ELECTRIFICATION OF PROCESS HEAT FROM TECHNOLOGIES TO LARGE SCALE IMPLEMENTATION

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Christian Collombet
Schneider Electric
31 rue Pierre Mendès France
38320 Eybens
France

Damien Feral
Schneider Electric
292-312 Cours du 3eme Millenaire
69800 St Priest
France

Abstract - Industrial emissions come mostly from process heating powered by fossil fuels. To reduce environmental footprint and transition towards cleaner energy, a growing opportunity is to implement electrical heating, leading to new power system applications. These technologies benefit from better efficiency, lower maintenance, and more accurate temperature control compared to fired heaters.
However, multiple challenges are associated with the adoption of process heat electrification. This paper explores the different technologies and possible applications of electrified heaters from the process efficiency perspectives, as well as the power control solutions according to the temperature control accuracy and flexibility. It addresses the impacts on power system in terms of power quality covering control strategy options according to heating circuits technology. It also unveils details on a large-scale electrical heater's implementation at a European End-User Refinery, illustrating the collaboration with a Process Licensor, how specific requirements for electrical, safety features, compacity and modularity have been considered for implementation.

I. INTRODUCTION

Globally, industrial operations are considered difficult to decarbonize, especially for heavy industrial sectors like oil and gas, petrochemicals, chemicals, metals and non-metallic minerals. They are traditionally referred to as "hard to abate" because their emissions originate mostly from the operation of high-temperature heating systems, for which scalable alternatives are still limited.

Indeed, in the European Union, 47% of the industry's energy demand comes from process heating requirements, while 22% is used for mechanical and lighting energy. More than two thirds of process heating requirements are fulfilled with fossil fuels such as gas, fuel oils, or coal. For the downstream energies and chemicals industries (covering oil refining, petrochemicals, and chemicals), heating applications represent more than 70% of the energy needs and industrial CO2 emissions [1]. Today, electricity supplies only 4% of the energy used for process heating, mostly for low- to mid-temperature processes. However, the accelerating energy transition, characterized by rapidly expanding renewable electricity generation and declining costs of technologies, has created new opportunities for industrial decarbonization through electrification.

II. REFINING & PETROCHEMICALS PROCESS ENERGY NEEDS

In oil refineries and petrochemical plants, large heat demand, often reaching hundreds of MW, across multiple process units (see Figure 2), comes from the need to drive chemical reactions, separate molecules, and generate hot utilities such as steam for heating and mechanical operations.

These needs are mostly satisfied today with fossil fuels such as fuel gas, natural gas, fuel oil, and other solid or liquid fuels, to power fired heaters, furnaces, and steam boilers. Electrically powered alternatives to these conventional heating systems can reduce the carbon footprint of the process and improve the global energy efficiency, while bringing additional benefits such as operational flexibility, lower maintenance, and safer operations.

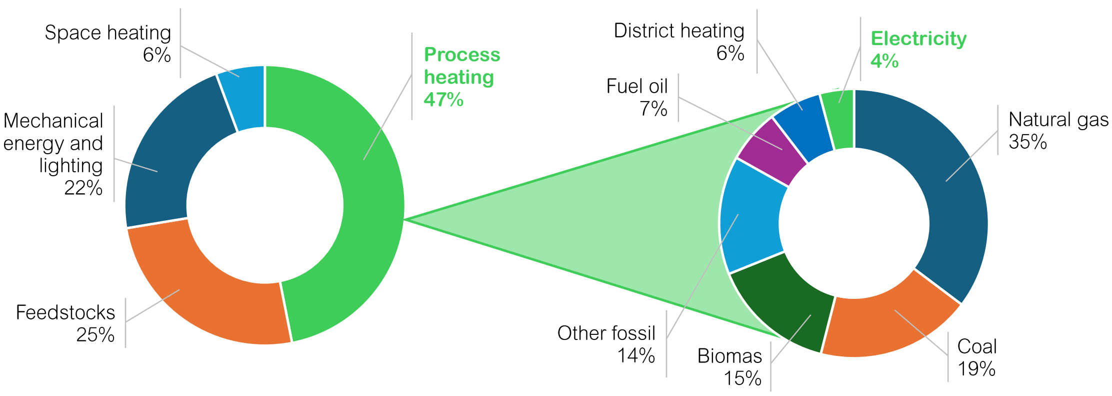


Fig. 1: Estimated energy demand in industry by end use and energy carrier for process heating forecast models in 2019 in the EU 27 [2]

