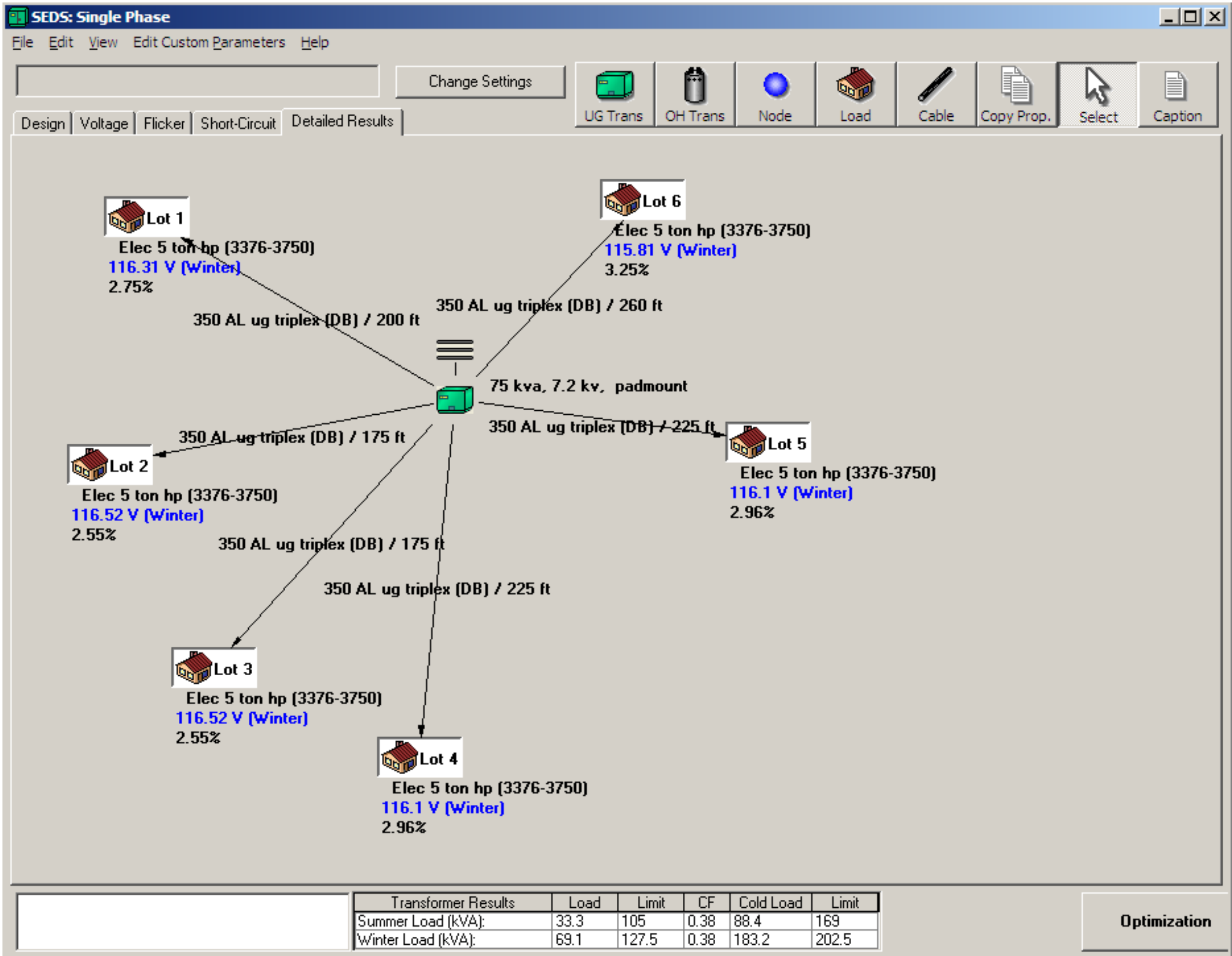

Figure 2 – SEDS Sample Results Screen

Design Optimization and Example

The SEDS design optimization feature is based upon a custom multi-pass algorithm that "crawls" from the loads back to the transformer and removes the voltage drop, flicker, transformer loading, cable ampacity, and short circuit violations while it traverses the topology. The algorithm methodically increases or decreases the conductor and transformer sizes to remove violations and minimize first cost plus cost of losses. If there are no technical violations, the algorithm will work to minimize the total system cost. This feature is useful to determine if there are alternative lower cost designs that could satisfy the technical requirements. It has been discovered that very few utilities effectively minimizing secondary system costs while attempting to meet the technical design requirements, such as voltage drop. Often secondary systems were designed with significant margin between the technical requirement and the actual designed value. In the example shown in Figure 2, the calculated flicker observed at the load labeled Lot 6 is 3.25%. In this example, the absolute limit set by the designer is 4.2%. Is it possible to lower the cost of this design by changing the transformer or secondary conductor such that the flicker is within 4.2%? This is precisely the question that is answered by the optimization algorithm. The algorithm tests various configurations within a set of user-definable constraints to find a lower cost option. The cost equation that is minimized is shown in Equation 1.

$$C_t = C_{trans} + \sum C_{cable} + \sum C_{node} + (A_{trans} \cdot Loss_{NL}) + (B_{trans} \cdot Loss_{LL})\left[\frac{KVA_{Loading}}{KVA_{Rating}}\right]^2 + \sum B_{cable} \cdot I_{cable}{}^2 \cdot R_{cable}$$

Equation 1: Total Cost Equation

C_t = Total owning cost of system

C_{trans} = Transformer first cost ($)

C_{cable} = Cable(s) first cost ($)

C_{node} = Node(s) or pedestal(s) first cost ($)

A_{trans} = Transformer A factor ($/watt)

B_{trans} = Transformer B factor ($/watt)

$Loss_{NL}$ = Transformer no load losses (watts)

$Loss_{LL}$ = Transformer load losses (watts)

B_{cable} = Cable B factor ($/watt)

I_{cable} = Worst case conductor current (amps) - Calculated

R_{cable} = Worst case cable resistance (ohms)

KVA_{Rating} = The transformer kVA rating (kVA)

$KVA_{Loading}$ = The worst case transformer kVA loading (kVA) - calculated

Equation 1 includes the A and B factors used to cost evaluate transformer losses. These factors are commonly used by planning engineers to cost evaluate distribution transformers during the procurement process. The remaining data is either calculated or required input data.

