Article Written by Fredrik Walldal Managing Director KraftPowercon, Inc & Felipe Atti Dos Santos Industrial Manager of Cromofix Cromo Duro Ltda.

Fredrik Walldal is the Managing Director of KraftPowercon, Inc. *He has been with 'KRAFT' for over seven years and holds an MSc degree in Industrial Engineering and Management from Chalmers University of Technology in Gothenburg, Sweden.*

KraftPowercon is a world leader in industrial power conversion since 1935 and has designed and manufactured plating rectifiers since the 1950-ies. Amongst notable achievements, KraftPowercon pioneered the world of metal finishing with the first switch mode rectifier designed specifically for this application in 1983. 35 years later this technology has become the industry standard. KraftPowercon's US headquarters that includes sales, service and assembly is located in Fairfield, CT.

Felipe Atti Dos Santos is the Industrial Manager of Cromofix Cromo Duro Ltda. *He has been with Cromofix since his Industrial Apprenticeship Training in Electronics in 1991. He earned his BSc degree in Mechanical Engineering from Universidade de Caxias do Sul, Brazil and holds an MBA degree from Fundacao Getulio Vargas, Brazil.*

Founded in 1982, Cromofix is a plating shop in Brazil that specializes in hard chrome plating. At Cromofix, Felipe has had firsthand experience with comparing the performance of different DC rectifier manufacturers and technologies; tap switch, saturable reactor, primary thyristor, secondary thyristor and switch mode.

The impact of rectification from a Metal Finisher's perspective

Choosing the right rectifier to power your plating process can have a big impact on your business' performance. Yet, to many metal finishers a rectifier is just a black box providing DC power to an electrochemical cell. While this may be true to some extent, there is a lot more going on than meets the eye.

The purpose of this article is to present the most important performance parameters influenced by the choice of rectifier and outline the impact this can have on any metal finishing business.

Below are some of the most influential performance parameters for any metal finishing operation directly related to the choice of plating rectifier(s):

Energy Consumption – Energy consumption in this case is determined by the amount of (AC) power consumed by a plating cell to achieve the intended result. Energy consumption is directly related to the efficiency of the rectifier; where efficiency is the Power out (kW) divided by the Power in (kW) expressed as a percentage value – the higher the value the better.

A modern switch mode rectifier offers efficiency as high as 90% at typical operating voltage levels for metal finishing (10-12 V_{DC}) while a modern well-designed SCR[1] **specifically designed for this output voltage** would typically offer efficiency as high as 80-85%.

It is important to note the **strong correlation between a rectifier's efficiency and how it is operated**. A general rule of thumb is that the efficiency of a rectifier decreases when the operating DC voltage is decreased. This curve (energy efficiency decrease) is much steeper for an SCR type rectifier than for a comparable switch mode unit. For that reason, a switch mode rectifier can retain a higher efficiency rating over a wider output range. An interesting observation on this subject is the common practice to purchase oversized SCR rectifiers to cater to multiple processes and to be 'on the safe side' if future needs change. This has led to a situation where there are quite a lot of inefficient rectifiers in use today.[2]

As an example, KraftPowercon conducted a real-life test in a plating environment comparing SCR type rectifiers (anno 1989) with modern switch mode rectifiers that showed that 34% less electricity was used to produce the same amount of ampere-hours.

- ➔ To determine if there are cost savings to be made upgrading to a modern rectifier, you first have to determine the efficiency of your current setup at normal operation. If you have SCR type rectifiers running at voltages below 10-12 V_{DC} or what they were initially rated for, chances are quite good that an upgrade to switch mode rectifiers can offer a substantial (10%-30%+) reduction in energy consumption.

- ➔ Another sign of poor efficiency is if the rectifiers during normal operation are running hot or easily overheat. Heat is in this case an indication of excess power loss – a true effect of a poorly designed unit. The rectifier pictured at right had a measured efficiency of <25%(!) at normal operation – the external cooling fan placed on the floor next to the unit gives a good indication that there might be opportunity to improve.

  Furthermore, it is worth noting another effect of excessive heat - component life time. Most of an electrical/electronic component's life time is determined by how hot they run; the cooler, the

[1] There are several circuit configurations for SCR type rectifiers. For the purpose of this article, we will refer to a six-pulse secondary controlled SCR, which is the most common by volume in the metal finishing industry.
[2] Comparable data from KraftPowercon's own SCR (max 24 V_{DC}) and Modular Switch Mode (max 15 V_{DC}) designs show an 8-10% efficiency difference in favor of the switch mode @12 V_{DC} output, ~25% @6 V_{DC} and >50% @3 V_{DC}.

longer and the hotter, the shorter. Suppliers of electronic components will guarantee life-time only provided that they are operated within pre-defined temperature limits. It's also a fact that the correlation between temperature and life-time is not a linear one, but best described as an exponential function, making the heat-problem even worse.

Product Quality – Improvement in product quality is perhaps one of the most significant performance parameters for any metal finisher, especially when dealing with sensitive processes and stringent specifications.

