



Pedagogical Tool For Selection Of Electrical Components Used For The Construction Of An Automatic Capacitor Bank For Power Factor Correction

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ABSTRACT-

This paper presents an excel application for the selection of electrical components used to build an automatic capacitor bank for power factor correction and its corresponding methodology to serve as a guide for electrical engineering students. The power factor indicates how efficiently energy is used in an electrical system. The losses that can occur are associated with voltage drops along the conductors, the different types of loads that are connected that do not have a linear compartment, such as mixed loads that are composed of a resistive, capacitive and inductive component, among other variables. Having a low power factor is an index of a strong wastage of electrical energy since this results in conductor overheating, unwanted tripping of protections, voltage variations, reduction in the useful life of the components and penalties imposed by the network marketer that are reflected in the billing of the service. Therefore, it is necessary to implement a system that performs a power factor compensation, one of them are the automatic capacitor banks that must be designed correctly and adequately to enter into operation according to the requirements of the load since this has a variable behavior at each instant of time. With the current regulations, there must be an efficient and accurate compensation to avoid problems with capacitive reactive power.

Keywords: Capacitor bank, Electrical system, Power factor, Reactive power.

I. INTRODUCTION

Industrial systems that are fed by alternating current, most loads need active and reactive power consumption for their optimal operation (Garcia, 2001). The power factor is known as the measure of the efficiency of electrical consumption, when we talk about correction, we seek

to increase the power factor by delivering reactive power according to the requirement, which brings technical and economic advantages for both the user and the marketer (Lopez, 2018).

Power factor correction in electrical systems can be performed by implementing components at different nodes of the system, which deliver reactive power to the receivers necessary for their operation. Among these are capacitors, synchronous motors and active power filters (Verma, 2021).

Capacitors are devices capable of storing energy through an arrangement of electrons in the dielectrics that occurs when a potential difference is applied at its terminals, they are implemented to counteract the reactive power delivered by the inductive loads present in the system and thus have a better power factor (Al-Muhanna, 2021).

Synchronous motors are alternating current machines whose excitation is regulated so that they only generate reactive power (overexcited), but normally synchronous motors are implemented that simultaneously perform the functions of driving a continuous active load and the production of reactive power compensation for the system (Cămui, 2020).

Active power filters are three-phase or single-phase inverters that inject to the system a current and/or voltage to neutralize harmonics due to the presence of non-linear loads and additionally present an improvement in the power factor (Milasi, 2021).

II. PROBLEM FORMULATION

In Colombia, the Resolution CREG 015 of January 29, 2018, Chapter 12, "Reactive Energy Transportation Costs", indicates that the transportation of energy over the established limit, which is presented in any schedule for 10 or fewer days will have an additional cost that will be determined by a factor M that will start at 1. If the transportation of reactive energy above the limit occurs on more than 10 days during a calendar month, the factor M will be equal to 1 during the first 12 months in which such condition occurs, from the date this regulation enters into force, from the thirteenth month of transportation of reactive energy with the same condition, the factor M will increase monthly by one unit until it reaches the value 12. The payment of additional cost for reactive energy transport shall be made when a network operator or an end-user is found to violate any of the following conditions:

When the reactive energy (kVArh) inductive consumed by a GO (Grid Operator) is greater than fifty percent (50%) of the active energy (kWh) that is delivered to it in each hourly period at voltage levels 3,2 or 1. To calculate the excess of reactive energy transport, the hourly reactive energy of the border points of the same system shall be added up, understanding as border point the connection points with other systems (STN, GO) at the same voltage level. The balance will be calculated based on arithmetic sums, considering the direction of the active and reactive energy flows through said border points. The payment will be distributed among the GOs transporting such reactive energy pro-rata to the amount of kVAR transported.

When an end-user registers in its commercial border an inductive reactive energy consumption is higher than fifty percent (50%) of the active energy (kWh) that is delivered to it in each hourly period. If the active energy is equal to zero in any period and there is inductive reactive energy transport, the cost of reactive energy transport will be made on the total energy registered in that period. When the transport of capacitive reactive energy is registered in a commercial border, regardless of the value of active energy, the reactive energy transport cost will be charged on the total reactive energy registered.

