REPLACEMENT OF A WOUND ROTOR MOTOR WITH AN ADJUSTABLE SPEED DRIVE FOR A 1400KW KILN EXHAUST GAS FAN

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Abstract: The use of adjustable speed drives for process fan applications in our industry is already well established. However, a variety of solutions are possible due to different requirements and influences in a particular application.

The paper describes the project concerning a conversion of a fan drive from fixed speed to variable speed. The different variants, which have been investigated, are stated and the final solution is shown in detail. Furthermore, all relevant concerns for the final decision making such as costs, reliability and efficiency were analyzed.
The energy savings and process advantages by means of applying an adjustable speed drive are pointed out and a ROI calculation justifies the expenditures.

Introduction

General: Nowadays all new installed process fans in a cement plant are equipped with variable speed drives. The technology especially in the field of frequency converters has in the recent years undergone a strong development and is judged to be reliable. For fan applications the system efficiency if operated with an adjustable speed drive is significantly higher compared to a damper controlled system.

Project

Initial situation: The Untervaz plant situated in Graubünden / Switzerland was founded in 1957. Today the plant has two rotary kilns with a common daily capacity of 2700 mt.

Initially the kiln exhaust gas fan was equipped with a slip ring motor in conjunction with a liquid starter. In order to control the gas flow a damper system has been installed. After several years of production one decided to install a direct current motor mainly because of the higher system efficiency and hence lower electrical energy cost. Furthermore the installation enabled an automatic control of the process.

After major problems with the DC drive it was decided to install the original slip ring motor at fixed speed to ensure the availability of the plant.

Data of the existing motor:

Motor type		Wound rotor
Shaft power	[kW]	1400
Nominal speed	[rpm]	1460
Stator voltage	[kV]	6
Secondary starter		liquid
Cooling		Heat exchanger Air/ Water