Cracking, poor adhesion, uneven plating thickness, over-plating and under-plating are all quality issues directly or indirectly related to the quality and accuracy of the provided DC power. While it is fair to say that this is only one of many variables, it does play an important role.

For ripple sensitive processes, like *e.g.*, hard chrome, decorative chrome, precious metals and copper plating the quality of the DC power directly impacts the quality of the finished product. High and/or variable ripple is known to cause poor adhesion, uneven deposition rate and cracking. By design, an SCR has high ripple content on the DC output, which is why it is most often necessary to invest in a ripple filter when this technology is used. Furthermore, the ripple content of an SCR also varies with the output voltage, which in turn means that it varies with the resistance of the electrochemical cell (resistance is in turn related to amongst other the concentration of the chemical solution, the temperature and the distance between the electrodes).

By design, a switch mode rectifier offers very little ripple content - typically, less than 2% across the output range for a well-designed unit and less than 1% at intended operation. This means that a switch mode power supply more or less eliminates the ripple variable from the complex equation of producing high quality parts.

Another variable well known to cause quality issues is manual operation. By default, any manual operation, like 'knob style' ramping, polarity reversal and time count varies. Most modern high-quality rectifiers (switch mode and SCR type) come with control options offering pinpoint accuracy and programmable recipes to minimize variables like plating time, ampere-hours, voltage and current levels.

The reduction of manual operation coupled with a low ripple content DC power supply, offers the end user a chance to optimize each plating recipe and to achieve **repeatable plating results**.

➔ If you are struggling to achieve repeatable plating results and are experiencing variable plating thickness, over-plating, under-plating, cracking or poor adhesion do not rule out your rectifiers and their operation as a potential source of variation/failure. Modern rectifiers offer the opportunity to more or less eliminate this variable.

Reactive Power Consumption – Simplified, reactive power is "non-working" power, or power that has to be supplied to the rectifier due to its design, operating output DC voltage and current. The relation between reactive and active power consumption is presented as the power factor and is

expressed as a value between 0 and 1, the higher the better – and by better we mean less reactive power consumption. [3]

Switch mode rectifiers generally offer a power factor >0.9 across the output range, while SCR type rectifiers have a power factor as low as 0.2 and as high as 0.8, depending on how it is operated (the lower the operating DC voltage, the lower the power factor and the higher the reactive power consumed).

To compensate for a low power factor and resulting high reactive power consumption many metal finishing facilities have to invest in and maintain quite expensive (active) capacitor banks.

Furthermore, some U.S. states have a 'penalty' charge for high reactive power consumption – a so-called KVAR charge.

- ➔ Check your utility bill for a 'KVAR' charge. If your utility company charges for reactive power consumption changing to switch mode power supplies with high power factor could offer substantial cost savings.

- ➔ If you are looking to expand and are limited by an already installed capacitor bank to compensate for high reactive power consumption; changing to switch mode rectifiers is one way of avoiding an expensive investment in this type of infrastructure.

Service & Maintenance – Keeping your rectifiers running is of course crucial – without power, there is no product. Yet, we all know that rectifiers sometimes over heat, don't start, go down or don't provide the required accuracy or power when needed for various reasons.

While failure happens, it is important to be able to identify the source of failure, fix it and return to normal operation as quickly as possible.

Trouble shooting an SCR type unit very likely requires outside service and expertise due to the variety of rectifier designs and ingoing components, the resulting number of potential issues and the complexity of tracing the root cause. When an SCR unit goes down, it is inoperable, which in practice means that a replacement rectifier needs to be readily available and/or onsite spare parts and trained service engineers. If this is not the case, a rectifier failure can cause lengthy and costly downtime.

Today's modern modular switch mode rectifiers offer the benefit of being redundant, *i.e.*, the rectifier will keep running even if one of the modules goes down. This affords the user the possibility to plan the service and maintenance of the unit during a planned stop while still being able to maintain more or less normal operation. A well designed modular system is also quite easy to trouble shoot and service. Their

[3] In layman's terms, you can say that the load side (rectifier, plating tank, cables, copper bus bars etc.) will generate (on the AC-side) a phase difference between the voltage and current. If you have a purely resistive load, no such phase difference will be present. This is, however, a very rare situation as most loads will have inductive and capacitive components. It's these components that will cause the phase difference. One way of expressing this phenomenon is called the power factor.

design typically includes self-diagnosing modules and few and easily replaceable spares that make them possible to service without external support.

At Cromofix, one of the most common failure types for their SCR units in operation has been blown diodes. An estimated 50% of all diodes have to be replaced on an annual basis, mainly due to accidental short circuit failures. This is both costly and time consuming, estimating 2-3 hours when replacing a batch of blown diodes. Continued operation with blown diodes also has an impact on the DC ripple content which in turn can have a negative impact on product quality as previously explained.

- ➔ Ask your rectifier supplier or service partner for typical response time in case of rectifier failure. Beware of long lead times for spare parts, which can be a nasty surprise.