Knowing the total active power demanded by the load and the total apparent power, the power factor is given by the expressions (Shanmugapriya, 2013).

$$pf = \frac{P}{S}$$

where P is the active power demanded by the system and S is the apparent power. If the power factor is below 0.9, the calculation of the total reactive power consumed Q at this point is made using the equation power consumed at this point, using the following equation

$$Q = \sqrt{S^2 - P^2}$$

With the value of reactive power and total active power consumed, the reactive power transported above the permitted limit as established by the Energy and Gas Regulatory Commission in Colombia (CREG) is calculated, as shown in the following expression

$$Q_{\text{excess}} = Q - 0.5 \times P$$

Once the amount of reactive power in excess is known, the capacitor bank is designed with a capacity greater than 25% of it, to consider a small growth in the load over time and taking into account the limit required for design, as shown in the following equation

$$Q_{\text{bank}} = Q_{\text{excess}} \times 1.25$$

III. APPLICATION DEVELOPMENT

For the development of the application, a database is created in Excel based on the catalog offered by different suppliers in which they will have the performance characteristics, references, the unit cost of electrical components to be used for the assembly of the capacitor bank. It is defined that the application will be for the calculation of capacitor banks at 220, 440 and 480 V at the nominal frequency of 60 Hz.

Considering the costs and characteristics of the conductors such as current capacity, gauge and diameter above sheath, to build a database. EMT piping is implemented since the installation areas are classified by fire risk or wet conditions. This database is associated with the power of

the automatic capacitor bank to perform the calculation of the current of the commissary and with it, to select the conductor to be implemented for the phases and the ground conductor.

After making the selection of the conductor, we proceed to calculate the necessary conduit to implement the service connection, taking into account that, in electrical distribution networks, where the beginning and end section of pipes is not completely straight, with a curve, the criteria of occupation of 40% of the area of the conduit cannot be exceeded. With the selection of the size of the duct, we proceed to select the terminals, joints and bends of the same dimensions, the quantities are determined by the segment that is going to make the connection, but in general, it is implemented:

- Quantity of pipe: One unit for every 3 meters.
- Quantity of bends: Three units
- Quantity of joints: Three units
- Number of terminals: Two units

*** CELDAS QUE SE DEBEN LLENAR POR TECLADO NUMERICO			
*** CELDAS DESPLEGABLES QUE SE DEBEN LLENAR			
POTENCIA TOTAL BANCO (kVAr)		4	
DATOS A INGRESAR DEL SISTEMA			
TENSION DEL SISTEMA (V)		220	
TIPO DE BANCO		Automáticos	
		No	
PASOS	POTENCIA DE PASO:	TIPO PASO	
PASO 1 (kVAr)	1,5	Automáticos	1
PASO 2 (kVAr)	2,5	Automáticos	1
PASO 3 (kVAr)			
PASO 4 (kVAr)			
PASO 5 (kVAr)			
PASO 6 (kVAr)			
PASO 7 (kVAr)			
PASO 8 (kVAr)			
PASO 9 (kVAr)			
PASO 10 (kVAr)			
PASO 11 (kVAr)			
PASO 12 (kVAr)			
TIPO DE PROTECCION		MINI-	
VALOR COFRE		\$1.250.000	
MANO DE OBRA PARA INSTALACION		No	
VALOR MANO DE OBRA PARA INSTALACION			
ACOMETIDA		No	
DISTANCIA EN METROS DE ACOMETIDA HASTA 21 METROS		0	
LUGAR DE DESTINO DEL BANCO DE		BARRANQUILLA	
VALOR TRANSPORTE		\$220.000	
DESCUENTO %		42	
VALOR TOTAL SIN ACOMETIDA		\$3.233.180	
VALOR TOTAL ACOMETIDA + MANO DE OBRA		\$0	
VALOR TOTAL CON ACOMETIDA		\$3.233.180	
INCLUYE KIT DE VENTILACION			

Figure 1: Application interface

The forced ventilation kit will apply for powers greater than 100 kVAR regardless of the system supply voltage, but it should be clarified that if the city in which the installation will be carried out in a hot climate, it must necessarily be equipped with forced ventilation.

A transportation quotation should be made through the transporters to determine the cost of this, it is not possible to have an estimated value because it depends on the size and weight of the box, in addition to the city to which it will be taken and the availability of roads.

With the database of all the components, the application is programmed to make the selection of switches, contactors, capacitors and controllers based on the power defined in each of the steps. The parameters with the highest hierarchy in the application are the power supply voltage level, the power in kVAR of each stage and the type of step (automatic or fixed). Some parameters must be entered to start up the application.

- Bank type: This parameter defines whether the steps will be fixed, automatic or mixed, i.e. a combination of fixed and mixed.
- The power of each of the steps must be defined using the drop-down list.
- An estimate of the value of the box must be contemplated.
- You must select whether or not the labor for the installation of the box is contemplated and if you have the installation of the box and if the value of the labor is taken into account.
- It must be selected if the connection for the installation of the box is contemplated and at what distance, so that the application makes the selection of the conductors.
- The destination place where the automatic capacitor bank will be installed must be selected, for the capacitor bank will be installed, to contemplate the value of the shipment of the capacitor bank.

IV. RESULTS

The analysis of the consumption matrix of one month of a user is carried out, from which we obtain that it is necessary to implement a capacitor bank of 30 kVAR at 220V, as shown in Figure 2.

