Volt/Var Control with Interactive Graphics Interface on Distribution Systems

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ABSTRACT

An interactive intuitive graphical simulation package for the analysis of electric distribution systems is presented. It links the interactive graphical design of an electrical network with specialized analysis algorithms. The interaction is facilitated by the use of a friendly graphic interface. The program incorporates complete models for the electric components. The problem of volt/var control is solved with a method originally proposed by Grainger and Civanlar. The method permits to allocate and size capacitor banks for loss reduction and voltage control for varying load conditions. The minimum number of capacitor is determined as well as the switching strategies that allow to respond to daily, weekly or monthly changes in reactive load.

1. Introduction

The analysis of the electrical distribution systems (EDS) has its particular features, since the models used in medium voltage (MD) do not let, in most of cases, make the suppositions and simplifications valid for the high voltage (HV) models. The new generation of programs applied to EDS in personal computers exploits the interactive environment through the menus and techniques of dialog boxes, with which man-machine friendly interfaces are obtained carrying along the increase in productivity [8]. The main reason of utilizing interactive graphics is the speed of interpreting the results and the communication between the user and the computer. The data is better understood in a graphic way or histograms than in a tabulating way. Having understood these advantages is how the graphic interactive programs have been developed for the analysis, design and teaching of the power electrical systems [2].

2. The Distribution Systems

The distribution systems include all the elements of electric energy transportation comprised between the primary substations, where the power transmission reduces to distribution levels, and the connections to the users. The distribution networks present very particular characteristics, which make them different from the transmission ones. Among these we can distinguish radial topologies, high R/X ratio, multiply connections (single-phase, two-phase, etc.), complex side structure, different nature loads, lines without transposition, distributed loads, etc. [18]

3. Interactive Graphic Interface in EDS

In the present section, we describe what a intuitive interactive graphic interface is and its application to the EDS. The advantages of the graphics against the numeric lists are unquestionable. It is said that "a picture is worth a thousand words," but in computation "an image is equivalent to 1024 words". Traditionally the engineers have exploited the visual communication to transmit their ideas more effectively and efficiently.

The pictures used in the past were done by draftsmen or sometimes by drawing softwares [14,17]. The developed program has the advantage of making the drawing of the network, besides doing a graphic analysis of the results, all of it working together without any need of resorting to a specialized package of drawing and even worse to an electronic sheet.

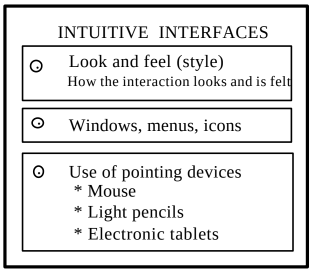


Fig. 3.1 Intuitive Interfaces

The application to the electrical engineering is attractive, by the easy representation of a network through icons, which can be represented fast and easily, identifying elements and connections. The system state must be reflected in images and the effects of the commands should be understood in terms of visual impacts. It is important that the developed interface be intuitive and count with buttons, menus and icons, which are easy to interpret and use. The development of graphic interfaces for the analysis of EDS, pass necessarily by the using of drawing from the network and the graphic analysis of the results. The single-line diagram is the obvious election for the model user-concept, in the analysis of the EDS, since the engineers are accustomed to display this type of systems in this way[1,6,14]

4. Control of the Voltage Level and Reactive Power in EDS

It is known the fact that the control of the voltage level and reactive power plays an important role inside the schemes of automatic distribution which are developing. The high costs of generation and distribution of energy obligate to pay special attention to the control of rush demand which confronts the system and of the energy losses along the time. The reduction of power and energy losses is a topic of interest for every electric company, independent from the point of the generation final consumption chain in which it is found. Developments in automatic distribution through computers in the substations and recollection systems of detailed information about the system let reduce in an effective way the losses which are produced in the system, by means of the control in real time of the voltage level outline and of the flow of reactive currents along the system[1,9,10,11]. The capacitors are widely used in the EDS for the compensation of reactive power voltage control and reduction of power losses. The benefits of its use depend on the type of capacitors (firm or interruptable), location of them, the size, its control scheme and the levels of harmonic distortion existing in the network (it begins resonating for certain harmonics with the inductance of the transformer and the network, which distorts the voltage wave; it will also depend on the regulation step and the load which will enter at each moment). Then the problem of location of the capacitors in the supply mains may be outlined as: to determine the place (number and location), type, size and control scheme of the capacitors to be installed. When the reactive power is given just by the power substation each of the components of the EDS (feeders, transformers, protection equipment) must be dimensioned for such levels of reactive load. The capacitors make flexible this need due to the diminishing in reactive power demand which faces the power substation, when reducing the current of the feeders. Benefits of the installation of capacitors:

