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Electrical Power Quality, Availability, and Energy Efficiency

Cheng LIU

ABSTRACT: A performant electrical distribution network is essential to ensure electricity quality, availability and reduce energy losses. The research has been conducted in a food company in Belgium. Energy losses occur in each part of the power system until it reaches to the consumer. Thus, Emission begins well before generation and continues well beyond consumption. Thus, CO2 emissions take place at generation and during transportation and consumption. Voltage reduction, transformers upgrade and replacement when selected following specific criteria defined in this paper will contribute also to improve quality of electricity generation, availability, and environmental impact.

KEYWORDS: Power factor correction; Transformers efficiency; Voltage reduction

INTRODUCTION

An electric power system is described as a network of electrical components used to supply (generate), transmit, and consume electric power.

Energy losses occur in each part of the power system until it reaches to the consumer. Thus, Emission begins well before generation and continues well beyond consumption. Thus, CO2 emissions take place at generation and during transportation and consumption [1]. Energy audit is a tool that permits to make a deep dive on different energy areas such as energy supply with transformers [2, 3].

Energy management is also a powerful tool to monitor continuously performance (issues etc.) [4, 5].

This paper makes a focus on main electrical element such as transformers and electrical properties such as power factor and voltage.Th research is based on survey and experimentation in a cosmetical industrial site in Europe.

POWER FACTOR CORRECTION

Material & Method

Power factor is defined as the ratio between the kW (actual load power) and the kVA (apparent load power) drawn by an electrical load. It is simply a measure of how efficiently the load current is being converted into useful work output. The lower the power factor of a system, the less economically it operates **[6]**.

Power factor is an expression of energy efficiency.

Power factor (PF) is the ratio of working power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA). Apparent power, also known as demand, is the measure of the amount of power used to run machinery and equipment during a certain period **[7]**. It is found by multiplying (kVA = V x A). The result is expressed as kVA units.

PF expresses the ratio of true power used in a circuit to the apparent power delivered to the circuit. A 96% power factor demonstrates more efficiency than a 75% power factor. PF below 95% is considered inefficient in many regions.

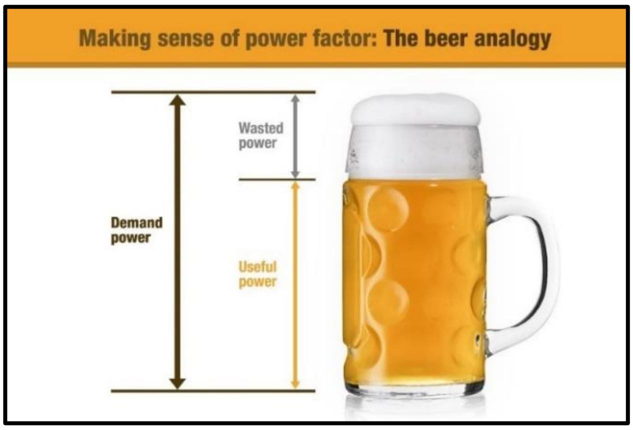

Fig.1. The beer analogy [7]

Beer is active power (kW)—the useful power, or the liquid beer, is the energy that is doing work. This is the part you want.

Foam is reactive power (kVAR)—the foam is wasted power or lost power. It's the energy being produced that isn't doing any work, such as the production of heat or vibration.

The mug is apparent power (kVA)—the mug is the demand power, or the power being delivered by the utility.

The benefits of improving power factor include:

- Energy cost reduction:
  - If a consumer is being charged for reactive power use
  - Possible reduction in a site's maximum demand
- Reduction in circuit currents:
  - Associated transformer and conductor losses reduced on consumers network and utility company's networks
  - Release of additional network capacity.
- CO2 reduction – The BEAMA Capacitor Manufacturers Association calculates that every kVAr of PFC installed results in a reduction of 160kg of CO2 generated per year **[8]** (through reduction of losses on the entire UK transmission and distribution network).

By reducing system's demand charge through power factor correction, strain is reduced on the electricity grid, and ultimately reducing its carbon footprint **[1]**.

Result & Discussion

Of the two substations on site, power factor correction equipment (PFC) was observed at the main incomer in the main substation, which is currently in service. The power factor for the whole site is maintained by three Riello units with a reactive rating of 750kVar. There are 4 stages of capacitor banks in each unit. The electricity invoices state the power factor as shown in table 1.

Table 1.

