The IEEE 8500-Node Test Feeder

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I. Objective

The Test Feeders Working Group (WG) of the Distribution System Analysis Subcommittee of the Power Systems Analysis, Computing, and Economics (PSACE) Committee has published several test feeders [1] and is in the process of developing new cases. This Test Feeder is one of the more recent, being introduced in 2010. This test feeder is derived from a real distribution circuit in the US. Some of the circuit parameters have been changed to make the test case more interesting. The purpose of the test case is to provide a benchmark for researchers who want to find out if algorithms they have developed will scale up and work well on large systems. While this is not as large as some systems currently being studied, it should present a reasonable challenge. Researchers are encouraged to try their methods out on this Test Feeder before submitting papers on methods that would be expected to be used in Distribution System Analysis packages on large circuit models.

II. Introduction

Many new methods are being proposed for distribution system analysis. While some of these appear to work well for the small test cases that exist, it is often difficult to judge whether the methods will scale well to large systems. Since many distribution planners are now solving models of distribution systems with several thousand buses, the WG was requested to provide a suitable test feeder. The 8500-node test feeder was developed to meet that need.

The test feeder has been designed to present challenges to distribution system analysis software in the following areas:

1. Constructing models of large unbalanced distribution feeders.
2. Solving large distribution systems containing numerous unbalances.
3. Modeling the 120/240V center-tapped transformer common in North American systems.
4. Modeling LV (secondary) distribution.

The 8500-node test feeder includes many elements that may be found on a North American MV distribution feeder: multiple feeder regulators, single-phase capacitor control, feeder secondaries, and service transformers. While the likely initial use of the test feeder is to simply solve the power flow for the defined loads, the test feeder was also selected for its potential for serving as the basis for future advanced test feeders. Two examples for which there is presently interest are

1. Distribution automations, including voltage and var control simulation, and
2. Daily and annual loading simulation for evaluating energy efficiency options, renewable generation, and electric vehicle impacts.

The 8500-node test system gives another benchmark by which Transactions reviewers can evaluate the claims of authors researching new methods for distribution system analysis. If the proposed method will perform well on this test feeder, it is

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more likely to perform well in actual practice.

The test feeder is provided with two versions of loads:

1. Balanced 120V secondary loads on the service transformers,

2. Unbalanced 120V secondary loads on the transformers.

The former can be represented adequately with a simple transformer model while the latter requires a specific model of the ubiquitous 120/240V, center-tapped residential service transformer.

The overall objectives of the WG are not only to provide benchmarks to confirm the accuracy and robustness of a given software but to promote the advancement of distribution system analysis tools. Calls for a smarter grid will require smarter, more capable tools to model the distribution system.

III. TEST CASE DESCRIPTION

A. Circuit Description

The 8500-node test feeder is a radial distribution feeder consisting of both MV and LV levels. As the name implies, there are approximately 8500 node points in the system for which voltages must be computed. These nodes occur at approximately 4800 1-, 2-, and 3-phase bus locations. Thus, it is a moderately large circuit that should be sufficient to exercise most distribution system analysis algorithms and prove the ability to handle large scale problems.

It is not as large as circuits some planners are studying but it has many interesting features and is quite realistic. The power flow is moderately difficult to solve at the specified load level, which should present a challenge to those interested in new algorithm development. It also exhibits approximately 10% loss at peak load, which is on the high side. This should provide researchers with a suitable test case for algorithms that are geared toward loss minimization.

The circuit contains 170km of primary (MV) conductor and the longest distance on the feeder from the substation is approximately 17km. The circuit contains one set of regulators controlling the feeder voltage at the substation and three sets of voltage regulators along the line.

The placement of the regulators and capacitors on the test feeder are shown in Fig. 1. For the initial version of this test case, only the regulator controls need be modeled; the capacitors may be assumed to be ON since the loading is a peak load condition. The benchmark represents only that one load condition. In future, this test case may be adapted for annual simulations for which it will be necessary to model the capacitor controls.

