THREE-PHASE DISTRIBUTION POWER FLOW WITH A
GEOGRAPHIC INFORMATION SYSTEM

INTRODUCCION

In this paper, the integration of the GIS database and application software is illustrated by using a three-phase distribution power flow. The database can be used for inventory, facility management engineering analysis and map productions. Facility data or network model can be retrieved from the data base. The work describes a complete modeling of elements in a distribution system. The paper report: lines, transformer, load and shunt var elements. The system configuration can be any combination of single, two and three phase circuits. The effects of neutral and ground return paths are include. Transformer losses (core and leakage) and lines losses can be clearly identified in a quantitative manner. Paper will discuss a method to simulate system in a rigorous way, because a typical feeder involves three-phase, two phase and single phase lateral lines. Finally we report the use of this system in Peru for the study of the Valor Agregado de Distribución (VAD) – yard stick competition – in order to obtain the electric rates in Peru for the next 4 years. The load forecasting is obtained from a hybrid system of cased based reasoning and expert system.

THE ELECTRICAL DISTRIBUTION SYSTEMS

The analysis of electric distribution systems is of great interest for utilities which want to increase their efficiency and improve energy management. The study of electric distribution system (EDS) should be focused on independent way because the used models in medium voltage necessarily do not incorporate the valid suppositions and simplifications for high voltage.

The distribution systems include all the elements of electrical energy transport comprised between the primary substations, where the power transmission is reduced to distribution levels, and the home connections to the consumers.

The distribution networks present very particular characteristics, which make them different from the transmission ones. Among them it is distinguished: radial topologies, high R/X ratio, multiphase natures, complex side structure, distinct nature loads, lines without transpositions, distributed loads, etc. Due to the growing complexity of the distribution systems, the electric companies have been incorporating increasingly automation and control schemes and remote measure of the networks.

This paper reports the application of models originally proposed in [1], in a real case of study.

Historically utilities computed the distribution losses by taking the difference between total system losses and transmission losses as determined by use of a power flow computer program or a survey method. This method is not accurate for determining the actual value of distribution losses and where they are actually occurring on the system. Most feeder are loaded in an unbalanced manner. This nature causes difficulty in analysis of a distribution feeder.

Nowadays, distribution engineers in the utility industry employ empirical methods mainly to predict the voltage for designing a feeder. Losses in a distribution system can not be accurately determined on a system wide basis[2,3].

In a distribution feeder, losses occur for the following reasons:

- line losses on phase conductors
- line losses on ground wire
- transformer core and leakage losses
- excess losses due to lack of coordination of var elements[3].
- excess losses due to load characteristics
- excess losses due to load imbalance on the phases.

The proper selection of the conductor size usually limits the line losses on phase conductors. The introduction of single-phase and two-phase systems causes additional losses on ground wires. Unbalanced load also adds line losses. The core losses of distribution transformer are sensitive to magnitude of system voltage. The quality of the transformer also affects the core loss. Since loads vary day to night and season to season the power factors along the feeder also vary. Without proper switchable var elements additional line losses occurs due to the poor power factor throughout the systems.

The load characteristics also play a role in distribution system losses. It is very important that load characteristics be accurately modeled.

Geographic Information System

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies[4].
Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods. And, before GIS technology, only a few people had the skills necessary to use geographic information to help with decision making and problem solving. This paper states a three phase load flow program connected with a geographic information system. The system provides an environment for building a distribution data base which includes both the graphic and alphanumeric data. The database can be used for inventory, facility management engineering analysis and map productions. Facility data or network model can be retrieved from the data base [5].

POWER FLOW IN DISTRIBUTION SYSTEMS

For the power flow analysis of electrical distribution systems, it can be used any of the conventional methods of power flow analysis such as node or meshing type - However, the EDS normally operate in radial configurations, and it has been demonstrated the convenience of using special methods of power flow, with better concurrence characteristics (speed and reliability). Among the special methods it is noticeable the ladder method, current summation method, and power summation method. In [2,6] they show that the power summation method is the most adequate for the solution of power flows in electrical distribution systems.

Three-phase Power Flow Analysis

The analysis module of three-phase power flow used is based on a specialized algorithm for radial distribution networks [2]. This makes an optimum use of the RAM memory, besides being very fast and precise as demonstrated in [6]. It permits to represent disbalances, returns and couplings and offers a graphical analysis of the results.

MODELING

The modeling methodology is divided into four major categories of load, lines and cables, distribution transformer, and shunt var elements.

Load modeling

A method for accommodating load compositions that vary by hour, day, season, etc. is used.