- Depending on the power factor of the system, the installation of capacitors may increase the capacity of the substations up to 30% [19];
- freed capacity in the supply mains, there are fewer thermal exigencies over the lines as a consequence of the reduction of the currents. Therefore a bigger capacity of power transmission is disposed;
- better voltage level, that is a better service to the customer;
- freed capacity in the generation, when reducing the losses; and
- reduction in the loses of capital which means perfecting or expanding a system [19,1,10,11]

The computer program analysis two problems, the capacitive compensation and the voltage regulation. The problem of compensation belongs to the determination, dimensioning and optimum control of time in the capacitor banks which will be installed in the system. The regulation problem, corresponds to the determination of the place in the supply main (feeder) of the minimum number of transformers with derivation control under load, so that the outline of the voltage level keeps inside the pre-established limits. The algorithms used in the present section are the ones from [9,10] and the modelation of the elements is detailed in [1].

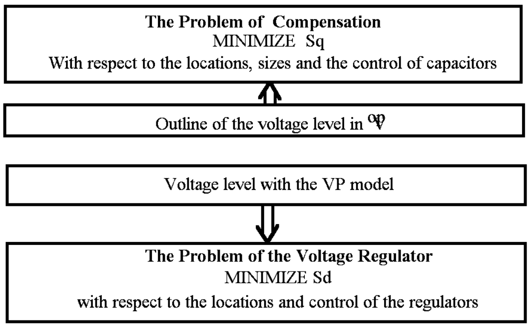


Fig. 4.1 Block diagram of the decoupled reactive model[9,10].

Cost function which can be expressed as:

$$S = Sd + Sq \qquad (1)$$

A decoupled model in which: **Sd** belongs to the location of the minimum number of transformers with control of branches under load, and **Sq** corresponds to the determination of the optimum location, size and control of "n" capacitor banks, the problem is discomposed in two sub-problems: i) optimize Sd in terms of the variables of the voltage regulator problem. ii) Optimize Sq in terms of the variables of the capacitive problem.

4.1. Optimum Reactive Compensation

It belongs to the determination of the optimum location size and control of "n" capacitor banks so that the following function maximizes.

$$S_q = K_p LP_q + K_e LE_q - \sum_{i=1}^{n} K_c \left(I_{ci}^{o}\right) I_{ci}^{o} \qquad (2)$$

$$LP_q = r \sum_{i=1}^{s} \int_{o}^{l_i} \left(F_q^{b}(y_i, T)^2 - \left(F_q^{rc}(y_i, T) - F_{cq}^{rc}(y_i, T)\right)^2 \right) dy_i \qquad (3)$$

where :

$$LE_q = r \int_{o}^{T} \sum_{i=1}^{s} \int_{o}^{l_i} \left(F_q^{b}(y_i, \tau)^2 - \left(F_q^{rc}(y_i, \tau) - F_{cq}^{rc}(y_i, \tau)\right)^2 \right) dy_i \, d\tau \qquad (4)$$

under the supposition that $V_i^{rc}(\tau) = V^{op}, \qquad V_{min} \le V^{op} \le V_{max} \qquad (5)$

4.2. Optimum Regulation of Voltage Level

The problem corresponds to the location of the minimum number of voltage regulators such that the following cost function is maximized:

$$S_d = K_p LP_d + K_e LE_d \qquad (6)$$

subjected to the restrictions of the voltage level

$$S_d = K_p LP_d + K_e LE_d \qquad (7)$$

$$0 \le \tau \le T; \qquad i = 1, 2, .., m$$

where:

$$LP_q = r \sum_{i=1}^{s} \int_{o}^{l_i} \left(F_q^{b}(y_i, T)^2 - F_d^{rc}(y_i, T)^2 \right) dy_i \qquad (8)$$

$$LE_d = r \int_{0}^{T} \sum_{i=1}^{s} \int_{o}^{l_i} \left(F_q^{b}(y_i, \tau)^2 - F_d^{rc}(y_i, \tau)^2 \right) dy_i \, d\tau \qquad (9)$$