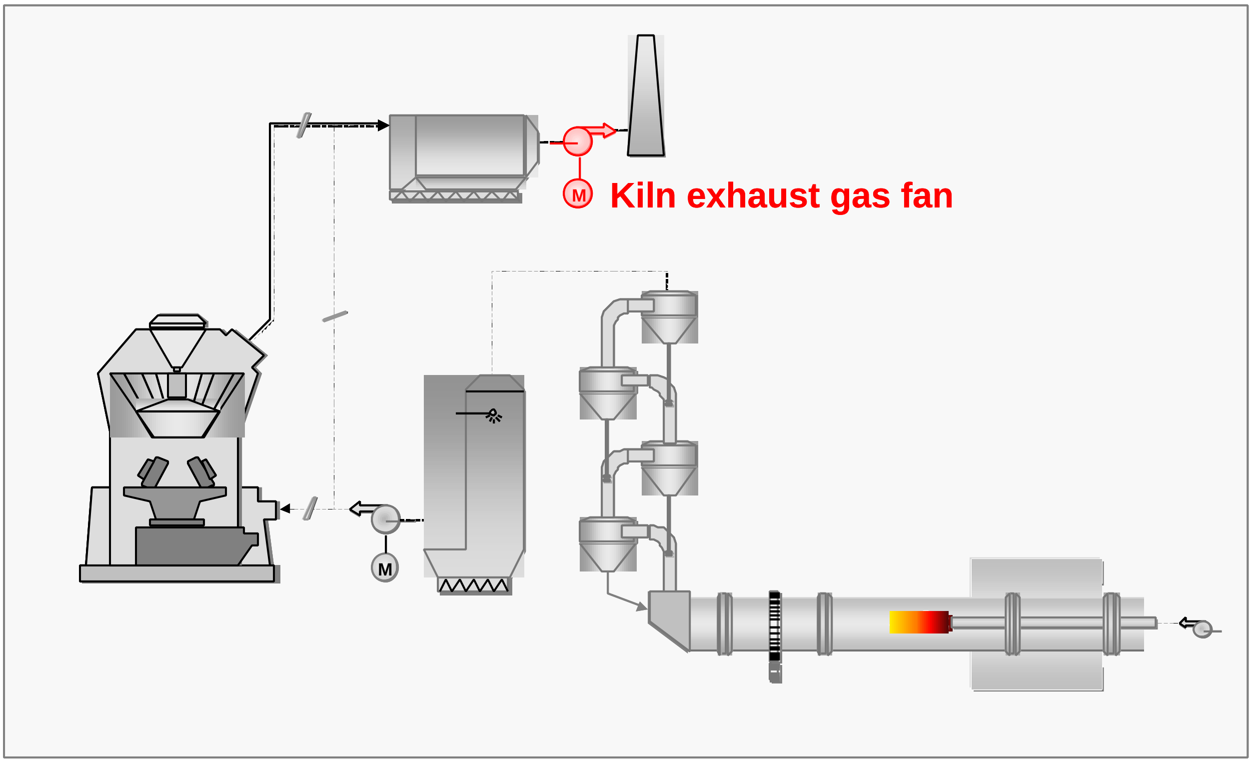

Figure 1 shows the given situation in the plant

<u>Objectives of the project:</u> The project comprised the replacement of the old drive system with a modern adjustable speed drive.

The following objectives have been set:

- Lower the specific electrical energy consumption by 2.5 kWh/$t_{clinker}$
- High reliability
- Lowest "Total cost of ownership"

Design data

Operational data: Depending on whether the raw mill is integrated the values vary in a certain range.

Gas flow (direct)	[m^3/h]	6600 at 95°C
Gas flow (compound)	[m^3/h]	5538 at 165°C
Flap position (direct)	[%]	70%
Flap position (compound)	[%]	45%

Control of gas flow: The gas flow of the fan was controlled by means of a radial inlet vane. This damper system is directly attached to the fan inlet and pre-spins the incoming air in the direction of the wheel rotation. This results in a better efficiency compared to other damper systems. However, in comparison with an adjustable speed drive the efficiency, especially in lower flow rates, is still low.

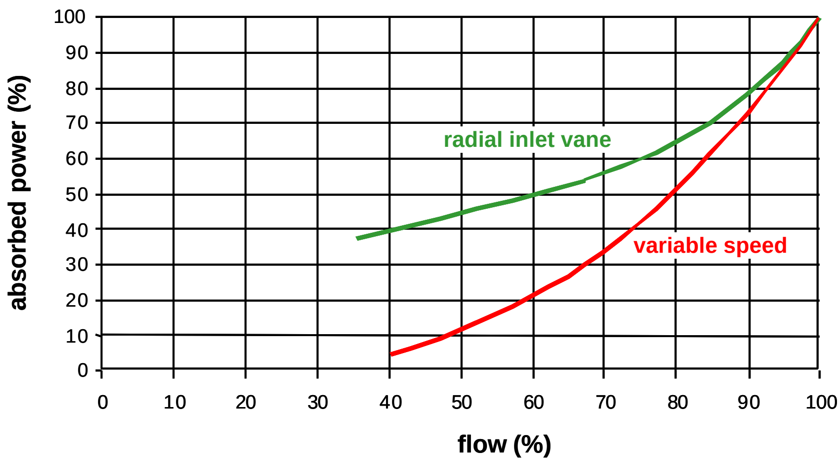

Diagram 1 shows the general comparison of flow rate versus power consumption for the two configurations – radial inlet vane and variable speed -

If the savings are calculated one should not forget to consider the fan efficiency, which might drop if an adjustable speed drive, is applied.

ROI: To justify the project and to predict the pay back period a ROI (Return On Investment) calculation was done. Due to the fact that already reliable values were available from the time when the DC-motor was in operation, there was no need to calculate the power savings again.

There are basically two different points were the fan is operated, one with the raw mill (compound) and one without it (direct).

Fix speed with damper:

Damper pos. [%]	Power [kW]	Hours per year (estimated)	Cons. energy [kWh]
70 (compound)	1330	5080	6'756'400
45 (direct)	850	2440	2'074'000
Total			8'830'400

Adjustable speed drive:

Operation	Power [kW]	Hours per year (estimated)	Cons. energy [kWh]
Compound	1250	5080	6'350'000
Direct	350	2440	854'000
Total			7'204'000

The total amount of energy saved if an adjustable speed drive is applied is 1'626'400 kWh. As shown below the investment is paid back after 29 months of operation. This figure may vary due to different hour values or operational points and the local cost structure of the electrical energy. For the calculation the actual energy costs of 0.042 US$ / kWh was taken.