- ➔ If you have SCR type rectifiers and are having issues with blown diodes investing in a rectifier solution that includes short circuit protection can be a good way to reduce unplanned downtime and maintenance costs.

Productivity – Imagine the impact of being able to produce (and sell) more with less effort. That is the combined result of improved product quality and reduced downtime for your plating line(s). We have already addressed how product quality can be improved by reducing the variability in power quality and accuracy enabling a repeatable plating operation and result, now let's look at downtime.

Downtime, or more specifically **unplanned** downtime, occurs when operation has to be stopped, due to an unexpected incident. Unplanned downtime from a rectifier perspective probably means that one or more of your rectifiers are not capable of operating as required. Typical rectifier issues (SCR & Switch Mode) include some sort of communication or component failure and/or overheating.

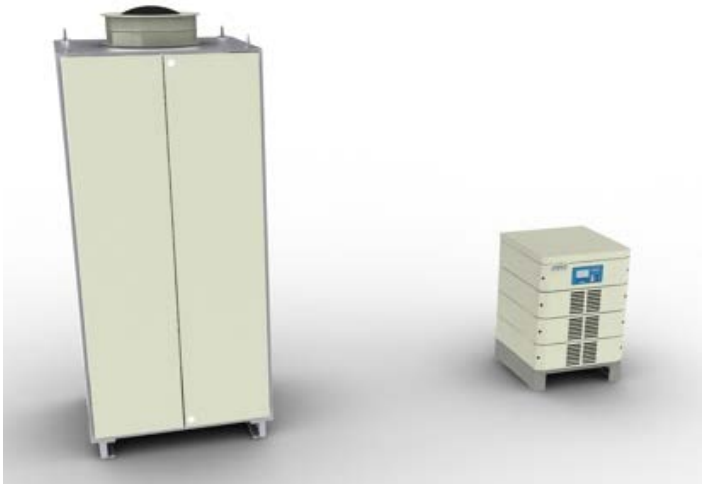
This is where the robustness of the design and choice of ingoing components of the rectifier plays an important role. Not all SCRs are the same, neither are all switch modes. However, in general a robust design includes protection against the often harsh conditions in which the rectifier will be required to operate, as well as efficient cooling combined with a choice of tested high-quality components.

In the end, it is very likely that either heat or corrosion or a combination of the two will ruin the capability of a plating rectifier to operate as intended. To secure longevity of a rectifier, it is of utmost importance to make sure that it is designed for the intended environmental conditions and rated for a duty cycle that corresponds with the planned usage.

- ➔ Although many rectifier manufacturers have similar designs, no two are exactly the same or use the same ingoing components. Do your research when selecting your supplier, including talking to fellow users and reading the fine print in the technical details.

Evaluating your options

The main options available to an end-user today is to invest in modern Switch Mode or SCR type rectifiers or keep and maintain what is already installed (commonly an older SCR unit). The table below outlines some of the key parameters related to each of these three options:



SCR & modular switch mode rectifier

	Old SCR	Modern SCR – six pulse, secondary control type	Modern Switch Mode
Efficiency	Depending on usage. Typical values at common operating output voltages: @ 12 V_{DC} ~80-85%. @ 6 V_{DC} ~60% @ 3 V_{DC} ~30% Beware of units running hot or in need of additional cooling.	Depending on usage. Typical values at common operating output voltages: @ 12 V_{DC} ~80-85%. @ 6 V_{DC} ~60% @ 3 V_{DC} ~30%	Depending on usage. Typical values at common operating output voltages: @ 12 V_{DC} ~90%. @ 6 V_{DC} ~80% @ 3 V_{DC} ~70%
Ripple	Very high at low voltage Typical <30% across output range <5% with ripple filter	Very high at low voltage Typical <30% across output range <5% with ripple filter	Very low Typical <2% across output range
Accuracy	Acceptable	Very high	Very high
Serviceability	Difficult to trouble shoot and repair. Use external provider. Different type spare parts for different configurations.	Difficult to trouble shoot and repair. Use external provider. Different type spare parts for different configurations.	Few spare parts easily replaceable with in-house staff.

Power factor	Depending on usage. 0.2-0.8	Depending on usage. 0.2-0.8	>0.9
Foot print	4x equivalent Switch Mode Unit	4x equivalent Switch Mode Unit	~25% of equivalent SCR up to 75kW
Reliability & Duty Cycle	Depending on condition and original design	Very high / Depends on design and choice of components	Very high / Depends on design and choice of components
Flexibility	Fixed size. No upgradeability	Fixed size. No upgradeability	Upgradeable to meet future needs

Conclusions:

The choice of plating rectifier can have a big impact for a metal finishing business.

Key performance parameters like energy consumption, maintenance and service costs, product quality and output volume are all directly or indirectly influenced by the choice of rectifiers.

The main options available as per today is to invest in modern Switch Mode or SCR type Rectifier or to keep and maintain what's already installed (assuming this is not a modern high-quality rectifier (Switch Mode or SCR)). All options come with a set of performance parameters and features that impacts your business.

Work closely with a professional supplier to determine the right choice for your business.

There could be opportunity to improve!