The circuit also contains four capacitor banks, three that include per-phase (single-phase) capacitor control. The capacitor is controlled to switches ON when the reactive power flow in the line is 50% of the capacitor size and switches OFF when the flow is 75% of the capacitor size in the reverse direction. Each controlled capacitor also includes voltage override where the capacitor turns ON at 0.9875pu and turns OFF at 1.075pu. It will be important to model these characteristics for daily and annual simulations.

The circuit model was based on an existing distribution feeder modeled in a commercial distribution software package. The model was converted to the OpenDSS program format as part of an EPRI research project. In the original model, the loads were attached to the primary line directly. Secondary line impacts were of interest in the research project so the customer service transformers and 15.24 meters (50ft) of service line were added for each customer load to represent a typical service drop.

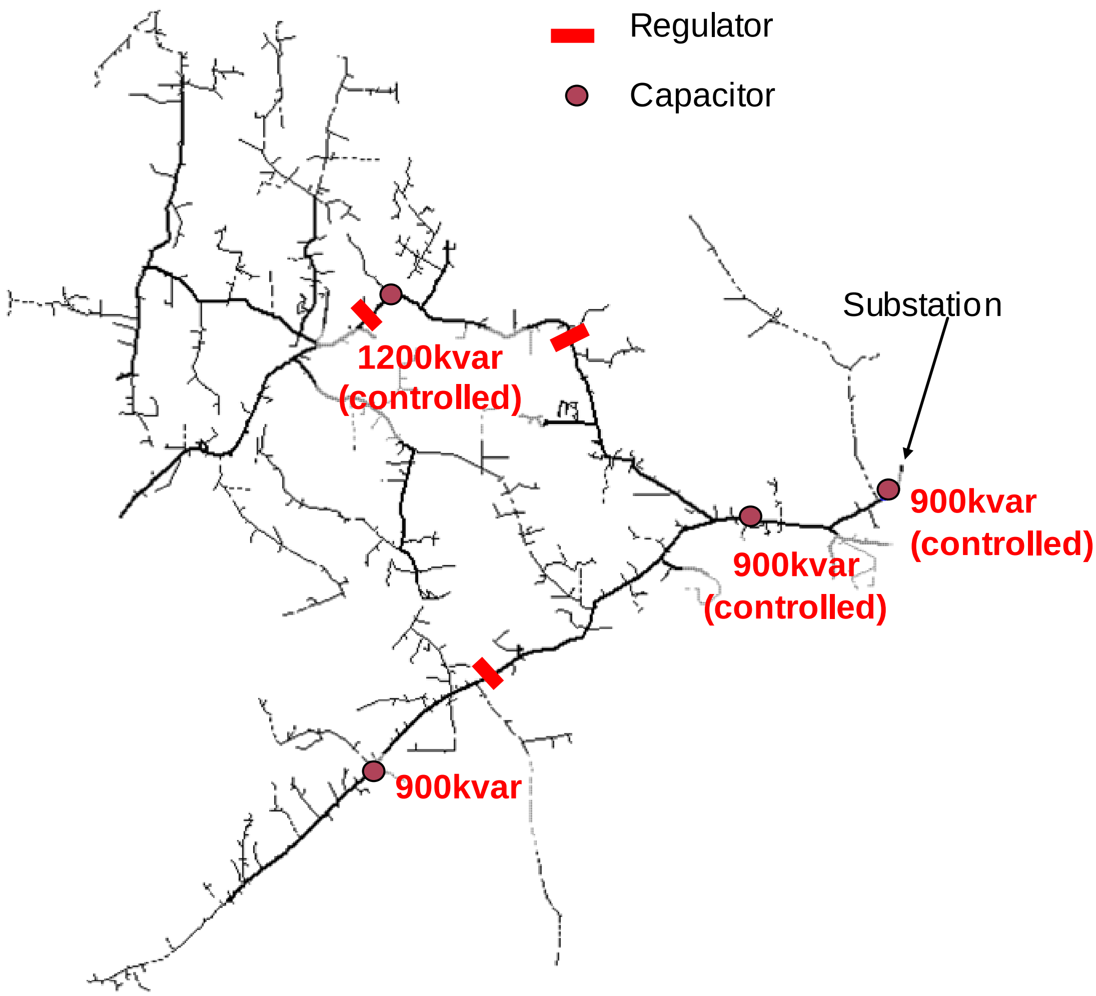

Figure 1. One-line diagram of the 8500-Node Test Feeder Circuit

The coordinates for the MV buses to reproduce this diagram may be found in the file **Buscoords.csv**.