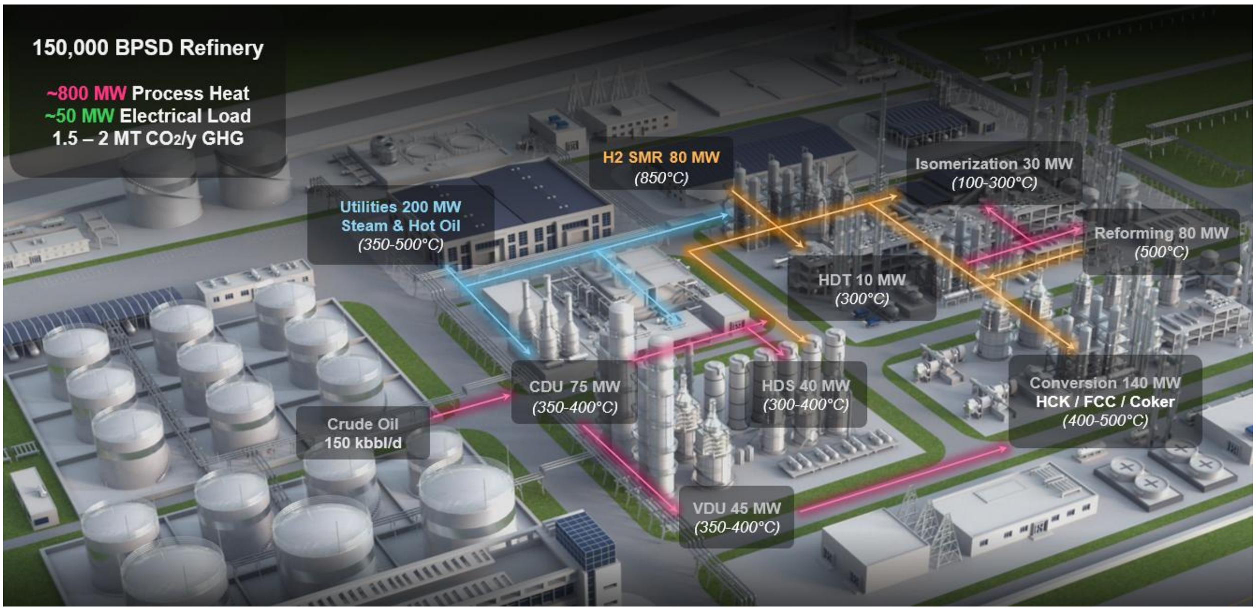


Fig. 2: Typical process heat demand in refining and petrochemicals

III. Electrical Heating Technologies and Applications

Industrial electrical heating can be achieved by different manners. Most commonly the Joule effect is used to produce thermal energy by circulating a current through the resistance associated to an electrical conductor. In industrial applications, this electrical conductor or heating circuit can take the form of physical heating elements being electrically powered (resistances) or the process fluid's (e.g. water) own conductivity (hence, resistivity) acts as an electric resistance between electrically powered electrodes.

The document explores some industrial heating technologies that are commercially available (Technology Readiness Level – TRL 8 & 9) or being currently developed at industrial pilot scale (TRL 6 & 7).

A. Resistive Immersion and Circulation Heaters

In resistive electrical heaters, the heating elements are generally composed of Nickel-Chromium resistance coils enclosed in a protective metallic tube sheath (the metallurgy can be adapted to the process requirements, typically stainless steel or higher quality alloys) filled up with compacted magnesium oxide acting as an electric insulator.

This technology is commercially available and applied in different industries including the oil and gas sector on catalytic units (catalysts regeneration or reduction heaters, gas or steam superheaters), gas heating skids (natural gas, combustion air preheating), gas dehydration (glycol reboilers), lube oil bath and hot oil heaters.

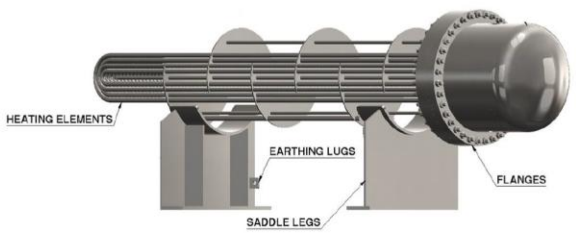


Fig. 3: Circulation and immersion resistance heater

The heating elements can be straight or U-shaped and are arranged in a bundle. The exact layout and pitch between heating elements is adapted depending on process requirements (e.g., duty, fouling service, fluid phase). The elements bundle can be immersed into equipment with static process fluid (e.g., immersion heater in a storage tank, oil bath) or be inserted into a shell or duct by flanged connections with a circulating process fluid around the heating elements (e.g., inline heater, heat exchanger, air/gas duct heater).

The heat is transferred from the heating elements by convection to the circulating process fluid, similarly to a hot fluid exchanging heat with a cold fluid in a conventional shell and tubes heat exchanger. In the case of resistive electrical heaters, the heat flux is not driven by the temperature difference between hot and cold fluids. Resistive heaters release a constant heat flux along the element, usually expressed in watts per square inch (WSI) or centimetres of heating element's surface, which can be modulated by the power inlet to reach desired temperatures.

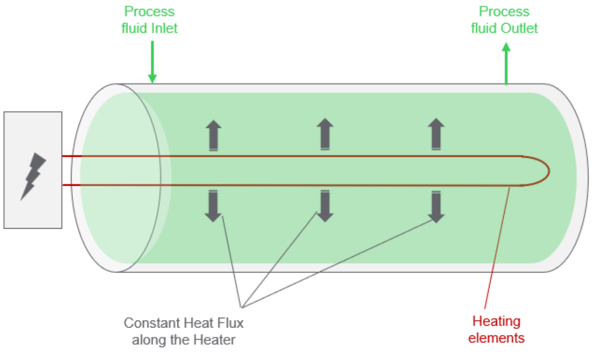


Fig. 4: Constant heat flux along the resistance heater

Thanks to precise power control and heat transfer directly to the process fluid, the energy efficiency for resistive heaters is high (typically 99%), with minimal energy losses through the power cables and thermal losses through the heater's insulation and shell. Contrary to steam heaters (vaporizers, heat exchangers), there is no heat loss through the steam distribution and condensate recovery.

The range of application in terms of heat duty typically goes from a few kW to between five and 10 MW per single bundle, while reaching process temperatures up to typically 400 to 650°C [3]. Higher process duty (> 10 MW) can be achieved by combining several heating bundles into a single vessel or associated in series or parallel depending on Process requirements, but this could cause other process constraints such as Pressure drop or flowrates and temperatures controls challenges.

