ALGORITHM FOR DETERMINING REACTIVE POWER COMPENSATED FOR INDUSTRIAL CONSUMERS WITH VARIABLE LOAD

HAZI GHEORGHE[†1], HAZI ANETA[1]

[1] *Université "Vasile Alecsandri"du Bacău, Calea Mărăşeşti 157,Bacău, 600115, Roumanie*

Abstract: The paper analyzes the optimal choice of banks of capacitors steps in case of industrial consumers with variable load. The difficulty of establishing scales is that the load varies greatly and that receptors are widespread in terms of location. This paper proposes a method of calculation as to maintain the power factor at the point boundary limits that does not lead to a penalty due to reactive power absorbed. It is based on measurement and verification requirements for each level of the relevant load. Finally it is presented a scheme to automate the steps.

Keywords: power factor, reactive power compensation, efficient algorithm

1. INTRODUCTION

Reactive power compensation is a classical problem. However, with the advent of digital technology, which provides an automatic adjustment of reactive power, some new difficulties arise in the case of industrial consumers with a random mode of operation. The paper [1] shows an overview of the state of the art for reactive power compensation. There are shown operating principles, design, features and examples of application of these technologies. It shows applications of thyristor static compensators used to improve voltage control and power factor in the transmission and distribution of electrical energy into AC. In [2] are shown reactive power compensation technology in public networks, in industrial networks and the use of static compensation. The paper [3] includes implementation compensation in complex network, benefits and compensation solutions. Also, there are shown modern technologies offered by ABB in this area.In this paper, the authors propose a compensation technology for industrial consumer that supplied to medium voltage. It shows how to calculate the reactive power steps and the use of PLCs for control unit.

Presentation of the proposed methodology is accompanied by a concrete example: reactive power compensation in industrial network 6 kV. Network diagram is shown in Figure 1. The network contains a substation of 20/6 kV, 2 X1600 kVA, three transformer stations of 6 / 0.4 / 0.23 kV and a ventilation well transformer station which contains, mainly, an engine of 315 kW 6 kV.

2. INPUT DATA

To establish the compensation optimal solutions are required measurements in installations analyzed. Volume of measurements must include at least the following characteristic values of load curves:

- Maximum active power absorbed, Pmax, [kW].
- Maximum reactive power absorbed, Qmax, [kVAR].
- Minimum reactive power absorbed (empty load), Qmin, [kVAR].
- Active power, Pi, [kW], i=1,2,...n, reactive power Qi, [kVAR], i=1,2,...n, in the characteristic points of the load curve. And load curves are useful, too.

