

Volt/Var Control with Interactive Graphics Interface on Distribution Systems

Raúl Vilcahuamán S. ^{abc}

Hugh Rudnick V.D.W ^c

Julio Arias C. ^b

a) Escuela de Post Grado

b) Departamento de Ingeniería Eléctrica
Universidad Nacional del Centro del Perú

Fax: (0051)(64) 231778

Calle Real 160, Huancayo, Perú

c) Departamento de Ingeniería Eléctrica
Pontificia Universidad Católica de Chile

Fax: (0056)(2) 5522563

Casilla 306, Correo 22, Santiago, Chile

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 (MV) 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.

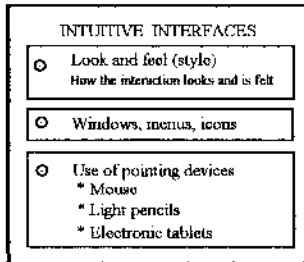


Fig. 3.1 Intuitive Interfaces

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].

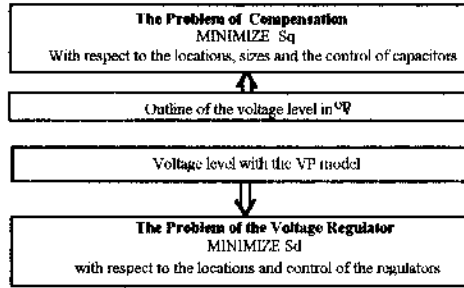


Fig. 4.1 Block diagram of the decoupled reactive model[9,10].

Cost function which can be expressed as:

$$S = S_d + S_q \quad (1)$$

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

$$S_q = K_p LP_q + K_e LE_q - \sum_{i=1}^n K_c (I_{G_i}^o) I_{G_i}^o \quad (2)$$

$$LP_q = r \sum_{i=1}^s \int_0^k \left(F_q^b(y_i, T)^2 - (F_q^{rc}(y_i, T) - F_{cq}^{rc}(y_i, T))^2 \right) dy_i \quad (3)$$

where :

$$LE_q = r \int_0^T \sum_{i=1}^s \int_0^k \left(F_q^b(y_i, \tau)^2 - (F_q^{rc}(y_i, \tau) - F_{cq}^{rc}(y_i, \tau))^2 \right) dy_i d\tau \quad (4)$$

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

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:

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

subjected to the restrictions of the voltage level

$$V_{min} \leq V_i^{rc}(\tau) \leq V_{max} \quad (7)$$

$$0 \leq \tau \leq T; \quad i = 1, 2, \dots, m$$

where:

$$LP_q = r \sum_{i=1}^s \int_0^4 (F_q^b(y_i, T)^2 - F_d^{rc}(y_i, T)^2) dy_i \quad (8)$$

$$LE_d = r \int_0^T \sum_{i=1}^s \int_0^4 (F_q^b(y_i, \tau)^2 - F_d^{rc}(y_i, \tau)^2) dy_i d\tau \quad (9)$$

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

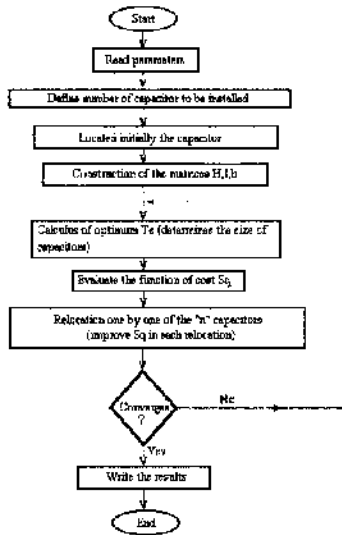


Fig. 5.1 Block diagram for the compensation

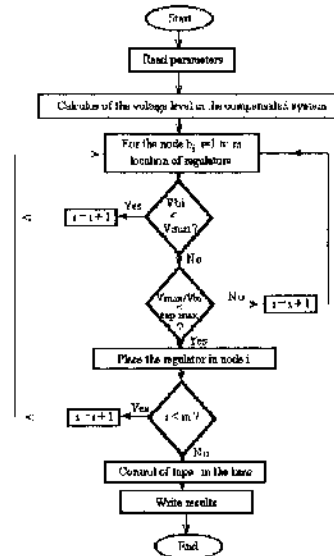


Fig. 5.2 Block diagram for the regulation [9,10]

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.