The most frequent power supply for these heaters is at low voltage (range from 400 to 690 V), especially for lower heat duties up to approximately 2 MW. Medium voltage heaters (typical range 4.16 to 6.6 kV) can be considered as well, particularly for larger heat duties (> 2-3 MW) to potentially lower the power system installation cost (MV/LV transformer, power cables), though they can be limited to 400-450°C process temperatures depending on suppliers.

B. *Radiant Heaters*

In radiant heaters, wall-mounted electrical heating elements (attached onto to the refractory walls of the heater) are providing heat to the process coils, similarly to the radiant section of fired heaters and furnaces. The heating elements can be of different types depending on process requirements (mostly temperature and heat flux), with the most common ones being Iron-Chromium-Aluminium metallic type (FeCrAl) for lower temperature and heat flux or silicon carbide type (SiC) for higher temperatures and heat flux.

This technology is now commercialized with first references of designs and implementation in downstream oil and gas and chemicals sector on process units (refining, chemicals, steam cracking).

The heat is transferred from the heating elements by radiation onto the process coils. Their layout will depend on process requirements, with the possibility to divide the heater into different heating zones allowing controlling and fine-tuning the heat flux individually for each zone. By controlling heat flux distribution along the process coils to reduce the risk of hot spots, radiant heaters can be adapted to fouling and coking services, film-temperature sensitive products, biphasic and phase changing applications.

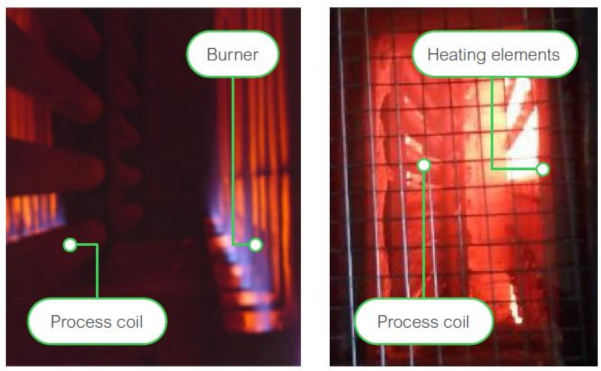


Fig. 5: Comparison between fired heater (left) and radiant electrical heater (right) [4]

Thanks to high controllability of the heat flux and precise power control, the energy efficiency for radiant heaters is high (typically >95%), affected mostly by energy losses through the power system and thermal losses through the heater's refractory and casing. Contrary to fired heaters, there is no emissions nor heat loss through the stack and flue gas, nor the need for combustion air pre-heating system.

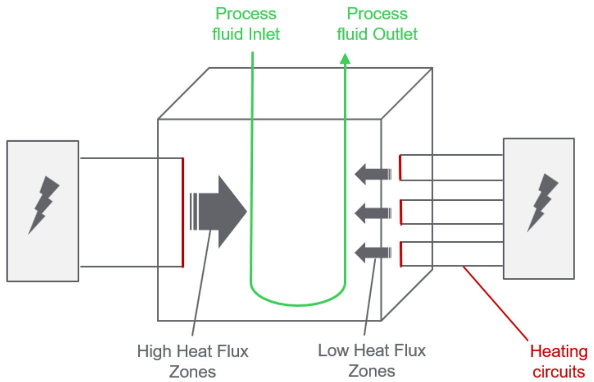


Fig. 6: Tuneable heat flux along radiant heater

Mutualizing radiant electrical heating elements and conventional burners into the same heater casing (in a retrofit or greenfield project), could allow hybridization of process heating applications. This requires more integrated power and process controls to eventually optimize the levelized cost of production (e.g., by incorporating intermittent renewable electricity, balancing the fuel gas network of the plant, optimizing the hybrid heater's energy efficiency, or participating in a flexibility or demand/response program to stabilize the electrical grid).

The range of application can go from about a MW scale to several 10s of MW scale in one or several heaters or modules (limitation will likely come from power availability), while reaching temperatures above 1000°C (depending on radiant heating elements nature and characteristics). Radiant heaters are powered today at low voltage (range 400 to 690 V) due to radiant heating elements power requirements.

C. *Impedance Heaters - Direct Tube Heating*

Impedance heaters use the natural electrical resistance of materials to generate heat by applying a current onto the process tube or coil where the process fluid circulates. This can be considered as direct electrical heating (heat directly applied from the tube itself), as opposed to indirect heating (heat applied using external electrical heating elements) for resistive or radiant heaters.

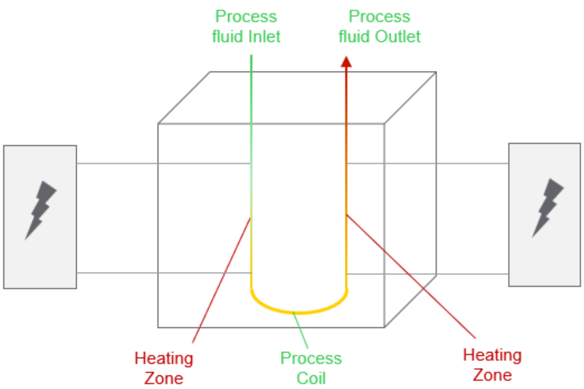


Fig. 7: Direct Tube heating technology

This technology is applied at on a relatively small scale in pipeline heat tracing across a large range of industries including food and beverage (e.g. chocolate or edible oil manufacturing), and oil and gas (tar, asphalt, paraffins, fuel oil). For large scale, it is still under development at industrial pilot scale and scaling-up to electrify fired heaters and furnaces, typically on ethylene production (steam cracking furnaces) applications.

