Reactive Power Consumption Analysis of a Medium Sized Factory

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Abstract. The paper achieves a study on the reactive power consumption in case of a medium sized factory. The factories as others industrial consumers usually have the power factor lower than the neutral one (in Romania was 0.92 and now is 0.9); that is why these types of consumers have to pay for reactive power. The reason for the power factor is small (sometimes much lower than the neutral) is not always just because of inductive receptors (as transformers, induction motors, induction furnaces, etc.) but also due to some technical-organizational issues. Many of these issues could have been avoided if more attention had been paid to the proposals made by the power installations designer in the design stage and it would not have been considered only the aspect of investment costs, which, though not decreased very much, provoke much more operating costs. This paper will emphasize these features that cause additional costs with reactive power for a medium sized factory who has more substations with two transformers in each of them. It also proposes, after an analysis of the current situation, technical-organizational solutions to minimize the reactive power consumption.

1. Introduction

Usually, industrial consumers such as factories have many receivers such as induction motors, transformers or induction furnaces, which make these consumers resistive-inductive, and therefore the power factor at the point of electrical energy measure will result in a sub-unit. In Romania, if the power factor was less than 0.92 (now 0.9), the electricity supplier billed the corresponding reactive energy. In addition to this additional charge, also energy losses in consumer installations are higher as a result of the flow of reactive current through them. In order to avoid this situation, industrial consumers are interested in applying measures to increase the power factor to a higher value than the neutral value, as close as possible to the unit.

Two main types of measures are possible to apply: technical-organizational measures and/or inductive reactive energy compensation by producing capacitive reactive energy with the help of dedicated installations. The first category includes those measures that can be applied and lead to an increase in the power factor without additional investments in capacitive reactive energy generation. Thus, reducing the no-load time operation of the inductive power receivers (e.g.: induction motors, transformers, etc.), increasing their load, reducing the supply voltage of the induction motors during periods of low load, and achieving good quality repairs (especially for the electric motors) are measures that once applied will result in an improvement in the power factor. Also in this category can be mentioned the possibility of optimal use of synchronous motors compensation capacity. It should
be noted that all these measures, except the latter, can only increase the power factor, and there is no impediment to their application. Synchronous motors (if found among the consumer's receivers) allow both inductive and capacitive power generation, the adjustment being made continuously, but the power is limited by the load factor.

In terms of the reactive energy compensation with dedicated types of equipment, there are three possibilities: the use of capacitor batteries [1], SVC (static VAR compensator) [2] or rotating synchronous compensators.

Nowadays, rotary synchronous compensators are no longer used due to the disadvantages related to maintenance costs, active power losses, and the initial cost of the investment. The main advantage of these compensators is that they allow continuous regulation of reactive energy, both inductive and capacitive.

The condenser batteries, made with different power levels, are the most common means of compensation for both low and medium power consumers. They are also used for high voltage side compensation. The main advantages of these installations are given by low power consumption, relatively low cost, very cheap maintenance. As a disadvantage, it can be remembered that they allow reactive power adjustment only in steps, cannot compensate for the capacitive regime and it can provoke disturbances at the commutation [3]. In addition, the reactive power supplied depends on the voltage level, which is another disadvantage.

SVCs have the main advantages: they can compensate for any regime (inductive or capacitive), provide fine power regulation, good behavior with dynamic load [4-5] and can be used on the low, medium or high voltage side. The main disadvantage is that they are still quite expensive. However, one or other option can be advantageous in different situations, a thorough analysis is usually required.

The paper is structured in the following sections: section 2 - analysis of the current situation; section 3 - technical and organizational solutions; section 4 - conclusion.

2. Analysis of the current situation

2.1. Data registered by the electricity supplier

The analyzed industrial consumer has its own transformer station being powered by the 110 kV grid. From the 110/20 kV, 10 MW transformer, four 20 kV cells are fed, figure 1.

One is the measuring cell, one is the reserve. From the other two cells, leaves two underground cables (L1 and L2) which feed four transforming substations in parallel, figure 2. The substations are each with two identical transformers of 20/0.4 kV, except for station 1, where we have two 20/1 kV transformers. It can be noticed that only in station 1 the transformers can be put in parallel (substations 3 and 4 are the same as station 2, only the powers of the transformers differ), respectively all the consumers can be fed at one moment only from one of the transformers. In the other three substations, at this time it cannot operate with the transformers in parallel, or so that all consumers are powered at a given moment only by one of the transformers.

The analysis started with the data recorded at the measuring point. The values recorded in the past three and a half months have been considered. Thus, for the first month, the consumption was according to figure 3. For these consumes of energy, the values of the power factor are in figure 4.

It can be seen that all values of the power factor are less than 0.92, except for a day when the factory was stopped for maintenance work. This stop is usually done once a year. In the next figures, the same consumption is shown for the other two and a half months.

