

Assessing the benefits and risks of application of inverter drives in industry

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Abstract—This paper presents the impact assessment of converters installed in an industrial plant on the power quality in internal power grid of the plant. The analysis of real measurements showed that the installation of inverter drives, despite many benefits, as energy savings, that have been reported in the paper, can also cause many problems. We observed multiple issues related to failures in the control and automation systems that could be due to the interference generated by simultaneous operation of inverter drives.

Keywords—power quality; converter drives; harmonic distortion, electric power drives

I. INTRODUCTION

The problem of power quality in industrial environment has been treated extensively in many publications, as [1]-[8], just to name a few. Therefore, we consider superfluous repeating the basics of this matter. Recently, real-life measurements and solutions attract more interest, as well [9]. Our goal is also to present a comprehensive assessment of benefits and risks associated with the replacement of traditional types of drives by variable-speed drives, shown on the basis of real-life measurements and calculations in a working food industry plant.

In complex technological installations requiring pumping of fluids between tanks and containers located at different levels, often in remote locations, it is necessary to adjust the levels and flows of media whose density is usually variable. In one of the fields of food industry which we consider, the complex technology of production imposed regimes, which cannot be met without the use of the appropriate class equipment and a fully automated control systems.

II. CONTROL OF FLOW IN PUMPING SYSTEMS

A. Throttling flow control

Until the seventies of the last century, all kinds of flow and efficiency control were carried out only by throttling of the pumped liquid by means of valves and dampers (manual, electric, pneumatic).

Because of problems with the control, the pumping systems were usually largely over-sized.

The pump characteristics is superimposed over the characteristics of the system and the operating point is determined by which one can determine the flow at a given pressure. Pump is working properly near the designed maximum efficiency. If the flow rate is controlled by throttling, it causes the following consequences:

- The reduction of the flow forces the pump to work against increasing pressure, so the pump output energy must be much higher than the optimal one. Excess energy is dispersed and transported by the flowing liquid,
- Low pump efficiency, resulting in further increase of losses.

Power output of the pump, due to high pressure in the system and the regulation by throttling, is much lower than the designed power for almost the entire range of adjustment, which results in energy waste.

In the presence of different density of liquids and frequent modification of system components, (causes additional increase in pressure of pumped fluid), the pump selection is often difficult.

Until recently we practiced oversizing of pump sets, leaving a large margin of safety. Unfortunately, this resulted in an increase of energy consumption of individual devices and the need for reactive power compensation with capacitor banks. In connection the necessity of reducing the ever-increasing energy costs (increase in prices of electricity) it was necessary to develop an appropriate strategy for the elimination and modification of the most important source of energy waste in the plant. The adjustment valve, which is undoubtedly the major source of the losses had to be replaced by another type of control allowing to reduce power consumption.

B. Flow control by changing of speed

In the late seventies and eighties, we began using DC thyristor controlled motors. Very good speed regulation characteristics of DC motors made it possible to reduce electricity consumption and contributed to the stabilization of the production process. Unfortunately, the disadvantage of this solution were: the high price of the motor, expensive repair and maintenance (need to replace the brushes, commutator turning

and lamelling), sensitivity to environmental conditions. Asynchronous motors in the era of slip control were not suitable for flexible regulation over a wide range of speeds. Speed change with the change of supply voltage is associated with the significant weakening of the motor torque, which already at the beginning discredit this type of regulation. Changing the number of poles allowed only a step change in speed. The motors speed regulation using variable resistance of the rotor winding allows good speed adjustment but this results in important energy losses in the additional resistance. Cascading systems has proved to be unacceptable in food industry, because of complicated design and high price.

C. Flow control using inverter drives

With the development of power electronics began the era of inverter drives. Modern inverter is now a pulsed voltage converter (full bridge) using the sinusoidal pulse width modulation in the inverter and is characterized by a control system simultaneously changing the voltage and frequency. Thanks to the digital control and regulation the drive speed can be controlled quickly allowing to adjust the drive to the required process parameters. The disadvantage of the inverter is generation of relatively low additional power losses (up to 5%) resulting from the pulse-width modulation and power quality issues.

In industry, we are usually dealing with 6-pulse inverters, whose disadvantage is the generation of higher harmonics which may affect directly the power quality in the network. This can be prevented by using filters, or for high-power drives (over 800 kW) by installing 12-pulse inverters, to minimize the negative impact of the inverter.

The most commonly used frequency converters and systems are equipped with a voltage inverter; the main switching elements are IGBT power transistors

III. OBJECTIVES OF THE STUDY

Described flow control methods in pumping systems are the basis for the analysis and the comparison of advantages of using the inverter drives for this purpose.

Converter systems, including inverters, despite significant technological advances and attempts of obtaining optimum performance of these devices, are still a source of disturbances which are their main drawback.

According to the Directive IEC / EN 61800-3, and based on the norm PN-EN 60 150, the drive systems with frequency converters must comply with conditions imposed by electromagnetic compatibility framework and power quality.