Fig. 8: Direct Tube heating demonstrator on Steamcracking furnace [5]

The process fluid temperature would be precisely and rapidly controlled, by acting on the power input of each process coil or heating zone directly applying heat onto the process. Operating temperatures for direct tube (impedance) heating systems is affected by the power input and material of the pipe. Because the heat can be generated in the same pipe that contains the process, these heaters are particularly well suited for high-temperature, high-pressure applications and/or with fouling and coking tendencies.

Thanks to high controllability of the heat flux, precise power control and application of heat through the tube itself, the energy efficiency for direct tube heating is expected to be very high by minimizing thermal losses through the heater's refractory and casing. Contrary to fired heaters, there is no emissions nor heat loss through the stack and flue gas, nor the need for combustion air pre-heating system.

D. Electrode Steam Boilers

Electrical boilers can generate steam at various levels of pressures and temperatures. The two main technologies commercially available are resistive steam boilers (described in § III.A. Resistive immersion and circulation heaters) and electrode boilers.

Electrode boiler technology uses the conductivity of water to carry the electric current via the energized electrodes through the water itself. Thanks to the resistivity of water, heat is generated until the water vaporizes into saturated steam. Based on the sub-technology, the electrodes can be either immersed or sprayed by the boiler feed water.

This technology is commercially available and applied in different industries (nuclear, food and beverage, oil & gas) as well as for district heating purpose. The steam output is varied by adjusting the water level or circulation pump's flowrate via its variable speed drive. The electrical power is controlled by the water level or flowrate contacting the electrodes, while the quality of boiler feed water can be adjusted online with chemicals dosage.

Electrode boilers energy efficiency is >99% since all electrical energy is converted into thermal energy with minimal thermal losses through the boiler's insulation and shell. Contrary to gas fired boilers, there is no heat loss through the stack and flue gas, nor the need for combustion air pre-heating system.

Electric boilers (electrode and resistive technology) will produce saturated steam at a given pressure and require an external superheater (resistive circulation heater) to produce superheated steam.

Electrode boilers duty can go up to approximately 75 MW scale in a single equipment, with a maximum generated steam pressure of up to 80 barg. Electrode boilers are powered by medium to high voltage (typically 6-24 kV) as a power source, with the maximum heat duty and steam output being proportional to the available voltage level [6].

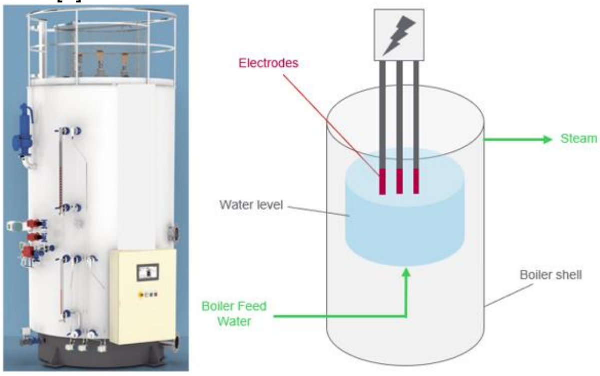


Fig. 9: Electrode Boiler Technology

Due to the ease and rapidness of starting-up from cold operations (few minutes), and operating flexibility (close to 0-100% range), electrode boilers can serve as a hybrid steam generation system (in parallel with gas-fired boilers) to benefit from intermittent renewable power, grid flexibility and demand-response mechanisms.

E. *Electrical Process Heating Technologies Summary*

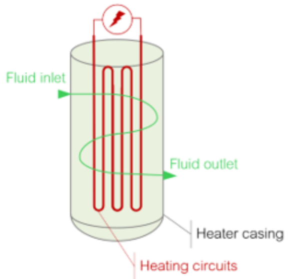
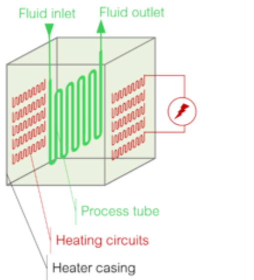
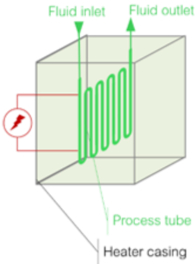
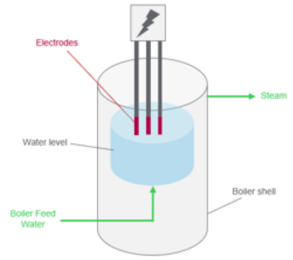
Technology	Immersion / Circulation resistance heaters	Radiant heaters	Direct Tube heating	Electrode Boiler
Illustration				
Principle	Process fluid in contact with heating resistances	Heating elements radiating heat onto the process stream circulating inside a tube	Process tube metallurgy used as a heating element (direct tube heating)	Energized electrodes generate heat thanks to water's resistivity
Applications range	Up to ~5-10 MW Temperature up to 400°C to 650°C	Several 10s of MW High temperature process ~1000°C	Existing in small scale <1MW In development for large scale High temperature process ~1000°C	Up to ~75 MW High Pressure steam ~80 barg
Examples of Potential Application	Process heaters – Clean service (steam, hot oil, liquid, gas) Kettle type reboilers / vaporizers LP steam boiler Superheater, Storage tank heating	Process heaters – fouling / coking service, liquid, gas biphasic, phase change Furnaces and reactors (cracking, chemical reactions)	Process heaters – fouling / coking service, liquid, gas biphasic, phase change Furnaces and reactors (cracking, chemical reaction)	Large scale MP to HP steam boiler Back-up boiler Hybrid steam generation in parallel with gas fired boiler
Maturity	Commercialized in multiple applications	Early commercialization for refining and cracking furnaces	Under development / scaling-up	Commercialized in multiple applications

Fig. 10: Summary of Electrical Process Heating technologies

IV. Power and Control Technologies for Electrical Heaters

Selection of power and control technology for electrical heaters and their arrangement shall consider:

- type/material, unit power and number of heating elements,
- range of variation, accuracy and time constant required for temperature regulation,
- impact of components or equipment failures on system downtime.