† Corresponding author, courriel *gheorghe.hazi@ub.ro*

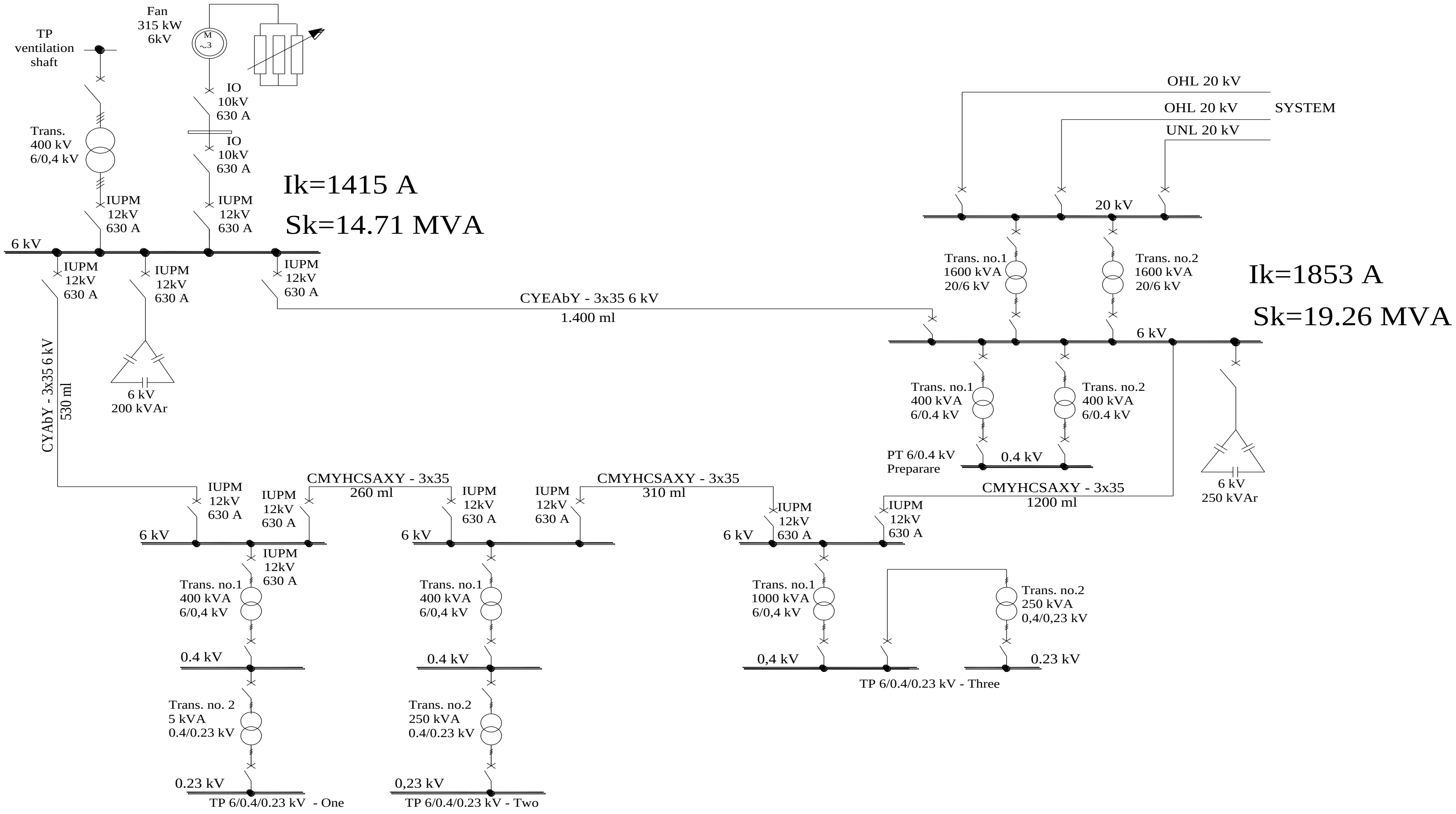

Fig.1. Network diagram

For example considered various measurements were made with actual capacitor batteries (ventilation and station 6 kV) connected or disconnected:

a. Measurements for engine 6 kV, 315 kW ventilation, without battery
   - P= 260 kW
   - Q= 264 kVAR
   - cosφ = 0.7
b. Load measurements at the delimitation point, with both batteries 6 kV (ventilation and station 6 kV) connected.
   - P= 800-850 kW
   - Q= 220-250 kVAR
   - cosφ = 0.96-0.97
c. Load measurements at the delimitation point, with 6 kV battery from ventilation connected and battery from the 6 kV station disconnected.
   - P= 845 kW
   - Q= 450 kVAR
   - cosφ = 0.87-0.9
d. Load measurements at the delimitation point, with 6 kV battery from ventilation disconnected and battery from the 6 kV station connected.
   - P= 845 kW
   - Q= 400 kVAR
   - cosφ = 0.9
e. Measurements at low load with both batteries 6 kV connected.
   - P= 138-550 kW
   - Q= 0-300 kVAR
   - cosφ = 0.6-1, capacitive

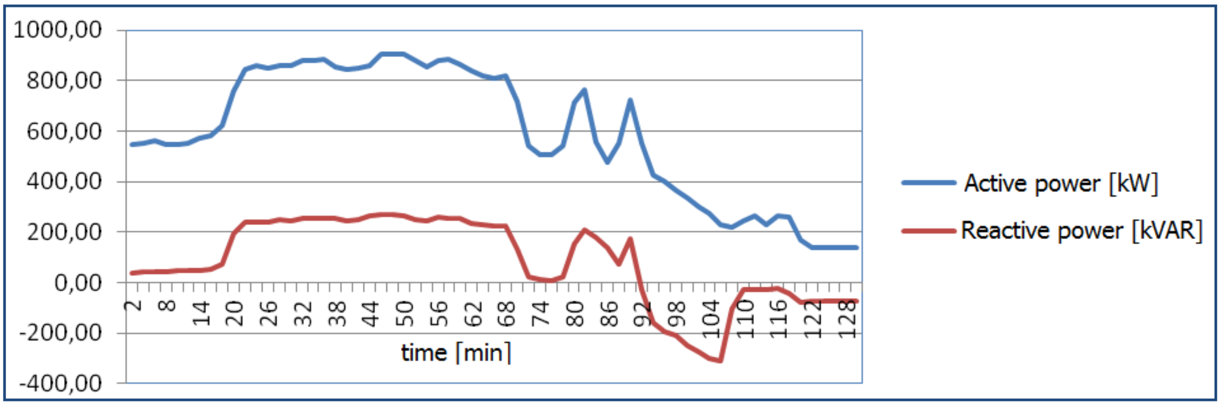

Fig.2. Active and reactive power variation over a range of 2 hours

Figure 2 shows the variation of active and reactive power for about 2 hours, with both batteries connected. This shows the incorrect operation of existing installations. This is due to fixed value of battery in station. Overcompensation is achieved in the low load regime and the goal.

3. THE ALGORITHM FOR ESTABLISHING REACTIVE POWER

Setting reactive power compensated and its value on the steps must take into account the need to maintain power factor at the delimitation point between values $\cos\varphi_{neutral}$ = 0.92 inductive and 1.