A pictorial representation showing percentages of the total load is used and is called load window. To develop a load window, key elements comprising the total load must be identified by appropriate survey methods, sample recordings, general knowledge of load characteristics and composition, etc. The percentage of individual elements in the total demand is dependent upon the time of the year and of the day, geographical location, socio-economic conditions and the diversity factors of the elements. It is believed a rough approximate of load window is better than none [1].

**TABLE 2 Steady-state component load models**

<table>
<thead>
<tr>
<th>LOAD TYPE</th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer, Distr.</td>
<td>0.00346 V + 0.01164<em>ΔV +0.0474</em>ΔV² +0.709*ΔV³</td>
<td>0.001 -(7.4 + 61.8<em>ΔF -64</em>ΔF²) + 10⁻¹⁰ * EXP(15.25 -24<em>ΔF + 152</em>ΔF²)*(1.0 + ΔV)</td>
</tr>
<tr>
<td>Fluorescent lights</td>
<td>(0.545 + 0.455<em>tanh(15.0</em>(ΔV+ 0.203)<em>α)² +0.0017</em>(1.0 + ΔF)*(1.0 + ΔV))⁰⁹</td>
<td>(8.7 + 66765*(ΔV + 0.25)⁶)* 1 -0.588* (1.0 + ΔV) + (1.0 + ΔF)⁻¹ + (0.0486 + 0.166<em>ΔV - 0.36</em>ΔF⁵)<em>EXP(2.58 - 6.7</em>ΔF + 10*ΔF²) * (1.0 + ΔV)</td>
</tr>
<tr>
<td>Hermetic lights</td>
<td>1.0 + 1.552*ΔV + 0.459 *ΔV²</td>
<td>0</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>0.798 + 0.606<em>ΔV + 1.146</em>ΔV² + 0.418<em>ΔF - 2.69</em>ΔV*ΔF</td>
<td>0.624 + 1.540<em>ΔV + 3.37</em>ΔV² - 0.889* ΔF - 7.37<em>ΔF</em>ΔF</td>
</tr>
<tr>
<td>Clothes dryer</td>
<td>0.995 + 2.032<em>ΔV + 0.900</em>ΔV² + 0.590*ΔV³</td>
<td>0.130 + 0.425<em>ΔV + 0.669</em> ΔV² + 0.467<em>ΔV³ - 0.342</em>ΔF + 0.670<em>ΔV</em>ΔF</td>
</tr>
<tr>
<td>Oven, grill, range</td>
<td>1.0 + 2.0<em>ΔV + 1.0</em>ΔV²</td>
<td>0</td>
</tr>
<tr>
<td>Duct heaters</td>
<td>0.992 + 1.553<em>ΔV + 0.848</em>ΔV² + 0.508<em>ΔF - 0.747</em>ΔV * ΔF</td>
<td>0.146 + 0.349<em>ΔV + 1.173ΔV² -0.1701</em>ΔF - 3.44<em>ΔV</em>ΔF</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>0.828 + 0.3871<em>ΔV + 1.623</em>ΔV² + 0.466<em>ΔF - 2.39</em>ΔV*ΔF</td>
<td>0.571 +1.407<em>ΔV + 3.22</em>ΔV² + 6.34<em>ΔV³ +44.48</em>ΔV⁴ +1.604<em>ΔF - 11.74</em>ΔV*ΔF</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>0.964 + 0.1943<em>ΔV + 1.6</em>ΔV² - 8.78<em>ΔV³ + 0.869</em>ΔF - 2.09<em>ΔV</em>ΔF</td>
<td>0.234 + 0.538<em>ΔV + 6.77</em>ΔV² + 6.31<em>ΔV³ - 0.624</em>ΔF - 9.12<em>ΔV</em>ΔF</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>0.887 + 0.0783<em>ΔV + 0.311</em>ΔV² + 0.869<em>ΔF - 2.09</em>ΔV*ΔF</td>
<td>0.473 +1.185<em>ΔV + 4.621</em>ΔV² + 2.074<em>ΔV³ - 0.624</em>ΔF - 9.12<em>ΔV</em>ΔF</td>
</tr>
</tbody>
</table>

**Fig. 1** Typical winter residential load window
TABLE 2 Typical load windows

<table>
<thead>
<tr>
<th>Load type</th>
<th>Residential%</th>
<th>Commercial%</th>
<th>Industrial%</th>
</tr>
</thead>
<tbody>
<tr>
<td>P and Q Coll.</td>
<td>10</td>
<td>15</td>
<td>67</td>
</tr>
<tr>
<td>Fluor. Light</td>
<td>10</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Incand. Light</td>
<td>30</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clothes dryer</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oven, flyer</td>
<td>35</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Duct heaters</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air cond.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air cond. (window)</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Air cond. (3φ)</td>
<td>10</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Lines and cables