Some heating applications can comply with electro-mechanical contactor switching technology while others require smoother or more accurate power flux control provided by SCR.

A. *Contactor Switching*

Contactor switching is a cost-effective control solution resulting in a kind of low precision duty cycle regulation. Heating circuits are switched-on and off according to the temperature demand.

A contactor is designed to be operated under its rated current up to millions of operations. This type of control requires a heater design with an appropriate number of heating circuits, as well as circuit power capacity to achieve the range of temperature variation and the temperature steps. The temperature setpoint is obtained by switching on or off the required number of heating circuits.

The main elements to be considered for contactor selection are:

- voltage, frequency,
- rated operational current,
- number of poles,

utilization category.

For heating applications:

- the voltage range is from 400V to 690V selected according to heating circuit power to limit the current and cable cross section
- the rated operational current is given by the heating circuit power and depends on the utilization category
- Number of poles is often 3 (4 poles if the neutral is distributed and needs to be interrupted),

Utilization category AC-1 according to IEC60947-4-1 [7].

In practice, most contactors have performance tested according to AC-1 and 1C-3 utilization categories.

TABLE I
CONTACTOR UTILIZATION CAEGORY

Category	Type of load	Contactor usage	Applications
AC-1	Non-inductive or slightly inductive load (cos φ ≥ 0.8)	Energization	Heating
AC-3	Squirrel-cage motors (cos φ 0.45 for Ie ≤ 100A) (cos φ 0.35 for Ie > 100A)	Starting Switching off during running	DOL, star-delta controlled motors

Along with the contactor, its protection must be selected according to the requirements of IEC60947-4-1 [7] which defines two types of permissible coordination between a contactor and its upstream protection against short-circuit currents. A short-circuit test shall be performed by manufacturers to qualify the coordination types between contactors and their protection against short-circuit current.

To satisfy Type 1 coordination, deterioration of the contactor and the relay is acceptable under two conditions:
- no danger to operating personnel,
- no danger to any components other than the contactor and the relay.

To comply with Type 2 coordination, only minor welding of the contactor is permissible, and the contacts must be easily separated. Following type-2 coordination tests, the switchgear and controlgear functions must be fully operational.

TABLE II
CONTACTOR PROTECTION COORDINATION

Type of coordination	Type 1	Type 2
Impact on heater	The controlled heating circuits is out of service, the contactor must be replaced.	The controlled heating circuit can be re-energized after the fault and its root cause elimination.
Maintenance	Qualified maintenance staff on site is required	Low impact on maintenance staff qualification. Assessment and retrofit of the contactor can be scheduled according to process convenience.
Impact on equipment to maintain continuity of service	To minimize the heating circuit unavailability drawers and switchboard form 3a minimum shall be used to enable shorter time to repair (*)	Drawers and switchboard form 3a minimum can be used to ease maintenance operations

In practice contactor switching is rarely used to operate a complete heater. Contactors operate heating circuits used to obtain the base temperature while SCR are used to regulate accurately around the temperature setpoint.

For Heating elements subject to a wide variation of their resistivity according to their temperature (Figure 8) require an accurate control of the power flux during heat-up.

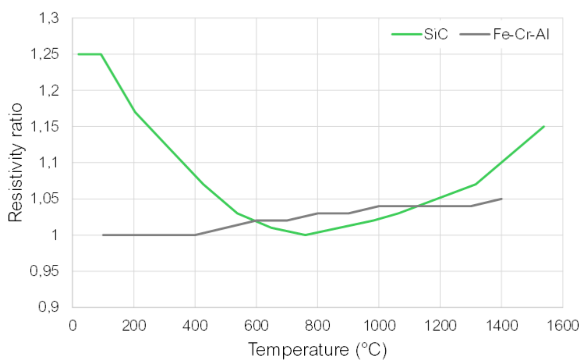


Fig. 11 Resistivity according to heating circuits material

Silicon carbide (SiC) elements usually cannot be switched by a contactor. The heat-up phase requires precise control to prevent damage caused by excessive power density. In this case, a control method using SCRs shall be used.

B. Silicon Controlled Rectifiers (SCR) in burst firing

SCR enables accurate duty-cycle regulation as well as phase-angle control.

The principle of duty-cycle modulation also called zero crossing control (or burst firing) is to switch the power on and off for a defined number of cycles within a given time frame to achieve an equivalent mean voltage over that period. On Figure 12, the duty cycle is 50% over a 200ms time frame, resulting in an average power delivery of 50% to the heating circuit during that period.