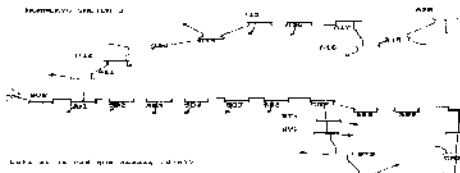


Fig. 6.1 Initial part of Huancayo system gate III

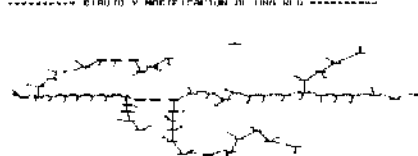


Fig. 6.2 Huancayo network gate III

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.

LINE	FROM	TO	TYPE	STATUS	DATE
1001	1000	1001	LINE	ON	10/10/80
1002	1001	1002	LINE	ON	10/10/80
1003	1002	1003	LINE	ON	10/10/80
1004	1003	1004	LINE	ON	10/10/80
1005	1004	1005	LINE	ON	10/10/80
1006	1005	1006	LINE	ON	10/10/80
1007	1006	1007	LINE	ON	10/10/80
1008	1007	1008	LINE	ON	10/10/80
1009	1008	1009	LINE	ON	10/10/80
1010	1009	1010	LINE	ON	10/10/80
1011	1010	1011	LINE	ON	10/10/80
1012	1011	1012	LINE	ON	10/10/80
1013	1012	1013	LINE	ON	10/10/80
1014	1013	1014	LINE	ON	10/10/80
1015	1014	1015	LINE	ON	10/10/80
1016	1015	1016	LINE	ON	10/10/80
1017	1016	1017	LINE	ON	10/10/80
1018	1017	1018	LINE	ON	10/10/80
1019	1018	1019	LINE	ON	10/10/80
1020	1019	1020	LINE	ON	10/10/80
1021	1020	1021	LINE	ON	10/10/80
1022	1021	1022	LINE	ON	10/10/80
1023	1022	1023	LINE	ON	10/10/80
1024	1023	1024	LINE	ON	10/10/80
1025	1024	1025	LINE	ON	10/10/80
1026	1025	1026	LINE	ON	10/10/80
1027	1026	1027	LINE	ON	10/10/80
1028	1027	1028	LINE	ON	10/10/80
1029	1028	1029	LINE	ON	10/10/80
1030	1029	1030	LINE	ON	10/10/80
1031	1030	1031	LINE	ON	10/10/80
1032	1031	1032	LINE	ON	10/10/80
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1048	1047	1048	LINE	ON	10/10/80
1049	1048	1049	LINE	ON	10/10/80
1050	1049	1050	LINE	ON	10/10/80
1051	1050	1051	LINE	ON	10/10/80
1052	1051	1052	LINE	ON	10/10/80
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1077	1076	1077	LINE	ON	10/10/80
1078	1077	1078	LINE	ON	10/10/80
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1080	1079	1080	LINE	ON	10/10/80
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1094	1093	1094	LINE	ON	10/10/80
1095	1094	1095	LINE	ON	10/10/80
1096	1095	1096	LINE	ON	10/10/80
1097	1096	1097	LINE	ON	10/10/80
1098	1097	1098	LINE	ON	10/10/80
1099	1098	1099	LINE	ON	10/10/80
1100	1099	1100	LINE	ON	10/10/80

Fig. 6.3 Lines, shunts and transformers data

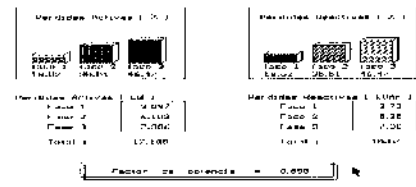


Fig. 6.4 Losses in Huancayo system gate III

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-1.

TABLE VI-1. Location and Size up to Four Capacitors

n	Sq	Location				Size			
		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.

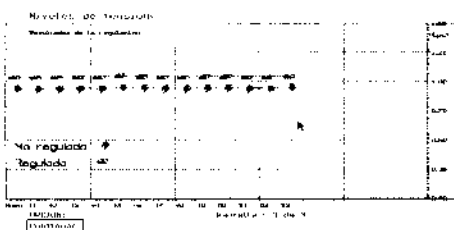


Fig. 6.5 Voltage level

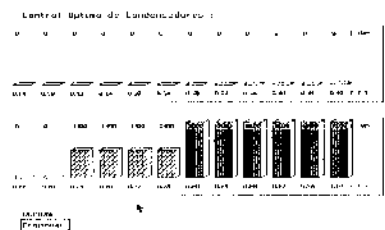


Fig. 6.6 Optimum control of capacitors

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).

8. Acknowledgements

We acknowledge FONDECYT, PNUD for investigations and developments done. We acknowledge the Antonio Rios's contribution for ending the work.

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