Three Phase Modeling in Distribution Systems

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ABSTRACT

The work describes a complete modeling of elements in a distribution system and its influence in digital simulations. The paper report: lines, transformer, loads 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 included. Transformer losses(core and leakage) and lines losses can be clearly identified in a quantitative manner. Paper will discuss a method to simulate systems in a rigorous way, because a typical feeder involves three-phase, two phase and single phase lateral lines.

1. Introduction

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[3,1].

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[1,2].
- excess loses 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 effects 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 a distribution system losses. It is very important that load characteristics be accurately modeled.

2. Modeling

The modeling methodology is divided into four major categories of 1) load 2) lines and cables 3) distribution transformer, and 4) shunt var elements.

2.1 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.**

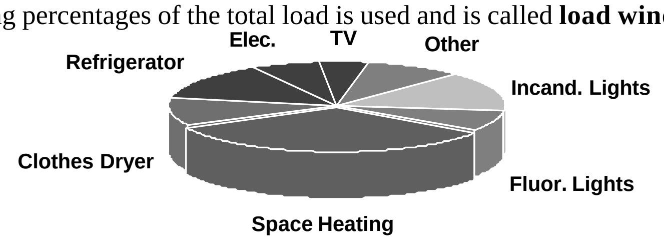

Fig. 2.1 Typical winter residential load window

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[1,3].

Table II.1 Steady-state component load models

LOAD TYPE	P	Q
TRANSFORMER DISTRIBUTION TYPE	0.00346 V = 0.01164*V + 0.0474*V^2 + 0.0709*V^3	0.001 +(7.4 + 61.8*F - 64*F^2)* 10^{-10} * EXP((15.25 -24*F + 152*F^2)$^{*(1.0 + V)}$)
FLUORESCENT LIGHTS	(0.545 + 0.455*tanh(15.0*(V+ 0.203)))*(1.0 +F)*$(1.0 + V)^{0.9}$	(8.7 + 66765*$(V + 0.25)^4)^{-1}$ -0.588*$(1.0 + V)^{2}$ * $(1.0+F)^{-1}$ +(0.0486 + 0.166*V -0.36*F^2) *EXP((2.58 - 6.7*F + 10*F^2) * (1.0 + V))
INCANDESCENT LIGHTS	1.0 + 1.552*V + 0.459 *V^2	0
REFRIGERATOR	0.798 + 0.606*V + 1.146*V^2 + 0.418*F - 2.69*V*F	0.624 + 1.540*V + 3.37*V^2 - 0.889*F - 7.37*V*F
CLOTHES DRYER	0.995 + 2.03*V + 0.990*V^2 + 0.590*V^3	0.130 + 0.425*V + 0.669 *V^2 + 0.467 *V^3 - 0.342*F - 0.670*V*F
OVEN, GRIDDLE, FLYER	1.0 + 2.0*V + 1.0*V^2	0
DUCT HEATERS (Including Blowers)	0.992 + 1.553*V + 0.848*V^2 + 0.508*F - 0.747* V * F	0.146 + 0.349*V + 1.173V^2 -0.1701*F -3.44*V*F
AIR CONDITIONER (Window-type)	0.828 + 0.3871*V + 1.623*V^2 + 0.466*F - 2.39*V*F - 2.39*V *F	0.571+1.407*V +3.22*V^2 + 6.34*V^3 +44.48*V^4 -1.604*F - 11.74*V *F
AIR CONDITIONER (1ϕ)	0.964 + 0.1943*V + 1.6*V^2 - 8.78*V^3 + 0.869*F - 2.09*V*F	0.234 + 0.538*V + 6.77*V^2 - 6.31*V^3 - 0.624*F - 9.12*V*F
AIR CONDITIONER (3ϕ)	0.887 + 0.0783*V + 0.311*V^2 + 0.869*F -2.09*V*F	0.473 +1.185*V +4.621*V^2+ 2.074*V^3 - 0.624*F - 9.12*V*F

Table II.2 Typical load windows

Load type	Residential %	Commercial %	Industrial %
P and Q constants.	10	15	67
Fluorescent Light	10	40	20
Incandescent Light	30	15	5
Refrigerator	0	0	0
Clothes dryer	5	0	0
Oven, griddle, flyer	35	20	4
Duct heaters	0	0	0
Air cond. (window -type)	0	0	0
Air conditioner (1ϕ)	0	5	0
Air conditioner (3ϕ)	10	5	4

2.2 Lines and cables

All distribution circuits, both overhead and underground are modeled on a per-phase basis. The methods by [4] 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.

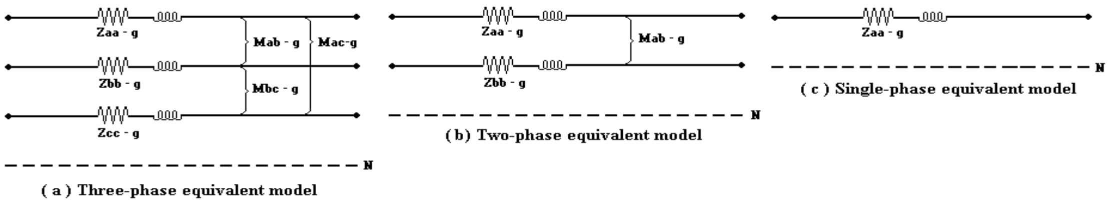

Fig. 2.2 Equivalent circuit impedance [4]