The basic steps are:

- Determination of reactive power absorbed at the empty, Q_{min}, by measurement or by calculation.
- Establishing the admissible limits for reactive power at the maximum regime, Q_{impmin}, Q_{impmax}:

$$Q_{imp\,max} = P_{max} \cdot tg(\arccos(\cos\varphi_{neutral})) \quad (1)$$

$$Q_{imp\,min} = P_{max} \cdot tg(\arccos(0.98)) \quad (2)$$

Choosing maximum of 0.98 power factor is justified by the existence of a margin of safety.

- Calculation of admissible limits for reactive power total installed, Q_{cmin}, Q_{cmax}:

$$Q_{c\,max} = Q_{max} - Q_{imp\,min} \quad (3)$$

$$Q_{c\,min} = Q_{max} - Q_{imp\,max} \quad (4)$$

- Establishing the total power of the battery, Q_{ct}:

$$Q_{c\,min} \leq Q_{ct} \leq Q_{c\,max} \quad (5)$$

- Establishing the amounts of reactive power local compensated, Qclocal:

$$Q_{clocal} = (0.75 - 0.9) \cdot Q_{local} \quad (6)$$

where Q_{local} is reactive power local consumed.

- Establishing the rated power of the battery, Q_{ct}:

$$Q_{cn} = Q_{ct} - Q_{clocal} \quad (7)$$

- The minimum reactive power compensated at empty, Q_{cgol}:

$$Q_{cgol} = 0.98 \cdot Q_{min} \quad (8)$$

It is recommended that local compensation operation be done only if the reactive power consumed locally are significant for to not significantly increase costs.

- Choosing the number and power for compensation steps.

It is preferable that the reactive power steps to be equal or in ratio at least to 1: 2. This procedure is approved by the majority of PLC that control power factor and automatic control of capacitor steps, [4].

  - It is established the minimum compensation step (at empty), $Q_{c1}= Q_{cgol}$ (night, weekends), if it is necessary.
  - It is chosen the number of steps

$$\begin{aligned} &n = 2 \\ &Q_{c2} = Q_{cn} - Q_{c1} \end{aligned} \quad (9)$$

It is checked that the power factor in delimitation point can be adjusted in the range 0.92-1 inductive, using the existing steps, in all characteristic regimes. If the power factor cannot be adjusted, then it is increased the number of steps:

$$\begin{aligned} &n = n + 1 \\ &Q_{ci} = \frac{Q_{cn} - Q_{c1}}{n-1}, \, i = 2, \ldots, n \end{aligned} \quad (10)$$

Procedure is repeated until the requirements regarding to adjustment of power factor are met.

For example examined, the data are shown in Table 1.

Table 1. Establishing the compensation steps for the example analyzed

No.	**Characteristic parameters**		**UM**	Calculated values	*Calculation relations*
0	**1**	**2**	**3**	**4**	**5**
1.	Operating voltage	U_s	kV	6.26	From measurements
2.	Maximum active power	P_{max}	kW	900	From measurements
3.	Admissible limits for reactive power at the maximum regime	Q_{impmax} - Maximum reactive power required in the delimitation point, at neutral power factor 0.92 Q_{impmin} - Minimum reactive power required in the delimitation point, at neutral power factor 0.98	kVAR kVAR	383.4 182.75	Rel. (1) Rel. (2)
4.	Reactive power absorbed in the maximum regime at the delimitation point	Q_{max}	kVAR	696	From measurements
5.	Admissible limits for reactive power total installed in the 6 kV battery	Q_{cmax} – limita superioară Q_{cmin} – limita inferioară	kVAR kVAR	513.25 312.60	Rel. (3) Rel. (4)
6.	Total power installed in the 6 kV battery	Q_{ct} – value adopted	kVAR	450	Rel. (5)
7.	Reactive power local consumed, Q_{local}	Q_{local} - reactive power absorbed by engine 6 kV, 315 kW ventilation Q_{clocal} – power ventilation 6 kV battery	kVAR kVAR	265 200	From measurements Rel. (6)
8.	Minimum reactive power compensated at empty	Q_{min} - Minimum reactive power absorbed at empty load (transformers) Q_{cgol} - minimum reactive power compensated at empty	kVAR kVAR	70.72 70	$S_0 = \frac{i_0}{100} \cdot S_n$ $Q_0 = \sqrt{S_0^2 - \Delta P_{Fe}^2}$ Rel. (8)
9.	Rated power of the battery	Q_{cn}	kVAR	250	Rel. (7)
10.	Choosing the battery steps	n=2 Q_{c2} – reactive power of the step does not satisfy the constrains at P=245 kW n=3 Q_{c2} – reactive power of the step Q_{c3} – reactive power of the step	kVAR kVAR kVAR	180 90 90	Rel. (9) Rel. (10)

4. CONCLUSIONS

In this paper the authors propose an efficient algorithm for determining the reactive power total compensated and power steps.

From work result the following conclusions:

- It is need to perform measurements for all levels of consumer load.
- Determination of total reactive power installed is based on the maximum load regime.
- It is good to establish a separate step for empty regime.
- The number of steps will be minimized, so that to maintain the power factor in range of 0.92-0.98 for all values of load.

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