With a large base of existing users and a large set of base designs, DSTAR members were able to test the ability of the optimization algorithm to minimize costs on standard designs. The results were impressive. Figure 2 shows a typical design used by one of the DSTAR member utilities. After running the optimization routine on the design shown in Figure 2, SEDS was able to reduce the overall system cost by 6%. Figure 3, shows the optimized design. The example results show that the transformer size was increased to 100kVA (from 75kVA) and the conductor sizes to each of the loads where decreased. It should be noted that the voltage drop and flicker at each of the loads has increased. However, the design criteria at each of the loads are still met. In this example, the optimization algorithm has removed the "excess" design margin and reduced the overall system cost. For systems of relative complexity, it would be virtually impossible to find an optimal solution manually.

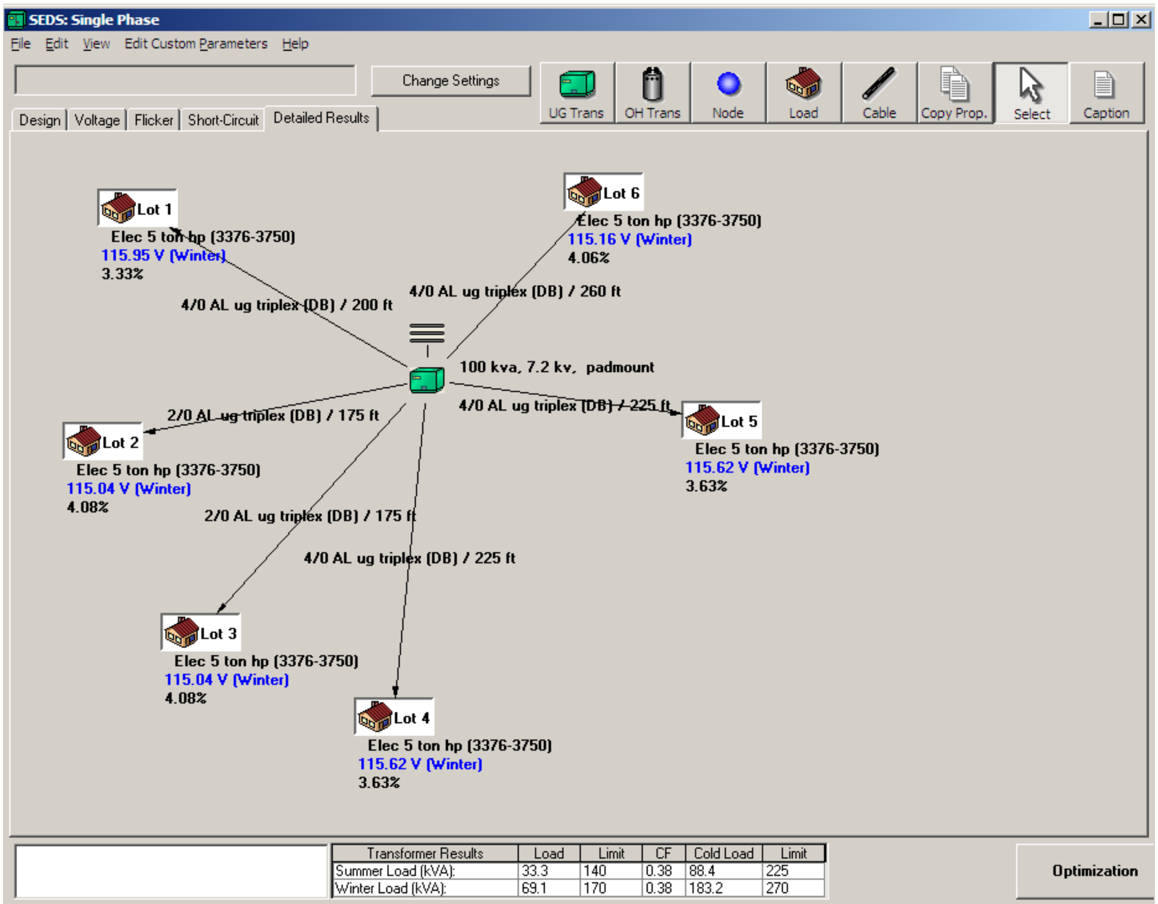

Figure 3 – SEDS Sample Optimized Results

Conclusions

Although the distribution system is a very dynamic portion of the utility system, and accounts for a substantial share of the utility's capital and operating expense, it has not generally received the same degree of research attention as the generation and transmission portions of the system. . Many of the major issues facing individual distribution utilities today apply to the entire industry and can be more effectively solved collaboratively. The DSTAR collaborative research and development model allows participants to leverage pooled funding, reduce their financial risk and gain wide industry acceptance of successful technology developments achieved through collaborative research and development efforts. The SEDS software is a product of this R&D model and has been used by DSTAR members for over 10 years to help them design their secondary systems. The new SEDS optimization feature uses a novel approach to find a design that minimizes costs while meeting a user defined design criteria. As distribution designers look for ways to lower costs and losses, optimization tools like SEDS will play an increasing role in overall system design.