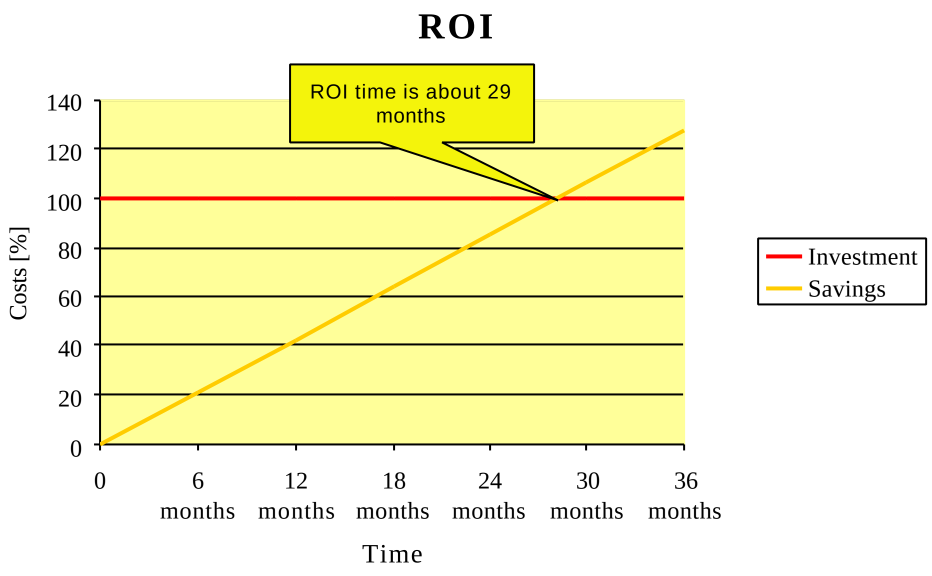

Diagram 2 shows the ROI calculation as the base for the investment

Investigated variants: The following systems were investigated and compared:

Medium voltage: With the medium voltage variant it was foreseen to keep the existing slip ring motor and to install a new frequency converter in medium voltage technique (6kV). The rotor slip - rings would have been short circuited externally.

The variant with a new medium voltage squirrel cage motor (e.g. 3.3kV) and a frequency converter on this level was not considered mainly because of cost reasons. Also the variants medium voltage converter and a step up transformer, DC-drive or slip energy recovery (SER) were no envisaged solutions.

Low voltage: The low voltage solution comprises a new low voltage squirrel cage motor in conjunction with a frequency converter. The voltage level was chosen to be 690V to lower the currents and therefore to reduce the cross section of the cables. From the very beginning it was intended to install a 12-pulse system to comply with the local regulation concerning THD_U (Total Harmonic Distortion) values.

Due to the fact that the plant made already very good experience with water-cooled motors the new one was also envisaged to be of this type.

Comparison of variants

Technology

MV Drives: The medium voltage frequency converter technology is somewhat new especially on the 6kV level. There are only a few suppliers around the world, which manufacture a real 6kV converter (see figure 2 below). The major advantage of this technology is that in case of an existing motor (revamping) the motor might be reused. Beside this the same voltage level for motors (if fixed or variable speed) can be maintained throughout the plant. However, the age of an existing motor plays an important role while comparing variants and one should be aware that the motor might soon be in condition for replacement.

The technology of the systems on the medium voltage level is fairly different from one to another supplier and shall not be explained in this paper.

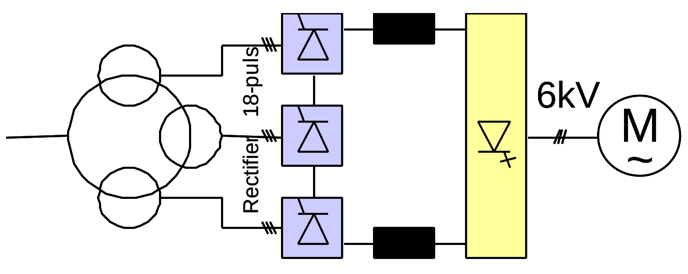

Figure 2 shows the typical electrical diagram for a 18 pulse 6kV drive

LV Drives: The investigated variant with a low voltage drive on the 690V level is getting a quite popular arrangement in our industry. The advantage compared to a lower voltage (e.g. 400V) is the lowered current from the transformer onwards and this results in smaller cross sections of the cables. Many manufacturers have the 690V converter in their program and therefore a certain competition is given. A 12-pulse arrangement was envisaged for the low voltage variant. With a three-winding transformer, where the two secondary windings are 30° phase shifted, two parallel mounted rectifiers are fed. This has the advantage that the 5 and 7 harmonic can be lowed or even eliminated.

Reliability / Availability: In terms of reliability it is too theoretical just to compare statistical figures. However, the calculated value of MTBF (Mean Time Between Failure) is usually higher if a system is set up with fewer parts.