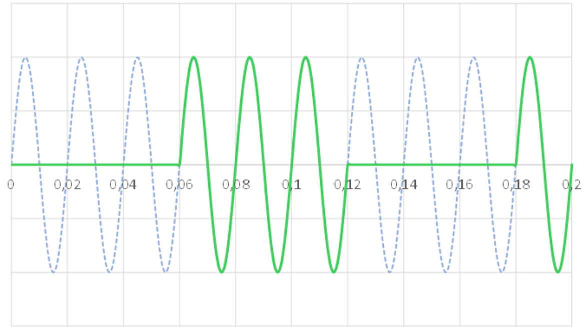


Fig. 12 Duty cycle modulation by burst firing (zero-crossing control) on phase to neutral voltage

For large power electrified heaters, it is recommended to use a minimum number of SCR to:
- prevent system voltage drop or voltage fluctuation while energizing the heater,
- enable scheduling of SCR to switch them in sequence and not simultaneously.

In this case, the heater is controlled by heating circuits that are small enough to minimize their switching impact on the voltage, and circuits control is sequenced to smooth peak power demand and minimize voltage fluctuations.

Figure 13 shows the control for a radiant heater made of 8 independent heating circuits in zero-crossing (burst firing).

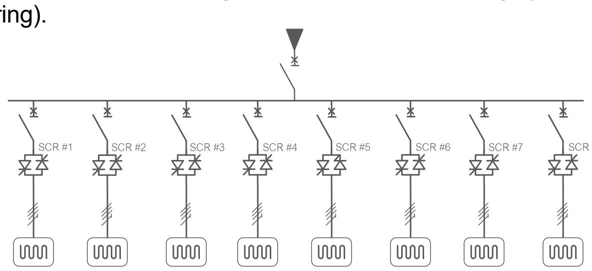


Fig. 13 Supply and control of 8 heating circuits controlled by SCRs in duty cycle (burst firing).

For an expected process temperature, a setpoint is assigned to each SCR. Without coordination or synchronization each SCR is controlled independently, resulting in fluctuating power demand (Figure 14).

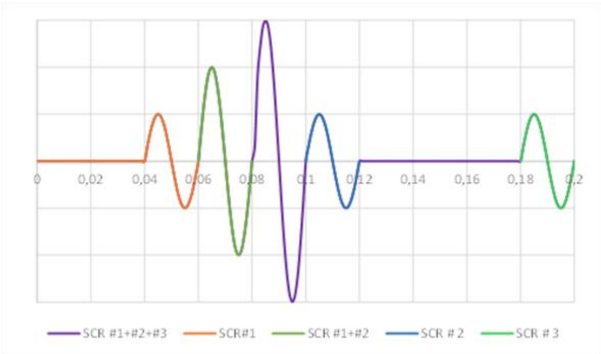


Fig. 14 Example of conduction periods of 3 SCR set at 30% without synchronization (load scheduling control)

If the 3 SCR are synchronized through a load-scheduling mode, the peak power demand is reduced, and the variations are smoothed (Figure 15).

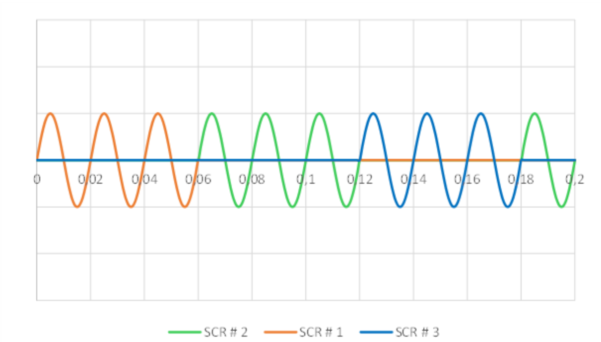


Fig. 15 Example of conduction periods of 3 SCR set at 30% with load scheduling control

C. Silicon Controlled Rectifiers (SCR) in phase angle

Phase angle control may be preferred to smoothen the start-up of heating circuit or to control accurately heating circuits power density at specific operating mode. This is the case, for example, during heating-up of silicon carbide heating circuits to ensure a limitation of the power density inside the heating element.

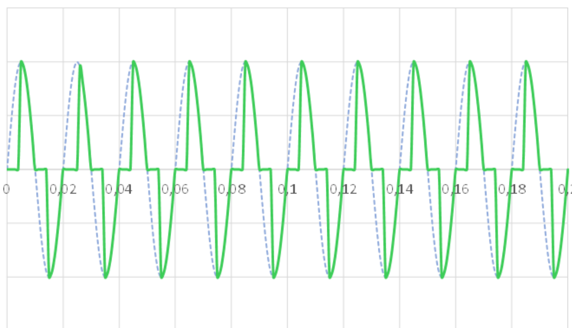


Fig.16 load voltage based on phase angle control mode

Phase angle control generates a phase shift between voltage and current delivered by the SCR, which leads to a consumption of reactive power thus impacting the power factor (Figure 17).

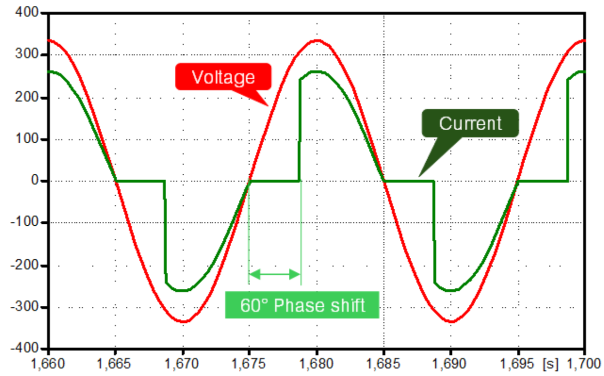


Fig.17 Phase shift between voltage and current due to a 60° firing angle of a SCR supplying a single-phase circuit

In continuous service at large scale, phase-angle controlled SCR, may impact the power quality depending on the firing angle range of evolution (Figure 18). Therefore, a power quality study shall be run to determine the impact on reactive power, voltage harmonic distortion and define mitigation solutions.