Both problems may be analyzed in an independent way, but in real terms they are related and cannot be put into practice one without the other since the regulation model requires the existence of a compensated system and the problem of compensation needs and outline of the voltage level inside a narrow band.

5. Structure of the Solution

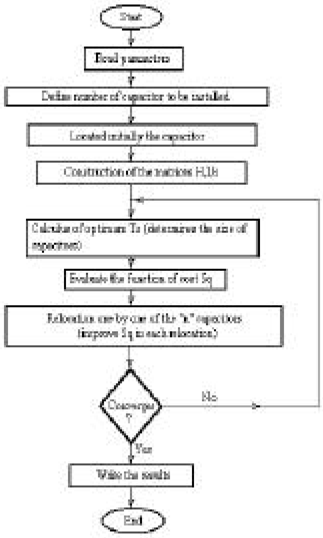


Fig. 5.1 Block diagram for the compensation

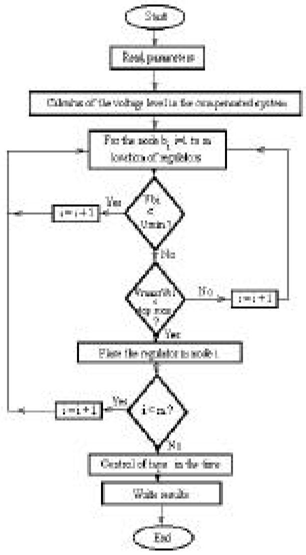


Fig 5.2 Block diagram for the regulation [9,10]

6. Numerical Results

It is detailed the study of a typical network of urban electric distribution; it belongs to Huancayo system gate III, corresponding to Electrocentro S.A. Company. The data are from [13,19]. The network of the problem belongs to a radial feeder, operating in 10 [kV]. The feeder does not have earth return.

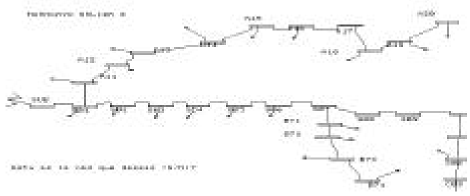
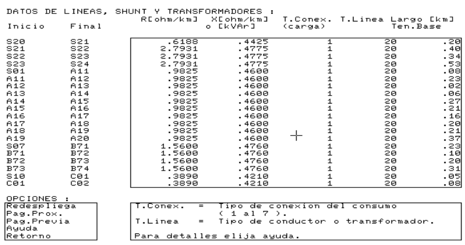


Fig. 6.1 Initial part of Huancayo system gate III

Fig. 6.2 Huancayo network gate III

Figure 6.1 illustrates part of the network seen on the monitor (the network is relatively big, it does not fit to be showed completely). The program AIDPRI (Graphic Interactive Analysis of Primary Distribution) [1] offers the possibility of sliding the image from up to down, from left to right (or viceversa), and using a zooming alternative. Figure 6.2 shows the use of a scale factor of 0.30.



DATOS DE LINEAS, SHUNT Y TRANSFORMADORES :

Inicio	Final	R[ohm/km]	X[ohm/km] o [kVAr]	T.Conex. (carga)	T.Linea	Largo [km] Ten.Base
S20	S21	.6188	.4425	1	20	.20
S21	S22	2.7931	.4775	1	20	.40
S22	S23	2.7931	.4775	1	20	.34
S23	S24	2.7931	.4775	1	20	.53
S01	A11	.9825	.4600	1	20	.08
A11	A12	.9825	.4600	1	20	.23
A12	A13	.9825	.4600	1	20	.02
A13	A14	.9825	.4600	1	20	.06
A14	A15	.9825	.4600	1	20	.27
A15	A16	.9825	.4600	1	20	.21
A16	A17	.9825	.4600	1	20	.16
A17	A18	.9825	.4600	1	20	.20
A18	A19	.9825	.4600	1	20	.21
A19	A20	.9825	.4600	1	20	.37
S07	B71	1.5600	.4760	1	20	.23
B71	B72	1.5600	.4760	1	20	.10
B72	B73	1.5600	.4760	1	20	.20
B73	B74	1.5600	.4760	1	20	.31
S10	C01	.3890	.4210	1	20	.05
C01	C02	.3890	.4210	1	20	.08