The availability of equipment is one of the most important things in our industry. Therefore also the MTTR (Mean Time To Repair) is crucial and may be influenced from the customer as well.

With the medium voltage solution the advantage is that the slip ring motor can remain and in case of a failure in the converter the motor would be started with the liquid starter and run further at fix speed. A prerequisite for this is of course that the damper system is still installed and operational.

Efficiency: The efficiencies of the two different systems were also compared (including transformer). It resulted as follows:

LV- Variant	93,5 %
MV-Variant	92,6 %

Mainly due to the lower efficiency of the existing slip ring motor the MV-Variant has almost a one percent lower overall efficiency.

Cost Comparison: The cost comparison in chart 1 shows the main items of the different variants. In the installation costs all relevant expenditures are considered, such as:

- Cables cost (purchase, laying and connection)
- Installation of frequency converter unit
- Installation of new motor (LV-variant)
- Adjustment of coupling and foundation frame (LV-variant)
- Installation of new transformer (LV-variant)
- Civil costs (MV-variant)

If comparing the total expenditure one should be aware that in case of the MV-variant only a frequency converter is calculated whereas in low voltage an entire new system including the motor was quoted. Furthermore it should be considered that in case of the MV- variant the motor might be replaced in the near future which would again cause significant costs.

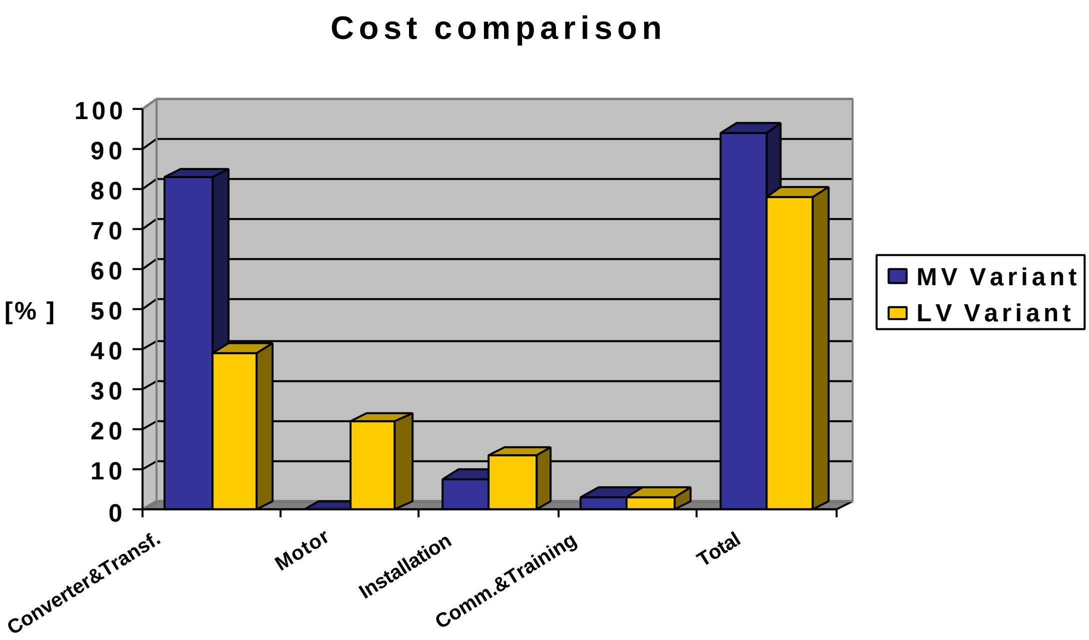

Chart 1 shows the detailed price comparison between the MV and the LV configuration.

Final solution: After comparing the different variants it was decided to go for the low voltage solution. The main reason was the lower investment costs and the compact design of the low voltage inverter. Due to the fact that the distances between transformer, frequency converter and motor are rather small the installation costs for the low voltage variant are not significantly higher.