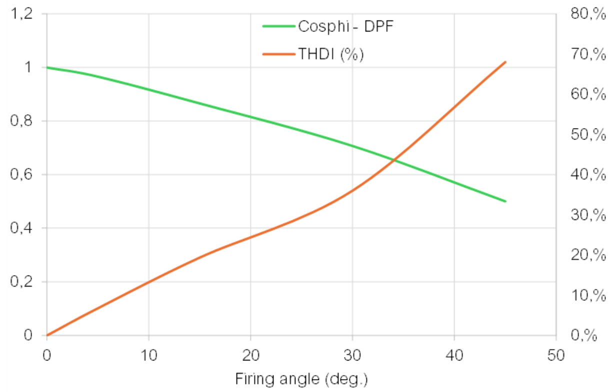


Fig.18 Power factor and current harmonic distortion according to firing angle for SCR supplying heating circuits

D. Summary of Control Technologies

Technology	Contactor switching	SCR zero cross control	SCR phase angle control
Typical range of heating circuit ratings	Up to 1000A @ LV	Up to 1500A (*) @ LV	Up to 1500A (*) @ LV
Principle	Modulation of heater capacity by steps of heating circuits ON and OFF	Duty cycle modulation of heating circuit supply voltage	phase angle control of heating circuit supply voltage
Heating circuits compliance	Heating circuits with constant temperature factor (ex: metallic type resistance)	Metallic resistance, SiC resistance under certain conditions	SiC resistance under certain conditions, MoSi resistance, direct heating
Limitations	System voltage fluctuation (i.e., flicker) as scheduling of contactors switching is complex and not accurate enough to limit the switching steps	System voltage fluctuation mitigated thanks to switching scheduling in duty cycle modulation	Harmonic distortion and power factor may be considered to evaluate the impact on installation
Operating time scale	Seconds	10^{th} of ms in duty cycle modulation	ms in phase angle control
Typical use	Radiant furnaces in association with SCR Immersed resistance	Radiant furnaces Immersed resistance Resistance for air dryer	Required for impedance heaters, and part time for SiC.

Fig. 19: Summary of Electrical Control technologies

V. Electrical Equipment for Heating Process Supply

Contactors and SCR must be installed in electrical equipment that complies with international standards, specifically the IEC61439 [8] series for LV switchgear and control gear.

A. Low Voltage Switchgear Standards

IEC 61439-1 [8] defines normal service conditions, construction requirements, technical characteristics, and verification tests. It is based on the concept of "assembly," which includes a metallic enclosure housing and combination of:

- busbars (phase, neutral and protective earthing conductors) with its associated insulators
- LV switching devices (ACBs, MCCBs, contactors, fused switches, disconnectors)
- LV control gear (relays, trip units, power meters)

IEC 61439-1 [8] defines assembly verification procedure that can be done by:

- laboratory type test (temperature rise, short-circuit withstand, voltage withstand, etc.)
- measurement (e.g. clearances and creepage distances)
- proof that the design rules given by the standard have been followed

IEC 61439-2 [8] covers power switchgear and controlgear (PSC) assemblies including:

- Functional Units (FU) such as ACB, MCCB, DOL starter, VSD, etc.

Forms of separation, meaning operator access to a FU with other parts energized, including risk of accidental contact and passage of objects (e.g. tools) from one FU to another.

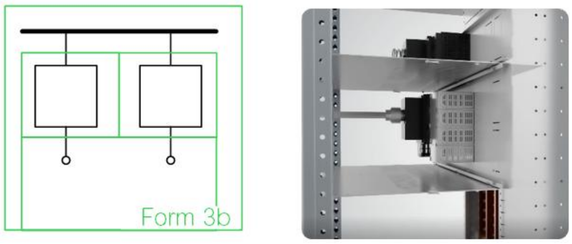


Fig.20 form 3b functional unit and its implementation

Level of service continuity (as per IEC 61439-2) defines the degree of operator safety and system availability for live circuits maintenance work and qualifies the withdrawability of functional units.

Combinations of functional unit withdrawability with panel form, result in different performances for safety and continuity of supply during maintenance.

- Withdrawable and disconnectable devices reduce the time to repair if spare parts are available on site,
- Form 3 or above, enable maintenance without a total shut-down.

High forms also limit damage and pollution propagation in the panel in case of internal arc.

B. Standardized modular equipment

The design process to build power system equipment to control and supply an e-heater can be organized in 4 steps as per Figure 21.