B. Load Models

The Test Feeder makes two load model cases available to users. The **balanced** secondary loading case models the residential loads connected to a 120V/240V split-phase transformer in a balanced configuration. That is, both 120V loads are equal to half the total load. This configuration is shown in Fig. 2. The second case, the **unbalanced** secondary loading case, was developed by taking the total load of the balanced secondary case and randomly unbalancing the 120V loads. The total load on each transformer is the same, but distributed differently. This configuration is illustrated in Fig. 3.

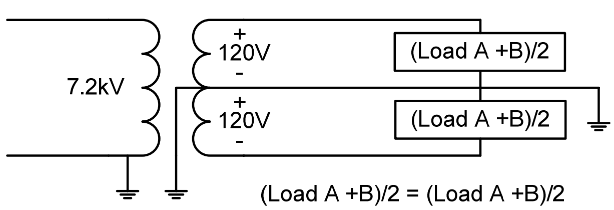

Figure 2. Residential Load Configuration in the Balanced Secondary Model

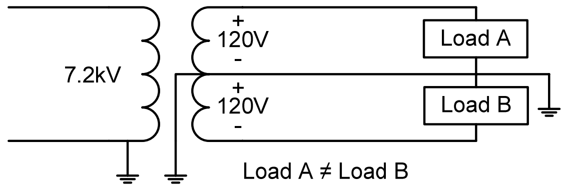

Fig. 3. Residential Load Configuration in the Unbalanced Secondary Model

The balanced secondary loading case can be adequately represented by a simple two-winding transformer model. However, a detailed model of the split-phase transformer is required to model the unbalanced secondary case. By providing benchmarks for both cases, researchers with programs not yet able to represent the split-phase transformer completely can still test the robustness of their methodology for large systems.

1) Difference in Balanced vs Unbalanced Loading

The difference in results between the balanced and unbalanced secondary cases can be illustrated for a single residential load simulated both ways. Table I shows the current magnitudes in the service conductor between the customer's transformer and load for the balanced secondary case. Table 2 illustrates the results of the same load sizes divided unequally between the two split phases. The residual current that flows in the return conductor/earth is equal to the difference between the phase currents and is quite substantial (21A).

TABLE I
CURRENT MAGNITUDES FOR BALANCE SECONDARY CASE AT SERVICE LINE

Element	Phase	Amperes
line.Tpx138236B0	1	16.275
	2	16.274
	residual	0.001

TABLE II
CURRENT MAGNITUDES FOR UNBALANCE SECONDARY CASE AT SERVICE LINE

Element	Phase	Amperes
line.Tpx138236B0	1	5.8142
	2	26.894
	residual	21.08

C. Center-Tapped Transformer Model

As mentioned above the test feeder is supplied in two forms: 1) balanced loading on the service (distribution) transformers and 2) unbalanced loading.

The balanced loading results can be matched with a relatively simple 2-winding model of the service transformer. However, to match the unbalanced case results the transformer must be modeled in greater detail. It is actually a 3-winding transformer with the following leakage impedances on the primary winding kVA base:

$Z_{12} = 1.8 + j\ 2.04\%$

$Z_{13} = 1.8 + j\ 2.04\%$

Z_{23} = 2.4 + j 1.36%

Where winding 1 = primary (H) winding; windings 2 and 3 = secondary (X) windings.

The no-load (idling) losses are assumed to be 0.2% and the magnetizing, or exciting, current is assumed to be 0.5%.

To simplify modeling, all distribution transformers are assumed to have the same percent impedance values. These are reasonable values for a modern distribution transformer with interlaced secondary windings commonly deployed in North America.

If you chose to omit the distribution transformers entirely and model only the primary, you would replace the transformer with the equivalent loading for winding 1 in one of the Solution files.