Date	**Tangent Phi**	**Cos Phi**
January 2019	0.3164	0.950
February 2019	0.3092	0.953
Mars 2019	0.3056	0.954
April 2019	0.3161	0.950
May 2019	0.3093	0.953
June 2019	0.3059	0.954
July 2019	0.3058	0.954
August 2019	0.3032	0.954
September 2019	0.3018	0.955
October 2019	0.3001	0.955
November 2019	0.2935	0.957
December 2019	0.2938	0.957

The reactive power charges are zero on the bills, so no action is required from an energy cost saving point of view.

Within the administrative building, there is no PFC equipment and the Power factor from the installed meters was measured at 0.94.

Issues identified

Some issues were observed regarding the site's PFC. In fact, in the table 2, it can be observed that main transformers have a good power factor. However, meters must be calibrated as power Factor is displayed differently from PFC equipment and adjacent metering.

Table 2.

Transformer number	Location	Power Factor (from PFC equipment)	Power Factor (from adjacent metering)
Transformer 1	Main substation	0,96	0,96
Transformer 2	Main substation	0,96	0,93
Transformer 3	Main substation	0,96	0,93

Table 3 contains the power factors monitored by the meters placed further downstream meters. It is suggested that steps are undertaken to improve power factor however this may not bring in energy savings due to power factor correction at the main incomer. Nevertheless, the improvement of the PFC downstream will at least avoid system inefficiency.

Table 3.

Area	**Power factor**
Kitchen	0,88
Dedusters	0,73
HVAC	0,77

Improving power factor will assist in:

- Energy savings
- Cost reduction
- Meters undertaking accurate measurements
- Reducing kVA demand
- Improving system efficiency
- Improving capacity utilization of network
- Increasing production rate and quality due to reduced interruptions
- Enhancing life of electrical network and components

VARIABLE SPEED DRIVES AND PFC

The use of variable speed drives (VSDs) has generally increased over the years, due to their energy saving capabilities. VSDs, by their principle of operation, generate harmonic currents which can interact with standard types of power factor correction, causing damage to the PFC. The site has added VSD control to motors over the years, and that PFC equipment originally considered appropriate, given building load types at the time of their specification, may no longer be suitable.

As a general rule of thumb, if the amount of non-linear load (of which VSDs can be considered), compared to the total connected load is between 15% and 50%, detuning reactors must be used. It is therefore recommended that the suitability of future PFC equipment installed be reviewed, with respect to local load types.

VOLTAGE REDUCTION

Material & Method

Since 1st January 1995, the current permitted phase voltage range in Europe at a consumer’s supply origin is 216.2V to 253.0V (230V +10% / -6%).

In theory, for private Low Voltage supplies:

- It would be acceptable for the voltage at a light fitting to be **203.23V** (the supply origin voltage at lower limit of 216.2V minus 6% allowable voltage drop).
- It would be acceptable for the voltage at, e.g., a socket outlet (‘other use’) to be **198.90V** (the supply origin voltage at lower limit of 216.2V minus 8% allowable voltage drop).

When considering voltage reduction as an approach to reduce energy costs, the fundamental requirement remains for equipment to be operated within its rated design parameters **[9]**.

Many areas will not save energy by reducing the voltage **[10, 11]**. For example, high efficiency lighting will compensate in a reduction in voltage by increasing the current. Heating elements which are controlled through thermostats will need to run longer to reach the required set point. Mechanical Loads make up a big portion of energy consumption that can be impacted by the voltage reduction. Savings from voltage reduction is generally limited to uncontrolled motors and drives i.e., ones NOT fitted with variable speed drives (VSD) as VSD’s tend to compensate for the lower voltage.

Result & Discussion

The site is served from a total of 3 transformers for the main site and 1 transformer for the administrative building. Identified substations of the site have been deeply analyzed:

- Data on installed transformers, such as rating, present tap settings, etc.
- Voltage levels at the time of visit, obtained from installed instrumentation ;
- Loading of Low Voltage (LV) panels at the time of visit, obtained from installed instrumentation.

The types of equipment installed on different parts of the site, e.g., Conveyor belts, elevator loads, duster plants, etc. have also been analysed.

The table 4 below presents the results of the voltage survey facility showing transformers tap settings and voltages.

Table 4.

Transformer number	**Location**	**Transformer type**	**Tap setting**	**Secondary Voltage**
Transformer 1	Main substation	20kV/410V; 1,25 MVA; Schneider Electric Vegeta Low transformer	1	395
Transformer 2	Main substation	20kV/410V; 1,25 MVA; GEC Alstom	1	394
Transformer 3	Main substation	20kV/410V; 1,25 MVA; GEC Alstom	1	396
Transformer 4	Admin building	20kV/410V; 1,25 MVA; Schneider Electric	1	392

The main transformers were on the lowest tap setting and the end of leg voltage was measured at 226V. Therefore, there is no opportunity for voltage reduction using the existing transformers.