2.3 Distribution Transformers

Distribution transformers must be included in the network modeling procedure since they are quite numerous . Single-phase transformer are represented by a 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:

$$P_{core}(pu) \cong \frac{kVA\ rating}{System\ base}\left(A|V|^2 + Be^{C|V|^2}\right)$$

$$Q_{core}(pu) \cong \frac{kVA\ rating}{System\ base}\left(D|V|^2 + Ee^{F|V|^2}\right)$$

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

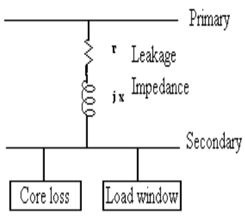

Fig. 2.3 Single-phase transformer with core loss

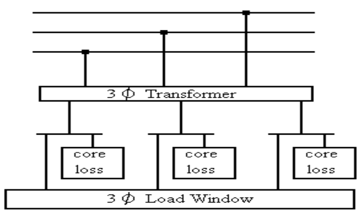

Fig. 2.4 Three-phase transformer with core loss

2.4 Shunt Var Elements

Capacitors are treated as constant shunt admittance element on a per-phase basis[2].

3. Method of Analysis

The method of analysis is from [2,3,5,6]. The three-phase load flow program is a module of AIDPRI[2,7].

4. Sample System

It is detailed the study of a typical network called Frontel Cholguan-Yungay. The data are from [7]. The network of the problem belongs to a radial feeder, the voltage base is 7620, Vse[pu]=0.992, active and reactive load factor of 1.0, unbalances of 0.25, 0.35, and 0.4; with coupling, without ground return.

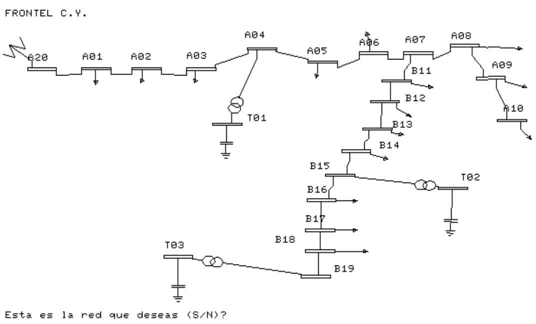

Fig. 4.1 Frontel Cholguan-Yungay network

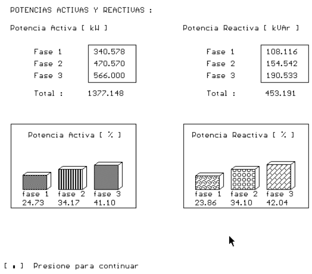

Fig. 4.2 Power by phase

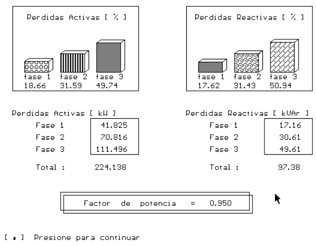

Fig. 4.3 Load factor

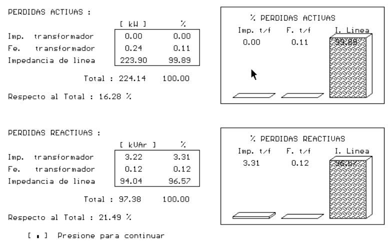

Fig. 4.4 Separate losses

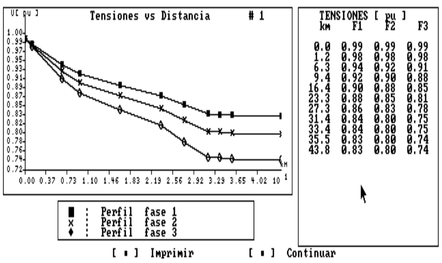

Fig. 4.5 Voltage level vs. distance

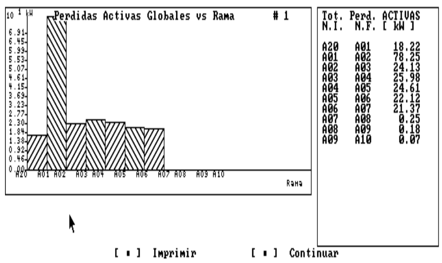

Fig. 4.6 Active losses vs. branch

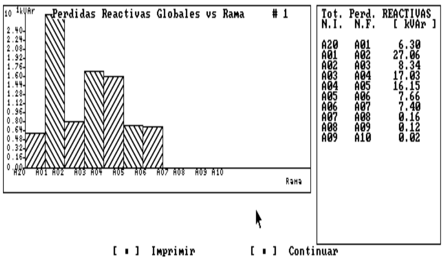

Fig. 4.7 Reactive losses vs. branch

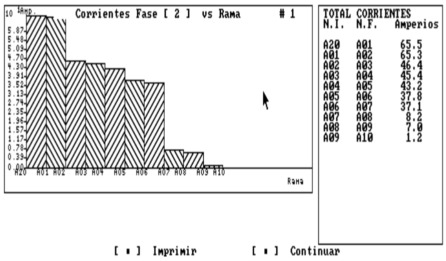

Fig. 4.8 Current phase two vs. branch

5. Conclusions

The present work present the use of a computacional package called AIDPRI. A three-phase distribution load flow 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 . Sample studies were performed to demonstrate the versatility of AIDPRI[7,3]. 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.

6. Acknowlegements

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7. References

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