All distribution circuits, both overhead and underground are modeled on a per-phase basis. The methods by [7] are used to compute circuit impedances for both underground and overhead conductor with neutral and ground return paths present. Line charging is ignored since it is relatively insignificant at distribution voltage levels.

\[
P_{core} (pu) \approx \frac{kVA \text{ rating}}{\text{System base}} \left( A \text{e}^{\frac{1}{2}} + B e^{\frac{e}{P}} \right) (1)
\]

\[
Q_{core} (pu) \approx \frac{kVA \text{ rating}}{\text{System base}} \left( D \text{e}^{\frac{1}{2}} + E e^{\frac{e}{P}} \right) (2)
\]

Typical values of A, B, C, D, E, F are:

A = 0.00267, B = 0.734E-9, C = 13.5
D = 0.00167, E = 0.2683E-13, F = 22.74

Distribution Transformers

Distribution transformers must be included in the network modeling procedure since they are quite numerous. Single-phase transformers are represented by series leakage impedance and shunt core loss function on the secondary terminal. It is recognized that core loss characteristic vary depending upon the quality of the transformer. Tests have indicated that real and reactive power core losses in per unit can be approximated as follows:

\[
P_{core} (pu) \approx \frac{kVA \text{ rating}}{\text{System base}} \left( A \text{e}^{\frac{1}{2}} + B e^{\frac{e}{P}} \right) (1)
\]

\[
Q_{core} (pu) \approx \frac{kVA \text{ rating}}{\text{System base}} \left( D \text{e}^{\frac{1}{2}} + E e^{\frac{e}{P}} \right) (2)
\]

Typical values of A, B, C, D, E, F are:

A = 0.00267, B = 0.734E-9, C = 13.5
D = 0.00167, E = 0.2683E-13, F = 22.74

FLUDIS GIS

It is reported the development of software for personal computers, which is formulated as a tool for the planning design and operation study of electrical distribution systems. This software has been called FLUDIS GIS. It is structured in a modular way including the following functions: network drawing, input and addition of data, storage and recovery of files, and three-phase power flow analysis. The package integrates software modules in MapInfo, Delphi and MS SQL. The GIS provides an environment for building an electric facilities database which includes graphic information and facility attribute data. The database can be used for engineering analysis, accounting and map production. Facility and network data can be retrieved by searching through the graphic and no graphic data files. The retrieved data can then be used to form input data files for electric distribution system applications. With the powerful graphic capability of the system, simulation results can be viewed from the computer screen along with the graphic displays.
Components of FLUDIS GIS

A FLUDIS GIS integrates five key components: hardware, software, electric data, power engineers, and models/methods.

Load forecasting

An hybrid system for electric load forecasting by using case-based reasoning and expert system called FUTURA is connected to FLUDIS GIS in order to get adequate load forecasting.

The systems used nowadays take into consideration just registered numeric information and the forecast is limited to extrapolation algorithms with rough results in a medium term. The limits that these methods present have motivated the development of FUTURA software which incorporates Artificial Intelligence (AI) techniques in order to benefit from another forecasting knowledge [8].

SAMPLE SYSTEM

It is detailed the study of a typical network called Red Example. The network of the problem belongs to a radial feeder, the $V_{se[pu]}=1.00$, active and reactive load factor of 1.0, unbalances of 0.1, 0.4, and 0.5; with coupling, without ground return.

Result exploitation

The distribution electric systems are considered nowadays as a monopolistic activity which should be regulated through legislation able to encourage efficiency and participation of private companies. Under this activity concessions are granted to install networks dedicated to give distribution service in a determined geographic area existing the obligation to do so.
In Latin America the methodology called Valor Agregado de Distribución –VAD or yardstick competition is mainly used to determine the income gotten from the distribution activity. In it the distribution company competes against an efficient model company. This analysis due to its size and importance is done every four years. The methodology of this paper was used to carry out the VAD 2001 study in Peru for the sectors 3 and 4.

CONCLUSIONS

The present work report the development of a computational package called FLUDIS GIS. The integration of the GIS database and application software is illustrated by using a three-phase distribution load flow program capable of modeling unbalanced line impedance and load conditions. Load components are modeled in the load flow as functions of their terminal voltage using the load window concept. Core and leakage transformer losses are identified. These include shunt var compensation in terms of size and location on a feeder, load imbalance, the effects of voltage reduction and load characteristics on system losses. The package provides an easy to use, state of the art tool for the analysis, design and planning of electrical distribution systems.

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REFERENCES