The basic parameters of power quality considered are:

- Voltage and current harmonics
- Voltage fluctuations and related disturbances
- Flicker
- Slow changes of voltage
- Rapid changes of voltage

- Voltage fluctuations
- Changes in frequency
- Voltage dips, short interruptions having effects on the control and protection systems.

These parameters should be analyzed in detail based on measurements made using a dedicated analyzer. During operation of technological equipment, the measurements of basic parameters of the two sets of electric pumps were carried out. Because of the tendency of destabilization of the manufacturing process associated with the regulations forced by performed tests, the measurements were performed at 5-minute intervals, first for the basic system (the inverter drive), then the redundant system (with adjustable throttling valve).

The results made it possible to make a factual analysis, and calculation of an approximate value of energy savings associated with installing of the inverter drives for the two test drives.

IV. ENERGY EFFICIENCY MEASUREMENTS

The long-term observations show that during normal operation, the pump station worked at a flow rate between 140-150m³ / h. The pump characteristics are shown in Fig.1

Active power consumed by the systems was:

- using the inverter drive:
 - The flow of Q = 140m³ / h - 30.8 kW
 - The flow of Q = 150m³ / h - 36.7 kW
- using a system of throttling valve:
 - The flow of Q = 140m³ / h - 58.9 kW
 - The flow of Q = 150m³ / h - 62.4 kW

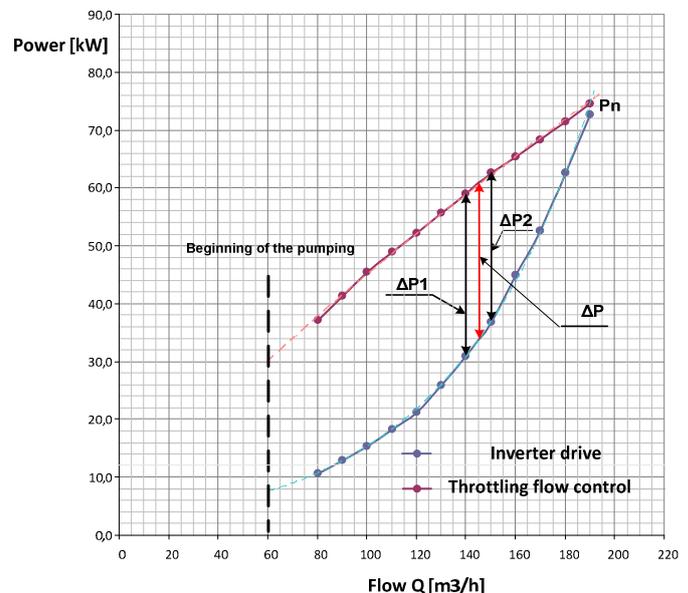


Figure 1. The characteristics of power drives with centrifugal pumps as a function of flow.

Inverter drives consumed over 3 years nearly 308.4 MWh (33,8 %) less than the system equipped with traditional throttling valve, which is closely associated to lower load of the drive (the lower the speed, the greater the difference in energy consumption between the inverter drive and throttling valve system).

V. ANALYSIS OF HIGHER HARMONICS AND THD

The voltage harmonics are generated mainly by nonlinear loads[2] [10]. The analysis focuses on the measurement of this type of interference, paying particular attention to the 5th, 7th and 11th harmonics whose impact on the apparatus installed in

the company internal network may have particularly serious consequences. As mentioned earlier, the PN-EN 50160 norm specifies the requirement that, under normal operating conditions, during each week, 95% from the set of 10-minute mean RMS values for each harmonic voltage should be within the limits set by the norm, which also contains tolerances for total harmonic distortion factor THD, and parameters related to fluctuations in voltage and frequency.

The measurements were performed using the Power Quality Analyzer Fluke 1760. Selected results are presented in the Table I.

TABLE I. RESULTS OF POWER QUALITY ANALYSIS

Total harmonic distortion (THD)							
Designation	Tolerance	95%-values			Max values		
		L1	L2	L3	L1	L2	L3
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
THD	0.00 - 8.00	4.26	4.24	4.37	4.34	4.47	4.41
Harmonics as % on nominal voltage							
Harmonic No	Tolerance	95%-values			Max values		
		L1	L2	L3	L1	L2	L3
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
2	0.00 - 2.00	0.02	0.02	0.02	0.24	0.27	0.26
3	0.00 - 5.00	0.25	0.10	0.10	0.36	0.22	0.22
4	0.00 - 1.00	0.02	0.02	0.02	0.07	0.10	0.08
5	0.00 - 6.00	3.68	3.82	3.74	5.85	6.09	5.92
6	0.00 - 0.50	0.02	0.02	0.03	0.08	0.09	0.09
7	0.00 - 5.00	1.61	1.61	1.61	2.23	2.24	2.24
8	0.00 - 0.50	0.02	0.02	0.02	0.05	0.06	0.06
9	0.00 - 1.50	0.13	0.14	0.07	0.23	0.19	0.19
10	0.00 - 0.50	0.01	0.01	0.01	0.05	0.05	0.04
11	0.00 - 3.50	0.46	0.40	0.40	0.87	0.94	0.88
Flicker							
Designation	Tolerance	95%-values			Max values		
		L1	L2	L3	L1	L2	L3
Plt	0.00 - 1.00	0.37	0.34	0.34	0.41	0.37	0.38