Q. BANCO	35													
PASO			TOTAL	465	ELIMINADOS	0								

POTENCIA REACTIVA PENALIZADA													
PEN HO 1	PEN HO 2	PEN HO 3	PEN HO 4	PEN HO 5	PEN HO 6	PEN HO 7	PEN HO 8	PEN HO 9	PEN HO 10	PEN HO 11	PEN HO 12	PEN HO 13	PEN HO 14
19,404	20,190	20,030	21,020	12,050	4,95	2,64	4,928	5,808	8,844	14,608	12,87	13,772	15,02
19,8	23,826	23,804	23,496	10,824	4,356	4,224	3,476	3,938	6,292	6,204	12,606	17,556	20,416
19,514	5,566	5,632	5,654	5,852	6,996	6,622	4,51	3,938	4,444	5,368	14,19	17,38	16,214
17,622	6,248	4,29	3,498	5,126	5,06	4,158	5,412	4,334	6,996	16,434	16,104	17,16	14,3
17,71	19,778	20,812	20,812	10,846	2,772	2,904	5,676	3,718	7,722	15,752	16,214	15,62	14,432
18,854	18,128	20,195	19,954	12,562	7,766	5,302	2,728	2,046	4,664	14,806	16,148	20,086	19,206
21,12	21,142	21,252	18,92	3,674	2,662	3,652	4,554	3,124	7,92	17,688	19,118	21,098	23,408
20,108	19,36	21,076	20,922	10,978	3,85	3,014	4,444	4,356	5,258	18,414	18,898	16,17	15,444
20,9	22,066	21,318	20,746	8,184	2,046	1,32	0,396	0	2,09	1,056	3,454	11,44	10,846
17,116	2,178	1,276	0,924	1,628	1,804	1,386	4,774	3,454	8,008	17,006	18,436	20,328	19,624
19,220	19,844	19,50	19,880	10,200	0,438	0,300	1,166	2,112	3,564	12,364	16,478	17,600	16,456
20,878	21,076	21,082	21,736	16,808	5,192	3,718	3,014	2,222	7,92	18,634	18,37	18,48	16,104
24,948	25,344	26,774	27,852	16,082	11,066	11,132	11,242	6,314	9,35	17,358	16,874	18,062	16,28
21,802	23,056	24,794	24,354	7,634	5,808	4,862	6,82	6,688	9,57	17,556	17,116	18,282	16,852
22,154	22,462	21,978	21,846	16,896	2,772	1,606	0	0,198	8,096	17,512	17,336	17,072	18,238
20,9	21,78	22,528	23,518	13,09	1,782	1,804	1,1	0,968	2,992	3,828	12,474	12,694	12,804
10,406	8,954	8,888	8,272	7,546	7,942	6,16	2,596	4,51	9,57	19,734	15,312	15,774	13,816
19,844	20,966	21,846	21,142	9,262	6,424	5,214	5,852	4,466	12,034	15,246	13,794	15,114	13,288
20,636	21,89	21,384	20,702	7,062	3,982	3,608	6,226	6,578	15,972	15,664	15,114	15,532	14,212
20,636	20,416	20,548	16,5	5,28	3,564	3,124	4,884	8,162	15,136	14,08	0	0	0

Figure 2: Customer penalized consumption matrix

As shown, the best distribution of the stages is 2.5 kVAR, 5 kVAR, 10 kVAR and 12.5 kVAR, to eliminate the excessive consumption of reactive energy, thus running the application, to know the cost of the solution, see Figure 3.

*** CELDAS QUE SE DEBEN LLENAR POR TECLADO NUMERICO			
*** CELDAS DESPLEGABLES QUE SE DEBEN LLENAR			
POTENCIA TOTAL BANCO (kVar)	30		
DATOS A INGRESAR DEL SISTEMA			
TENSION DEL SISTEMA (V)	220		
TIPO DE BANCO	Automáticos		
	No		
PASOS	POTENCIA DE PASOS	TIPO PASO	
PASO 1 (kVar)	2,5	Automáticos 1	
PASO 2 (kVar)	5	Automáticos 1	
PASO 3 (kVar)	10	Automáticos 1	
PASO 4 (kVar)	12,5	Automáticos 1	

Figure 3: Distribution stages

V. CONCLUSIONS

Implementing capacitor banks with control systems allow us to have control of the power consumption at each instant of time, which will allow students to try different strategies to achieve the expected result. If the design is done with a higher number of steps, we can talk about a finer compensation.

The most effective reactive power compensation taking into account Resolution 015 of 2018 of the CREG, is that of automatic capacitor banks with staggering steps, for accurate compensation.

To calculate the reactive power required in the capacitor bank, it is necessary to obtain the parameters of the network with which it is operating, which can be obtained using the consumption matrix.

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