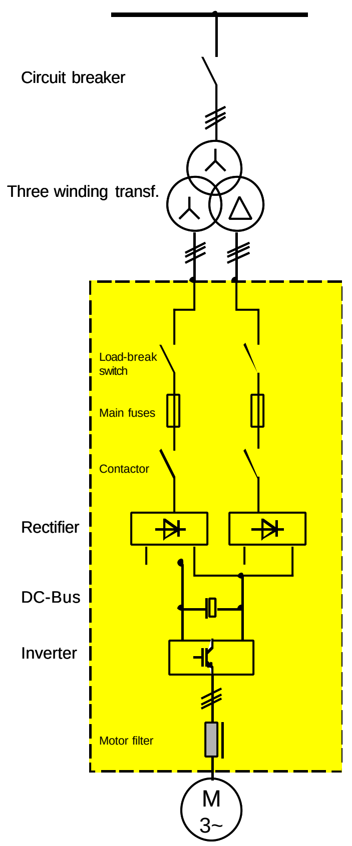

Figure 3 shows the electrical diagram of the applied solution

Frequency converter: Because of the very compact design the frequency converter fitted in an existing electrical room just beside the motor and hence no civil work was required.

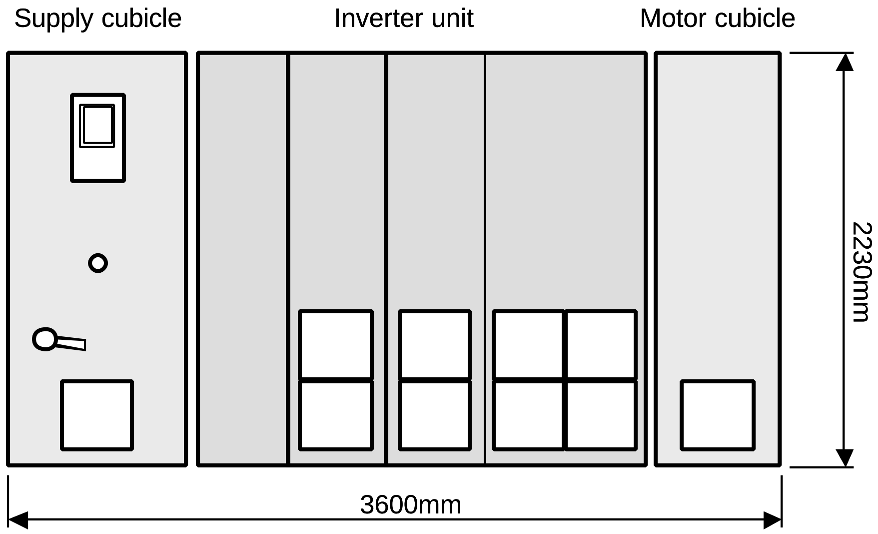

Figure 4 shows the drives panel layout (depth of cubicle 600mm)

Usually frequency converters of this size do have two smaller units connected in parallel, which accommodates half the power each. With the purchased system this is not the case anymore. The rectifiers are still connected in parallel but there is only one inverter bridge installed.

Water cooled motor: Due to the fact that the existing slip ring motor was already water-cooled the new low voltage motor is also of this type.

The ordered motor does not have a heat exchanger but is surface cooled. The major advantage is that the heat is discharged very efficiently this means that no fan is needed for the internal air circulation. This has the advantage that the motor efficiency is approximately 1.5% higher compared to motors with an air/water heat exchanger.

Protection: For the protection of all the equipment the following measures were taken:

Motor

Danger	Protected by
Over current	Frequency converter
Over voltage	Frequency converter
Over temperature windings and bearings	PT100
To fast voltage rise (du/dt)	Motor filter
Bearing current	Insulated NDE bearing
Condensation	Space heater

Frequency converter

Danger	Protected by
Over current	Itself
Over temperature	Itself
Over voltage	Itself and screened transformer
Earth fault between transformer and FC	External earth fault detection

Worst case scenario: The project team was setting up a certain worst case scenario for the occurrence of a failure.

If one of the parts failed the first action obviously would be to try to fix it. In case of an irreparable item the old drive system should be installed again. Prerequisite for this is that all installations such as cables, damper and starter remain but this is certainly justified if such an important drive is concerned.

Summary: For adjustable speed drives the solution with a **690V** low voltage arrangement gains popularity especially because of economical reasons. But one ought to compare the so-called "Total cost of ownership", means all costs caused by the system over its lifetime, shall be considered.

Furthermore all different requirements and influences have to be investigated when a system is purchased such as local support, reliability, efficiency etc.

The purpose of replacing the drive at the Untervaz plant clearly was to lower the specific electrical energy consumption in conjunction with a high availability of the system. The fact that the investment will be repaid in less than three years of operation time certainly justifies the expenditure.

In the near future the frequency converter technology will certainly develop especially in the medium voltage field and one can be curious what the next generation might bring.

References: Slip Energy Recovery Paper, IEEE 1998