OPCIONES :

Redespliega
Pag.Prox.
Pag.Previa
Ayuda
Retorno

T.Conex. = Tipo de conexion del consumo (1 al 7).
T.Linea = Tipo de conductor o transformador.
Para detalles elija ayuda.

Fig. 6.3 Lines, shunts and transformers data

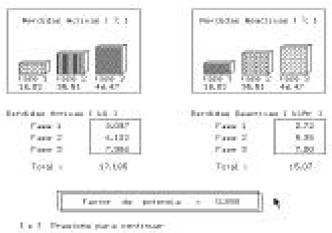


Fig. 6.4 Losses in Huancayo system gate III

The line data may be entered with codes which represent standard conductors, or by means of resistances and reactances given by the user [1,3,4,14]. It is illustrated a graphic output of the losses given by AIDPRI [1], the unbalances are 0.25, 0.35, and 0.40, without earth return, active and reactive load factor of 0.5. In the optimum reactive analysis, as data in the study Huancayo Gate III, the costs of power, rush energy and capacitors installation cost will be used for the power factor. These values are 0.899, 120 and 0.030, respectively. It was specified that the voltage level not vary more than 5%, for both the superior limit as well as the inferior one. The results of diverse simulations are detailed in table VI-I.

TABLE VI-I. Location and Size up to Four Capacitors

		Location				Size			
n	**Sq**	**Lc. 1**	**Lc. 2**	**Lc. 3**	**Lc. 4**	**Sz. 1**	**Sz.2**	**Sz. 3**	**Sz. 4**
1	41104	S10				1770			
2	64084	S10	S10			1400	1400		
3	38463	S10	A14	A11		1660	300	300	
4	37407	S10	A14	A11	S03	1620	300	300	300

The optimum number of capacitors to be installed is two, and this belongs for a maximum Sq (met maximum save of costs by reduction of power and energy losses). The program suggests that: two regulators be installed, the first in node C06 and the second in S14.

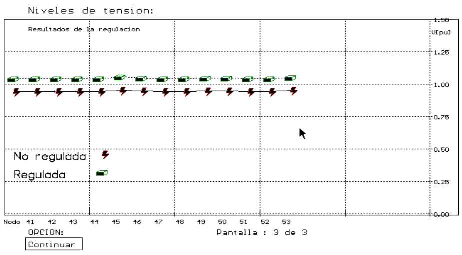


Fig. 6.5 Voltage level

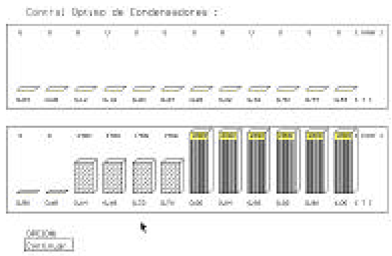


Fig. 6.6 Optimum control of capacitors

7. Conclusions and Comments

The present work has presented the development and use of AIDPRI[1] for the design and study of electrical distribution networks, usable in personal computers. The use of interactive and intuitive interfaces in the network drawing and the creation of a data base in the reactive analysis make the program an easy-to-use tool in a professional environment. The application of graphic interactive interfaces, plus the use of single-line diagrams, icons and tabulated data, make the distribution engineer's labor easy. The program is adequate for the and of a big quantity of data corresponding to the diverse parameters of the electric energy distribution networks since it has an adequate administration of the related parameters. The program determines the location, dimensioning and time control of capacitor and transformer banks with control of derivations under load in EDS, so that the economical profits derived from a save in energy losses be maximized. It also seems attractive the possibility of relating the package with geographic bases type GIS (Geographic Information Systems).

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