The transformers in the main substation have three tap settings as shown in table 5.

Table 5.

High Voltage	Tap setting	Low Voltage	Low Voltage change (from nominal)	Energy consumption (from nominal)
20500	1	410	-2,5%	-3,9%
20000 (nominal)	2	410	0%	0%
19500	3	410	2,5%	+3,9%

All transformers have a tap setting of 1 resulting in a secondary voltage of around 395 V. This gives a step-down ratio of 0.02. This would indicate that the High Voltage (HV) voltage to the site is around 19750V (395V/0.02).

Transformers with further tap changes is represented in table 6.

Table 6.

	HV	3 phases LV	Single phase LV	End of Leg Voltage	Energy saving
Existing (-2,5% voltage)	19750	395	228	226	0%
1 tap change (further 2,5% voltage reduction)	19750	395	223	221	3,90%
2 tap change (further 5% voltage reduction)	19750	395	217	215	7,80%

The administrative transformers tap setting was not known. However, it was calculated as having a tap setting of 1 (-5%). This was deduced as the end of line voltage off the transformer was measured at 386V. If we know that the incoming voltage is 1950V, and tap 3 is 20000V to 410V, (step down ratio of 0.0205), tap 3 would equate to a secondary voltage of 405V. Tap 1 would reduce the voltage by 5% resulting in a voltage of 385V. Therefore, there is no option to tap down these transformers further.

TRANSFORMERS

Material & Method

New transformers

Whilst distribution transformers are highly efficient, they usually operate continuously incurring a permanent standing loss **[12].** This loss is a function of the transformer rating, design and the materials used in its construction. Low loss transformers optimize design and materials to reduce losses when compared to standard transformers.

While it would never make economic sense to replace an operating transformer in good condition, new purchases should consider the life cycle cost benefits of a low loss design.

This rule should be used when having to replace any of the older transformers on the site.

Transformer upgrades

Upgrading a transformer to a low loss transformer with multiple tap settings may be an option if the transformers cannot be tapped down far enough (and the end of leg voltage is high) and where the transformers are approaching the end of their useful life (30 years).

As part of the functionality of a transformer, two types of losses are created (no load loss and load loss). These losses are in the form of heat which can amount to many kW on larger transformers. By design these can be reduced with the effect of increasing the energy efficiency of the transformer **[13].**

Benefits of low loss transformers:

- Low loss distribution transformers are a more efficient transformer compared to traditional transformers and hence reduce energy consumption.
- Running costs of low loss transformers are lower compared to traditional transformers.
- If installed indoors, due to the lower loss, there is reduced heat to be dissipated away from the substation compared to traditional transformers reducing ventilation problems.
- Overall dimensions of low loss transformers compared to traditional transformers can be reduced due to less cooling radiators.
- By lightly loading the transformer, higher efficiencies can be achieved.

Low loss transformers are more environmentally friendly due to less heat being wasted to the environment.

Multi tap transformers can also be provided to take the voltages down even further in areas where the primary voltages are high.

Result & Discussion

It is recommended that the 2 GEC® Alstom Transformers are replaced with Multi tap low loss transformers.

Savings related to the above are estimated as 21462 kWh per transformer with a cost saving of $1,309 per transformer per year. This is purely the savings in the losses through the transformer, it does not take account of any other costs i.e., depreciation, interest rates, system costs.

POWER CABLES

Power cables have losses as a result of their resistance, which is a function of the cables' cross-sectional area. The temperature limitation of the insulation significantly influences the standards used for power cable sizing. In turn, this leads to an economic approach of minimum first cost.

When specifying new cables, the site should determine the costs and benefits over the life of the cable for an increased cable size compared to the minimum size required to carry the current. Power cables that supply motors running near full load for many hours should be oversized in new construction or during rewiring. This practice minimizes line losses and voltage drops. Of course, this advice is valid for all heavily used cables.

The site can either require that a life cycle cost/benefit calculation is carried out for all new significant cable installations; or determine a suitable policy of over sizing.

CONCLUSION

By reducing the reactive power produced by power generators through power factor correction (PFC), not only have system operating efficiency and economic targets been enhanced but greenhouse gas emissions have been also reduced **[14]**.

Voltage reduction, transformers upgrade and replacement when selected following specific criteria defined in this paper will contribute also to improve quality of electricity generation, availability, and environmental impact.

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