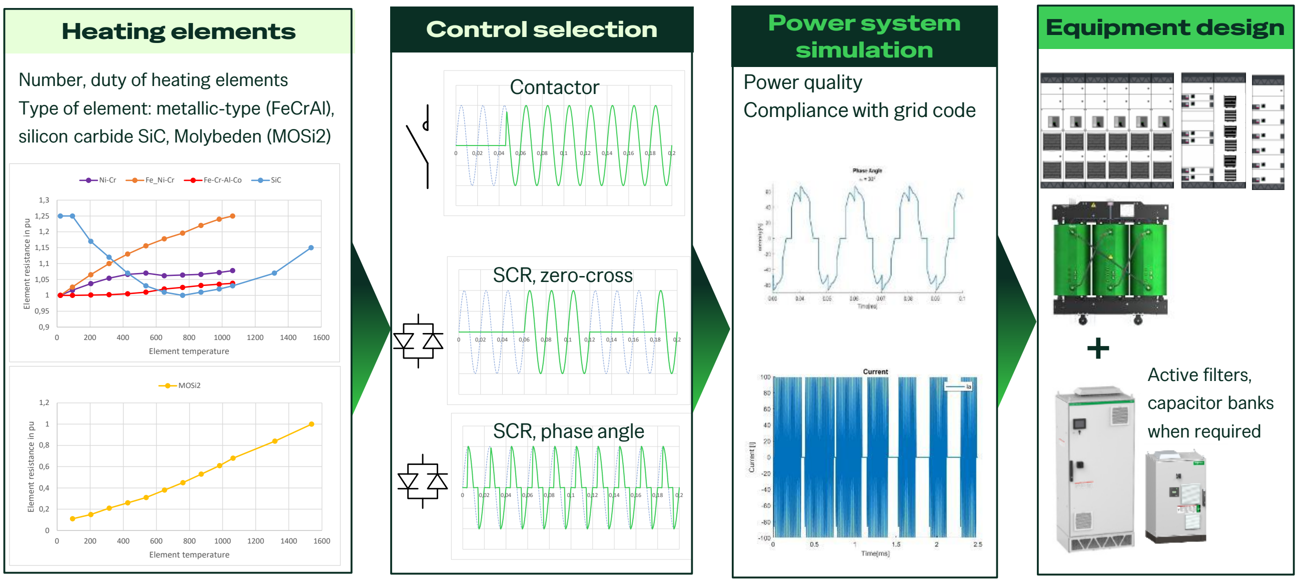


Fig. 21 the 4 steps design methodology

Once the solution is defined for a specific project the implementation can be optimized and fastened thanks to the use of standardized modular set of switchgear (Figure 17) as well as a control architecture based on functional units.

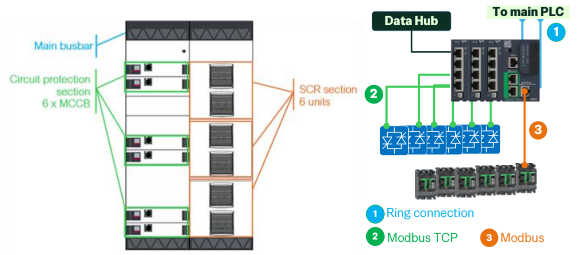


Fig.22 example of power modules for 6 SCR units and corresponding control functional units

C. Implementation

The single line diagram presented on Figure 23 has been designed to supply an electrical radiant heater for a petro-chemical application. This electrical furnace contains 60 metallic type heating circuits of various duties corresponding to different heating zones. To enable an accurate temperature regulation along the furnace zones, each circuit is controlled by a SCR.

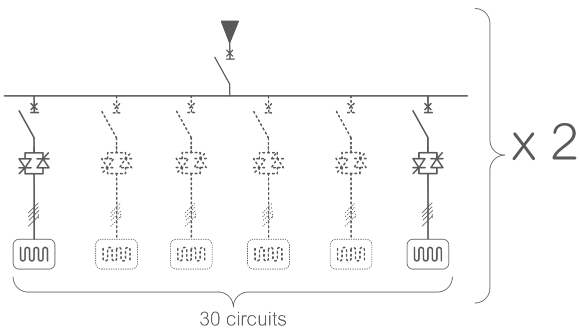


Fig.23 SLD for a 60 circuits radiant electrical heater

To minimize the site work, the choice has been made to:

- Assemble the furnace by modules on site (Figure 24),
- Deliver a prefabricated substation containing switchgear and MV/LV transformers (Figure 24 and 25).

Fig. 24: electrical heater and prefabricated substation [9]

Fig. 25: LV Switchgear with SCR inside substation [9]

II. CONCLUSIONS

Refining, Petrochemicals and Sustainable fuels production emissions originate mostly from process heating powered by fossil fuels. To reduce this industry's environmental footprint and transition towards cleaner energy, a growing opportunity is to implement electrical heating, leading to new power system applications. These technologies benefit from better efficiency, lower maintenance and more accurate temperature control compared to fired heaters.

However, multiple challenges are associated with the adoption of process heat electrification, especially the impacts on power system in terms of availability, power quality, control strategy options according to the electrical heating technology, specific requirements for safety features, compacity and modularity to be considered for implementation.

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VI. REFERENCES

[1] Concawe – CO2 Reduction technologies, 2019
[2] Fleiter et al., 2023a, forecast model.
[3] OGCI and WOOD – Pathways to Decarbonize Refining
[4] Axens Heurtey Petrochem Solutions – Electric Tubular Heater
[5] Linde Engineering – Eurpean Refining Technology Conference, 2025
[6] Parat, High Voltage Electrode Boiler
[7] IEC60947-4-1 Low-voltage switchgear and controlgear - Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters.
[8] IEC61439 Low-voltage switchgear and controlgear assemblies - Part 1: General rules, Part 2: Power switchgear and controlgear assemblies.
[9] Schneider Electric and Axens Heurtey Petrochem Solutions – European Refining Technology Conference 2025.

IV. VITA

Christian Collombet holds a MSc in Electrical Engineering from Grenoble INP. He joined Schneider Electric in 1995 and has 30 years in power system design and power system calculation software. He has authored and co-authored technical papers and chapters from the Electrical Installation Guide. He is member of IEC/TC18 WG 33, and AFNOR UF18. Christian is a distinguished technical expert in power system design.
christian.collombet@se.com

Damien Feral is the Decarbonization & Process Electrification Technology Senior Principal, Director Energies & