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ECONOMICAL ASPECTS OF ENERGISING ELECTROSTATIC PRECIPITATORS WITH HIGH-FREQUENCY SWITCHED POWER SUPPLIES

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ABSTRACT
There is a slow but clear trend to change from conventional mains-frequency operated HV-supply packages for Electrostatic Precipitators to HV-supplies that are high-frequency switched.
The main driver for this trend is the easy installation, smooth HVDC and the resulting improved ESP collection efficiency.
With more than 1200 high-frequency switched HV supplies in operation today, ALSTOM has gathered a sizeable experience in the use of such equipment.

In another paper presented at this conference, Lena Lillieblad et al discuss and compare different ESP upgrade methods to reduce the emission – and mention the high-frequency switched HV-supplies as a "favourite" especially from the cost/achieved result point of view.

This paper focuses on the economy in using the high-frequency switched HV-supplies and states that it is **always** profitable for the end user to use this type of equipment even though the component cost at first sight would seem higher.

INTRODUCTION

Around 1990 ESP control experts - at what was then Flakt - judged that high-frequency switching technology could be expected - mentioned in the order of importance – to most likely provide:

- Easier installation
- Lower weight
- Higher power conversion efficiency
- Increased corona power resulting in higher collection effiency

This list convinced the R&D responsible persons to initiate the development of high-frequency switched HV-supplies for ESPs.

The new product range was branded "**SIR**", which stands for **S**witched **I**ntegrated **R**ectifier.

Today, with more than 1200 SIRs in operation and ca 12 000 MWe of coal fired boiler ESPs energized by SIRs, the early advantage list has been turned almost upside down, and several more important advantages have been found:

- SIR technology certainly does increases the ESP collection efficiency
- It does have a very high power conversion efficiency
- It loads the three phases evenly under all operation conditions
- It creates ignorable disturbance back to the mains supply line
- It is a complete one-box unit that includes controller and has outputs for HVDC and rapper operation and with such a simple installation that even we could not foresee the simplicity
- Rated at 60 kW it weighs in at a mere ca 250 kg

This paper looks into all these mentioned points from the economical point of view, and initially also discusses the main driver for using SIR: The increased ESP collection efficiency.

Throughout this paper the ALSTOM brand name "SIR" is used. One reason for this is the simplicity of the word. Another reason is that some technical features that SIR has may not necessarily be available in high-frequency switched HV-supplies designed and built by other vendors.

HOW THE SIR TECHNOLOGY INCREASES THE CORONA POWER

The power input into an ESP supplied by conventional TRs is physically limited either by:

- Sparking in the ESP, or
- TR maximal current capability
- Prevalent back-corona

Sparks will be ignited at the highest kV that can be supplied - the peak voltage.
A conventional mains frequency operated TR feeds the ESP bus section with a HVDC.
Superimposed on this DC there is a ripple component of about 30-40 % peak-to-peak due to the nature of rectified AC through thyristors.

This means that an ESP which operates at 40 kV as read on the panel kV-meter and is limited by sparking, actually is limited by a maximum peak voltage at around 46 - 48 kV, avoltage at which the sparks would be ignited.

A SIR installed in the same ESP gives a ripple of less than 1 kV. Hence the SIR in that same bus section will continuously operate at the mentioned peak kV levels.

As the SIR controls the output with transistors that work at a much higher frequency, the regulation becomes more exact and this also contributes in the strive to stay closer to the absolute maximum voltage.

Everyone may not be familiar with the fact that a control cabinet for a traditional TR must use thyristors, which can only be turned on and then stop to conduct only when the AC-supply passes zero. This, of course, complicates regulation especially at such a low frequency as 50 or 60Hz.

The consequence is, that a SIR can usually deliver 2-3 times more corona power into the ESP than a conventional TR. Or - which can be very attractive when the ESP is old and has fragile emission electrodes - it may be possible to avoid sparking completely by limiting the kV or mA to a safe value below the sparking level while still operating the ESP at a much higher power level than was possible with a conventional TR.

SIR has a superior control as it works with 10 – 20 µs duration pulses compared to 10 or 8,4 ms pulse duration for a 50 or 60 Hz TR.

This makes it possible to rise/stop the HVDC flow at sparking much faster with a SIR than with a conventional TR. The HVDC can also be resumed much faster with a SIR than with a conventional TR after sparks or arcs. Both effects improve the ESP collection efficiency.

As SIRs can, and does, feed more power into an ESP, the emission can be reduced after the majority of all ESPs in the world - or ca 80 % of the installed fleet.

The exceptions may be ESPs which precipitate high-resistive dust where more corona power is not an issue, and those very few oversized ESPs where the power input is already so high, that a further power increase cannot reduce the emission further.

For the high-resistive ESPs a SIR will be operated in a very similar way as a conventional TR: In in Semipulse™ mode [also called Intermittent Energisation or abbreviated I.E.].

SIRs GIVE AN UPWARDS PARALLEL SHIFT OF THE U-I CURVE

All can agree that SIRs - because of the smooth HVDC they produce - are capable of increasing the corona power. Here comes a statement that may be a bit more difficult to swallow:

"SIRs use more kV to drive the same current through the ESP compared with a conventional TR"

This relatively unexpected discrepancy is ESP process related. A kV-increase shift always seems to be present, and may be e g 10 % or less, but for some processes a SIR may operate at a kV level which is a much as 20 % higher for the same current, compared with a conventional TR.

The increased kV with SIRs will accelerate the dust particles better. For low- and medium-resistive dusts the ESP collection efficiency is therefore increased, even at the same corona current, and often quite a lot.

We still wait for a solid scientific explanation for the U-I curve shift that we see.

During our field-work we have established that kV readings in existing traditional TRs are notoriously unreliable regardless of supplier.

When comparing SIRs with conventional TRs in A-B tests it is therefore necessary to calibrate the kV metering circuitry of the existing TRs carefully. Very often we have then found the kV readings to be 10-20 % off the correct value - both upwards (then usually due to aging of HV-measuring resistors) and sometimes also downwards.

Presently we judge it true to say that an ESP bus section does present a process-related, higher impedance to a SIR than to a conventional TR. This is of no importance to the end customer, but has been an initial ESP sizing/selection issue when selecting the SIR rating for a specific use.

SIRs DRAW POWER FROM THE THREE-PHASE MAINS EVENLY UNDER ALL OPERATING CONDITIONS AND CREATE ALMOST NO DISTURBANCE BACK TO THE MAINS SUPPLY

A SIR draws electrical power from the mains supply line in a different way than a conventional TR.

A conventional TR is connected - via anti-parallel thyristors - directly into the TR primary. The thyristors are switched on as needed by the TR controller (often called "AVC" in USA) during their respective mains half-periods. The thyristor ignition angle is the way in which power into the ESP is controlled.

The maximum amount of the half-period duration that can be used is approximately 60% the half-period duration, or 6 milliseconds out of the total 10 for 50 Hz and a little less for a 60 Hz operated TR.

The reason why only half of the half-period can be used is the phase-shift between current and voltage that the thyristors see: A thyristor can only be triggered into conduction when *both the current and the voltage are in the same phase position* - and this is what determines the maximum conduction duration.

This continuous partial utilization of the half-period produces distortion back to the mains supply line. The disturbance is even further amplified, and made more serious, as a TR is connected only between two of the three phases - and thus *always* creates an unbalance between the phases.

As a matter of fact, a conventional thyristor-controlled TR violates many rules that utility companies have set up as permissible levels of equipment disturbances to the mains.

The only reason why thyristor controlled TRs are still used is that there has been no commercially attractive alternative available.
Now there is: Transistor controlled switched technology power supplies**.**

A SIR draws power equally from all the three mains phases. SIR connects to the mains through a full-wave three-phase rectifier, and charges a capacitor to an almost smooth DC. From this DC a transistor bridge switch produces the high-frequency AC that SIR uses to create the HVDC. This way of loading the mains line via a large capacitance produces only small disturbances. Not even during Intermittent Energisation with SIRs will the distortion to the mains created by a SIRs surpass authorities' prescribed levels.

ON THE IMPORTACE OF SIRs HAVING A HIGH POWER FACTOR
First of all, lets look a bit into the definition of *Power Factor*. We state immediately that the Power Factor is interesting - and that cos φ is usually not the same as the Power Factor. And that - at a theoretical best - the Power Factor can have the value 1.

The Power Factor is by definition kW divided by kVA, or in words *"actual load power"* divided by *"appearent load power"*. VA is defined as Vrms multiplied with Arms (where "rms" stands for Root Mean Square, which is always a calculated value").

For a pure DC the kW value is the same as the kVA value. And then, of course, the Power Factor has the value 1.

For a perfectly shaped sine wave - with no phase shift between voltage and current wave-forms - the kW value is the same as the kVA value, and hence the Power Factor would be 1 for this case.

The phase-shift is denominated "φ" and is the angular shift between the sine waves of voltage and current.

Only for a perfectly shaped sine wave - but with a phase shift between voltage and current - the Power Factor is equal to cos φ.

In the real life the mains waveform is never a perfect sine wave. Therefore, the phase shift - cos φ - becomes less interesting because it differs from the true Power Factor value. The Power Factor value is often [far] lower than cos φ. A conventional mains (e g 50 or 60 Hz) operated TR for ESP may have a Power Factor of e g 0,63 during full-wave operation at normal kV and mA values.

For SIRs the Power Factor is much, much better: ca 0,95.

Please note, that when the mains supply contains a lot of voltage spikes or other disturbances, it is recommended to install an LC filter - and possibly also snubber circuitry to protect mainly the semiconductor circuitry of the SIRs. An LC filter reduces the Power Factor, usually to ~0,85. The LC filter can never completely protect a SIR from extreme voltage spikes that may occur - a direct hit into the mains power line by a thunderstorm lightning will always kill a SIR, while a conventional 50 or 60 Hz TR might in a very lucky case have a slight chance to survive such an event with limited damages.

When the kVA is much higher than the kW - which is what a *low Power Factor* means - the *power losses increase in the mains supply line*.

A calculation example:
A conventional TR and a SIR are both rated to have the same mains input power [expressed in kW]. Their respective Power Factor is 0,63 and 0,95.

The mains power loss in the mains feeds is inversely proportional to the **square** of the Power Factor.

For the SIR: 1 divided by 0,95x 0,95 = 1.1 This means a 10 % higher loss than if the Power Factor had been = 1.

For the conventional TR: 1 divided by 0,63x 0,63 = 2,6 This means a 160 % higher loss than if the power factor had been = 1.

The conventional TR versus SIR: 2,6 divided by 1,1 = 2,3

So, the SIR gives a power loss in the mains feeds which is only 1/2,3 = 43 % of the same losses with a conventional TR.

Expressed differently: The power loss in the mains feeds is ca 130 % higher with a conventional TR than with a SIR.

Therefore, the mains feeder cable and the intermediate voltage step-down transformer that supply the ESP can be smaller sized when SIRs are used than when conventional TRs are used.

A SIR draws power from all the three mains phases evenly, while a conventional TR is usually only powered from two of the three phases. An uneven load will, of course, increase the mains feed power loss, but this SIR advantage is not accounted for in the Power Factor figures which are only given for the individual SIR and conventional TR at their respective mains connection points

Thus, to summarise, SIRs very high Power Factor (compared with conventional TRs) means:

- Smaller dimension mains cables can be used
- Smaller sized intermediate mains feeder transformer for the ESPs can be selected
- Massive power loss reduction in mains power cables and mains feeder transformers during SIR operation - compared with conventional TR.

The economical advantage of the near unity power factor for a SIR must be site evaluated from case to case.

In the above the Power Factor has been assumed to be constant for both SIRs and conventional TRs. This is definitely not true for conventional TRs, for which the Power Factor varies with the ESP process. A much lower Power Factor than 0,63 is thus not at all unusual with conventional TRs.

With dusts that give back corona the Power Factor decreases, and if then intermittent energisation [IE] is used, the Power Factor decreases even further - with virtually no lowest value (above zero) to be stated. For Semipulse™ operation with a conventional TR the worst case is usually 1:3. The operation at 1:3 often gives the same power loss [heat] in the mains supply line as full-wave operation (1:1). Therefore the very bad Power Factors seen at Semipulse™ operation with conventional TRs need usually not influence the power line cable and supply transformer sizing.

For SIRs the Power Factor remains almost the same for all ESP processes. Even operation in Semipulse™ mode [I.E. mode] changes this very little.

The entire above discussion takes a starting point from the definition of ***Power Factor***. It is possible - and with the same results outcome - to make a similar discussion with the starting point taken from the ***Form Factor*** of a conventional TR, but in this paper we will not perform that exercise.

For a conventional TR the manufacturers' sheets often state a Form Factor of 1,4 or near this value. However, the Form Factor depends to a great deal on the ESP process and even more on the thyristor ignition angle, and would usually vary between 1,3 - 1.8.

For a SIR the form factor is 1,2 thus very near the ideal figure of 1,11 valid for sine-wave. The Form Factor is per definition calculated as the Vrms divided by the Vavg, or Arms divided by Aavg.

SIRs HAVE A VERY HIGH POWER CONVERSION EFFICIENCY

The mains *power supply line losses* are larger for a conventional TR than for a SIR and are determined by the Power Factor - as above discussed. The ***Power Conversion losses*** - the losses within the TR itself and in the control elements (the thyristor cabinet for a conventional TR) - are much larger with a conventional TR. This means, that with the same mains input kW, a SIR can provide the ESP with more HVDC power than a conventional TR. The power conversion losses are often (correctly) called the heat-loss.

A conventional TR has a **power conversion** loss, which is approximately proportional to its power output. A quite old "rule of thumb" says that 15 % conversion losses can be added to the panel instrument readings of kV multiplied with mA - to provide a relatively accurate momentary TR mains kW-consumption. Some TR manufactures, however, may state the power conversion losses to be lower than 15 %.

A 60 kW SIR has a power conversion loss, which over its entire operating range is always less than 3 kW - including the cooling fan power consumption. At zero corona current the SIR power loss is 0,5 kW. From this point there is an approximately linear power loss up to the 60 kW HVDC max point, at which the conversion loss is just below 3 kW. At full load this means a ca 5% conversion loss for a SIR - thus only a third compared with a conventional TR.

If an LC mains line filter is added, the power conversion loss is increased with ca 500 W at full HVDC output from SIR.

Let's make some very simple calculations based on the following assumed data:

Cost for a conventional TR:	No cost (e g existing)
Cost for a SIR:	25 000 USD
Cost per kWh:	5 cent
SIR and conventional TR HV - output:	60 kW HVDC
SIR power conversion loss:	3 kW
Conventional TR conversion loss:	9 kW
ESP operational time per year:	7000 hours

How long time - using these simple data only - will it take for a SIR to pay for itself? Or expressed differently:

"Assuming that both provide the ESP with same HVDC power, how long will it then take before an expensive SIR gives a profit compared with a conventional existing TR".

Difference in power loss: 9 - 3 kW = 6 kW

Value of power loss saving per year with SIR: 7000 hours x 6 kW x 0,05 $ = 2100 $

So, in this example SIR will have paid an assumed 25 000 $ cost in ca 12 years.

Or, if you assume the conventional TR is not a gift but has a price tag of 10 000 $, then the "advantage SIR" break-even point would come within 7-8 years.
The above calculations are overly simplified:

- No interest rate on the investment is calculated
- A constant, pretty high kWh price is assumed (5 cent)
- A 15% conventional TR power conversion loss is assumed.
- The usually higher kV output with SIRs (and resulting collection efficiency improvement) for same current fed to the ESP is not at all considered

But on the other hand: Who believes in a future reduction of kWh-cost ?

And both a conventional TR and a SIR will live much, much longer than 10 years…

More importantly: This calculation only considers the economical benefit with SIRs for one of its "assets" - its very high Power Conversion efficiency.

ALSTOM can today not with a scientific confidence state if the HVDC power consumed by the ESP for the **same emission** is in fact same, smaller or even possibly larger with a SIR compared with a conventional TR. We have in some specific cases taken on a guaranteed reduction of power consumption for a SIR up-grade at 30% and passed the performance test but:

We have hard data from only a few ESP plants that show a lower specific HVDC power consumption with SIRs compared with a conventional TR at an equal kW level supplied into the ESP

The T/R up-grade jobs for SIR usually concentrate on the improving the ESP collection efficiency. The improved efficiency figures usually come with significant corona power increase into the ESP, and usually result in major emission reductions indeed.

Further down in this paper we demonstrate in a summary calculation that a SIR is less costly to install than a conventional TR - and that the total investment cost for a SIR into a green-field ESP is in fact lower than for a conventional T/R package.

SIR IS AN ALL-IN-ONE-BOX UNIT, COMPLETE WITH CONTROLLER INCLUDING OUTPUTS FOR HVDC AND RAPPER MOTORS

A complete conventional TR necessarily consists of:

- The TR - which is usually located on the ESP roof
- The control cabinet - which is usually located in the ESP switchgear room
- Signal- and power cables routed between each TR and its control cabinet in the switchgear room

The ESP also needs rapper controllers and motor groups. These are traditionally located in separate full-size control cabinets in the ESP switchgear room.
However, since more than 15 years ALSTOM always delivers rapper control as an integral part of the TR controller, and also includes the rapper motor control groups (for tumbling hammer rappers) in the TR control cabinet.

The rapper motor drive cables between the switchgear room and the gear motors on the ESP sides [or top] are still needed.

It should be noted that an ALSTOM thyristor controller for TR and rapper has a total of no less than 72 cable connection points. Other vendors have a similar design, of course. Although seldom all connection points are used, a large amount of cable connections need to be run into and within each cabinet and finally to the TR on the ESP roof and to the rapper motors situated at the roof and/or sides of the ESP.

Furthermore, the signal cables should preferably be routed separate from the power cables to provide good quality kV and mA wave-forms for accurate thyristor control at sparks and back-corona optimising.

Installing and commissioning a conventional TR therefore consists of the following:

- Building a switchgear room area. Per TR a minimum floor area needed might be two square metres, but often 5 or more square metres are used for each TR. The price for each square metre of switchgear room area depends, of course, very much on location. Quite often so called "raised floors" are used in switchgear rooms, with a walking area consisting of sturdy floor panels and a [often relatively low] "installation space" underneath - and this increases the cost. The switchgear room square metre investment may be quite low in low-cost regions, e g China and India but extremely high in e g USA and Germany. The thyristor sets produce quite a lot of heat often requiring air conditioning. This, of course, raises both the investment cost and the operation cost. **Often the investment cost for the switchgear room area alone is same or near the same as the total purchase cost for the conventional TRs with their control cabinets - and this comparison holds true relatively independent of country.**

- Installing the TR cabinets in the Switchgear room. With each control cabinet weighing 125 kg minimum and often more, this is a quite heavy and time-consuming manual work.

- Routing and installing signal and power cables for TR and rappers - with or without conduits depending on local regulations
- Lifting the TR to the ESP roof - often the weight is 1000 - 2000 kg, depending on rating and design: Often major height cranes with jibs [at high costs] are required
- Connecting the signal- and power cables at both ends. This usually also means verifying the cables after installation - this cable verification alone will usually take more than half a man-hour day per TR. Frequently a fire-tight seal of the cables into the control cabinet is required by local regulations, especially so if raised floors are used. This also adds time and cost.

With a SIR the majority of the above costs disappear or are reduced, and further:

- The only electrical design cost for a SIR installation is to calculate the mains supply and rapper cable lengths. No special cables at all are used resulting in a minimal electrical design cost.

- A 60 kW SIR weighing only ca 250 kg is lifted with a simple hoist to the ESP roof and installed there. No heavy cranes are required. No protective oil pans with sewage system are required because of the small oil volume in a SIR. No extra supports or rails on the ESP roof ares required with SIRs.

  The SIR stands on its HVDC duct, and a pre-fabricated duct - straight or bent 90 degrees - that makes the HVDC connection very simple indeed. An ESP roof free from completely free fromoil trays with pipes, rails and other obstructions is the result. Best of all: No design cost, building cost or final checking or administration costs for those absent items.

- For new ESPs the low weight of SIRs may even allow a less heavy ESP roof structure, which means a reduced ESP investment cost. Rails for the T/R movement and 2000kg capacity hoist beams are definitely not needed any longer.

- For an ESP upgrade with SIRs, there is no need to think about signal qualities, cable quality etc. Just prepare a HV-duct to accommodate the SIR, and then connect the mains and the HVDC when the SIR is delivered to site. Then connect the supervisory communication network - this is all.

- Run and connect a three-phase cable from the switchgear room to each SIR. Usually a drawer-style power distribution cabinet for the whole ESP occupies less area than a few TR control cabinets only. Sometimes it is more economical to bypass the switchgear room altogether and instead run a high-voltage cable directly to the ESP roof and have a step-down transformer and distribution centre located on the ESP roof. Thus no ESP switchgear room at all required. And definitely no air conditioning. Installing a SIR can usually take 3-4 hours or even less. No special cables or routings required. But be very cautious and follow all SIR grounding instructions meticulously!

- For rappers, just run and connect the three-phase cables between the SIR built in circuit protectors and the rapper motors. These cables will usually be favourably short.

- Practically no commissioning costs with SIRs: All wiring is inside the SIR, and is factory pre-tested.

MAINTENANCE COMPARISON BETWEEN CONVENTIONAL TRs AND SIRs

SIRs - just like conventional TRs - may need some service throughout their technical lifetime. Again the comparison usually turns out to be favourable for SIR:

- Diagnostics take place at one location. No need for a cumbersome moving back and forth between the switch-gear room and the ESP roof. For a SIR all is in one box.
- Modular design. A broken SIR module can be exchanged at site within less than one hour.
- SIR modules are low-weight. The heaviest module is the HV tank including oil and it weighs a mere 60 kg. No cranes needed for an exchange work. And a spare module
- Self - diagnostics. If SIRs' control PC-board is alive most internal and external faults will be automatically identified and logged.
- A SIR is so small that a field tent can easily be raise raised if the weather conditions are too tough for the personnel.
- One supplier makes the SIR unit. One expert can fix all and any problems or advice the plant in case of a self-repair.

CABLE SIZE COMPARISON BETWEEN SIRs AND CONVENTIONAL TRs

SIR needs less **primary** current, it has a better power-conversion efficiency and gives a balanced system load on the three-phase mains supply. A SIR minimises the energy-loss which immediately reduces the operation cost. Table 1 shows a cable size comparison based on a 400 V AC supply, 50 or 60 Hz.

Table 1 Mains cable comparison between conventional TRs and SIRs

SIR rating *HVDC kV and mA, almost ripple free*	**Incoming feeds** *without heaters or rappers*	**Conventional TR** *kVpeak at ESP load and mAarithmetic*	**Incoming feeds** *Without heaters or rappers*
SIR 80 kV 250 mA	***32 A*** *Three-phase*	**80 kV 250 mA**	***44 A*** *Only two phases used*
Cable size mm^2 Cu-cable + earth	*3x10 + 10*	Cable size mm^2 Cu-cable + earth	*3x16 + 16*

SIR 70 kV 400 mA	***42 A*** *Three-phase*	**70 kV 400 mA**	***74 A*** *Only two phases used*
Cable size mm^2 Cu-cable + earth	*3x16 + 16*	Cable size mm^2 Cu-cable + earth	*3x35 + 16*

SIR 70kV /800 mA	***105 A*** *Three-phase*	**70 kV 800 mA or 60 kV 1000 mA**	***148 A*** *Only two phases used*
Cable size mm^2 Cable + earth	*Cu-cable: 3x50 + 25* *Al-cable: 3x70 + 21*	Cable size mm^2 Cable + earth	*Cu-cable: 3x95 + 50* *Al cable 3x120 + 41*

SIR estimated cable cost advantage example for an ESP equipped with 3xSIR 70 kV 800 mA and 100 m distance between the SIR and the mains supply connection point
Reduced cost for the three SIRs is $ 11.250 or $ 3750 per SIR. Please note that the cable cost saving for the shorter rapper cables used with SIRs will be an extra bonus saving that can be added.

This cable cost comparison is only approximate, and is based on European conditions and cable sizes. All cable cost calculations must be made individually for each country and according to local- and site-specific requirements.

Table 2. SIR cost savings compared with traditional TR

Direct Costs	***SIR advantage***	***Saving***
Switchgear room building cost	No need of switchgear room area. A T/R control unit needs typically 5-10 m^2	$ 1.500/m^2 $ 7.500 for a 5 m^2 typical installation
Cables – dimensions & lengths Cable trays	SIRs' 3-phase power supply and higher Power Factor gives smaller cable dimensions. Integration of all functions into the SIR unit gives less and shorter cables.	$ 3.750/bus section estimated in a typical installation
Oil tray, rails, reinforcements, etc.	Oil tray not needed. No TR rails needed. Roof-reinforcements not needed. A 60 kW rated SIR weighs only 250 kg and contains only ca 40 litres of oil.	The saving is very significant, but needs to be site evaluated.
Installation	A SIR installation is much quicker than installing a conventional TR. Estimated cost for SIR about USD 1.250 per bus section and USD 3.750 for a conventional TR	$ 2.500/ SIR
Start up/commissionin g	A SIR start-up is quicker because everything is at one location - no interconnection cables to check.	$ 300 / SIR
Transport	SIR is smaller and weighs less, which saves costs. SIR is usually transported by air which gives a quicker delivery	$ 250 /SIR
SIR Operation savings		
Power efficiency	SIR has a lower power conversion loss than a conventional TR. The economical value of e g a 6 kW saving per SIR must be site-evaluated.	Varies, but about $ 2.000/year is a common figure
Future possibility		
Alternate location of the SIR	SIR can be more freely located than a heavy conventional TR. This may be utilised to position the SIR differently to reduce costs for stairs and walkways.	Significant saving potential. Site specific.

This estimate ***does*** include the cost for the cable, a cable tray or cable ladder and a schematically calculated labour cost for the installation. Of course, for USA and some other countries the differential costs for conduits would also have to be included in an estimate. The conduit costs for a conventional TR will usually be double compared with a SIR, because signal and power cables for a conventional TR will necessarily have to be routed in two separate conduits.

SUMMARY - FINAL CONCLUSIONS

If a green-field SIR investment of $ 25 000 and the "advantage-SIR" profit (only where a figure is mentioned in table 2) are subtracted, the first year cost for a SIR will be 25 000 - 16300 $ = 8700 $. With an estimated profit - also taken from table 2 - of 2000 $ per year, a SIR will then have entirely paid for itself within about 4-5 years.

But this comparison does not consider the cost for the alternative: The conventional TR itself.

In most countries in the world it is not possible to purchase a conventional TR with an associated TR control cabinet for the above mentioned 8700 $.

The conclusion must therefore be, that a SIR pays for itself usually within the first year in a green-field installation, and within several years in an ESP upgrade situation.

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