Slow voltage variations				
Designation	Tolerance range	L1	L2	L3
Overvoltages 100%	253.00	228.27	228.85	228.10
Overvoltages 95%	253.00	227.05	227.58	226.80
Voltage dips 95%	207.00	224.46	225.07	224.28
Voltage dips 100%	195.50	225.80	226.39	225.63

Data analysis and observation (10-minute recordings):

- The fifth harmonic - exceeds the permitted limits (Fig. 2)
- The seventh and eleventh harmonic – within the limits (Fig. 3)
- harmonic distortion factor THD within the limits (Fig. 4)

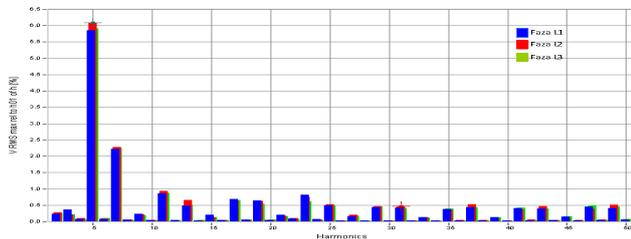


Figure 2. Bar graph of voltage harmonics (3 s average).

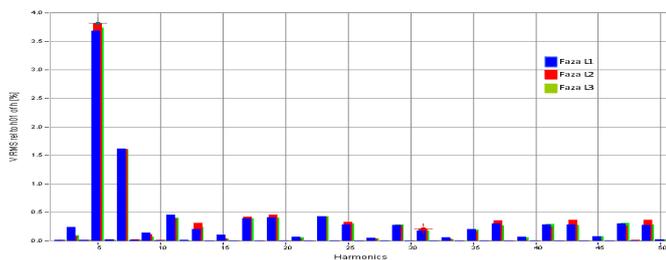


Figure 3. Bar graph of voltage harmonics (10 min. averages).

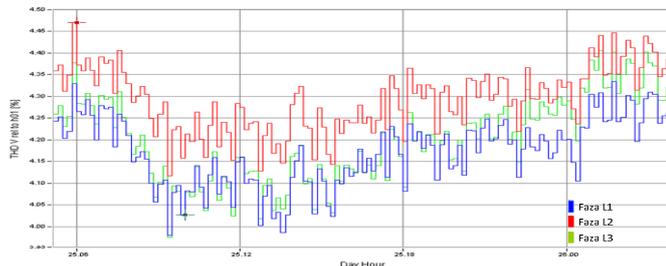


Figure 4. THD values registered in 2 days (10 min. averages).

VI. EVALUATION OF MEASURED PARAMETERS AND ADVANTAGES OF USING INVERTER DRIVES

The analysis and the real-life observation shows that the use of inverter drives for centrifugal pumps is very beneficial for both the technological process (greater range of flow adjustment) and for equipment.

- The current during start-up and operation is reduced, so the apparatus is less susceptible to damage.
- The pumps do not have to work all of the time at high back-pressures, which undoubtedly reduces the ability to quickly wear the bodies, seals and bearings.
- Manual valves are also less likely to wear when pumped medium flows at reduced pressure.

- Pipelines are less susceptible to high vibrations associated with the phenomenon of cavitation .

A. Return on investment:

It follows from calculations involving the investment of installing the inverter system that it could pay off after two years of operation.

B. The impact assessment of inverters on power quality in the internal network of the plant

The analysis of measurements show, that despite many benefits that have been reported earlier, the installation of inverter drives can present many problems.

Signaled by the technical service issues related to failures in the control system could be due to interference generated by the inverters.

Parameters recorded by the analyzer point out that the power quality parameters show:

- a large variability over time
- significant values of the 5th harmonic, which may adversely affect the operation of the generator, transformer and motors.

The concentration of several inverters within the same distribution network is unfavorable, due to the possibility of interferences, as evidenced by measurements. Exceeding the limits of harmonic distortion should be an alarming signal for technical services. The persistence of such a high level for a longer period of time can lead not only to interferences that may affect the control systems, but also the generators and transformers. The influence of high-frequency currents can lead to increase of losses associated with eddy currents, which can result in shorter service life of affected devices [5].

VII. CONCLUSIONS AND RECOMMENDATIONS RESULTING FROM THE ANALYSIS

It is advisable to:

- verify the installed filters for their proper selection for each inverter installed in the plant.
- carry out measurements of earthing resistance of branch stations and switchgears.
- check the screen of motor cables driven by inverter systems.
- install the equalizing connections between section switchboards
- exchange motors for the types suited for inverter operation

The older generation of inverters can be improved by installing efficient chokes and filters.

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