D. Services

All the services from the distribution transformer to the load have been simplified to be identical runs of 4/0 triplex, 50 ft in length. Only one service drop per transformer is modeled. The 4/0Triplex linecode (impedance matrix) is defined as follows in the Linecodes2.dat file.

```
[Linecode]
name=4/0Triplex
nphases=2
units=kft      !  ohms per 1000 ft
[Rmatrix]
  0.40995115   0.11809509
  0.11809509   0.40995115
[Xmatrix]
  0.16681819   0.12759250
  0.12759250   0.16681819
[Cmatrix]
  3.00000000  -2.40000000
 -2.40000000   3.00000000
```

Ohms, Series Impedance form

nF, Nodal Admittance form

The triplex cable actually consists of 3 conductors: two phase conductors around a neutral conductor. The neutral conductor has been reduced out of the matrices and is not explicitly modeled in this representation. Thus, the triplex cable is modeled as a two-phase line with earth return (see Figure 3).

As indicated above, the impedance matrices R and X are given in ohms per 1000 ft. The C matrix is in nF per 1000 ft. The C matrix is a **nodal admittance** matrix while R and X are **series impedances** matrices.

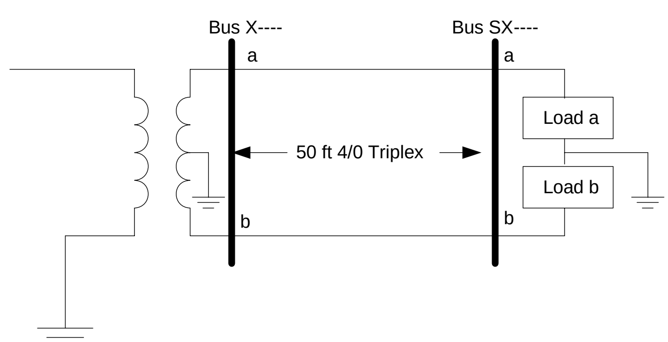

Figure 3. Secondary Load Model Detail

1) Naming Convention

All the buses on the secondary (X) side of the distribution load transformers begin with “X”. The rest of the bus name corresponds with the bus name on the primary side of the transformer.

All the buses at the load end of the triplex service cable begin with “SX”. The rest of the bus name corresponds with the

IV. PERFORMANCE

The 8500-node test feeder was adapted from a feeder modeled with EPRI’s OpenDSS computer program, which is freely available on the internet.[4] You may download this program and execute the model to obtain all the results it computes for the solution and to observe its performance. On a Lenovo ThinkPad T61 laptop, the program compiles the circuit model from its script files in approximately 1s. The initial snapshot power flow also takes approximately 1s. This would be a good target value to compare for a typical simple power flow solution. It is difficult to establish firm times due to disk caching and differing CPU performance, but this should give developers new to this field a rough idea of the expected performance of distribution system analysis software.

The OpenDSS solution algorithm requires at most 16 iterations to solve the initial power flow at a given regulator tap position. The regulator taps are changed 5 times during the initial solution, yielding a total of 62 iterations through the solver. This all occurs in approximately 1s. Since the OpenDSS is not optimized for this type of solution, particularly in its regulator model, it should be relatively easy for a good algorithm to beat this solution time on a modern computer. If solution times are much longer, it is an indication that the developer may still have some work to do.

In future Smart Grid applications, it will be important to perform not just one solution but daily or annual solutions. After the initial solution, one would ideally hope to achieve several solutions per second.

V. REFERENCES

[1] IEEE PES Distribution Systems Analysis Subcommittee Radial Test Feeders, http://ewh.ieee.org/soc/pes/dsacom/testfeeders.html.

[2] R. C. Dugan, William H. Kersting, Sandoval Carneiro, Jr., Robert F. Arritt, and Thomas E. McDermott, “Roadmap for the IEEE PES Test Feeders”, Panel on Advances in Distribution System Analysis, *Proceedings of 2009 IEEE PES Power Systems Conference and Exhibition (PSCE 2009)*, Seattle, March 2009.

[3] W. H. Kersting, “Center Tapped Wye-Delta Transformer Bank Test Case,” 2004 *IEEE PES General Meeting Conference Proceedings*, Denver, June 2004.

[4] OpenDSS Program, SOURCEFORGE.NET, URL:http://sourceforge.net/projects/electricdss.