The data of the electricity supplier only provides information on the general electricity consumption. They are sufficient only if the power factor compensation at the measuring point is achieved. In order to carry out more in-depth analysis, and possibly, propose other solutions, further measurements are required. So, the next step consisted in performing the measurements and records in the substations of the consumer.
Figure 1. Electrical diagram of the 110/20 kV power station

Figure 2. Electrical diagram of substations 1 (left) and 2 (right)
Figure 3. Active (kW) and reactive (kVAr) power (month 1)

Figure 4. Power factor (month 1)

Figure 5. Active (kW) and reactive (kVAr) power (month 2)
Figure 6. Power factor (month 2)

Figure 7. Active (kW) and reactive (kVAr) power (month 3)

Figure 8. Power factor (month 3)
Figure 9. Active (kW) and reactive (kVAr) power (half a month)

Figure 10. Power factor (half a month)

2.2. Measured and recorded data in the substations
The measurements and records were done with Fluke 435 power quality and energy analyzer, on the secondary bars of each transformer. Only in one of the substations (substation 4), the measurements were realized on different receiver groups because we did not have access on the secondary bars of the transformers.

Substation 1, transformer 1 (1000 kVA, 20/1 kV), registration time - 24 hours

Figure 11. Power factor (Substation1, transformer 1)
Figure 12. Active power (Substation 1, transformer 1)

Substation 1, transformer 2 (1000 kVA, 20/1 kV), registration time - 27 hours

Figure 13. Power factor (Substation 1, transformer 2)

Figure 14. Active power (Substation 1, transformer 2)
Substation 2, transformer 1 (2500 kVA, 20/0.4 kV), registration time - 27 hours

![Active Power Chart](image)

**Figure 15.** Active power (Substation 2, transformer 1)

Substation 2, transformer 2 (identical with transformer 1), registration time – 32 hours

![Power factor Chart](image)

**Figure 16.** Power factor (Substation 2, transformer 1)

Substation 2, transformer 2 (identical with transformer 1), registration time – 32 hours

![Active power Chart](image)

**Figure 17.** Active power (Substation 2, transformer 2)
**Figure 18.** Power factor (Substation 2, transformer 2)

**Substation 3, transformer 1** (both transformers are like in the substation 2), registration time – 23 hours

**Figure 19.** Active power (Substation 3, transformer 1)

**Figure 20.** Power factor (Substation 3, transformer 1)
Substation 3, transformer 2, registration time – 28 hours

![Active power](image1)

**Figure 21.** Active power (Substation 3, transformer 2)

![Power factor](image2)

**Figure 22.** Power factor (Substation 3, transformer 2)

Substation 4 (two transformers 1600 kVA)

Making measurements in this substation was difficult because there was no access to the secondary bars of the transformers. On the two transformers, which cannot be parallel operated, several consumers are grouped on each transformer. Measurements were made on the cables that feed six main consumer groups. Only on two of them recorded significant values: one a maximum of 140 kW but at a power factor greater than 0.92; on the other, a maximum of 135 kW, with a short duration, the power factor being around 0.9. The other four records showed insignificant power up to 35 kW.

3. Technical and organizational solutions

3.1. Substation 1

In this substation the power factor was relatively high (higher than 0.9) and there is no reason for investment in reactive power compensation. On the other hand, there is a rapid fluctuation of reactive energy from inductive to capacitive, which would complicate the type of the compensation system. It has to be taken into account that the capacitive energy can compensate the reactive energy of the other substations.
It is also important to state that in this substation, all consumers can be supplied from a single transformer, but the consumed power does not allow this (being periods when the total power exceeds the rated power of a single transformer). Consequently, based on the data recorded in this substation, no technical or organizational measures are required for the optimization of energy consumption.

3.2. Substation 2
The first transformer is periodically loaded with power from 200 kW to 700 kW, the average power is about 400 kW. The maximum apparent power was 750 KVA, about 30% of rated power. The power factor is around 0.8 at the secondary bars, but in primary, it is much lower because of the reduced load (smaller than 15%).

The other transformer is loaded with a maximum apparent power of 550 KVA (22% of the rated power). Of course, in this situation the power factor is low.

The best solution for this substation is to make a connection between the secondary bars of the two transformers, this will allow the operation with a single transformer at a given time. By connecting in parallel the two transformers (using two couplers) will be possible to carry out maintenance work at each transformer without interrupting the activity. On the other hand, operation with a single transformer will automatically increase the power factor in this substation.

3.3. Substation 3
Also, in this substation, the situation is just like the previous one. The two 2500 KVA transformers, each was loaded with a maximum apparent power of 600 KVA (24%) and 450 KVA (18%) respectively. It is necessary to make a coupling between the secondary bars of the two transformers, and not powering one of them. This is mandatory at this time considering also the other benefits.

3.4. Substation 4
Although in this substation the transformers are of lower power (1600 KVA) their load is very low, and the lack of the possibility to operate with a single transformer is an obvious disadvantage.

4. Conclusion
This paper examines how the electricity is consumed by a medium sized factory. The exposed situation highlights the special importance that should be accorded to the design of the electricity utilization installation. In the analyzed case, the lack of the possibility of putting all the consumers from a substation in parallel is the main misconception that involves a lot of disadvantages that can hardly be solved later on. Besides the fact that the safety of operation is low due to this design error, the compensation of the reactive energy is also hard to solve and is only achievable with additional costs.

In this paper, we presented only the solutions referring to the improvement of the existing equipment exploitation, without proposing static compensation solutions.

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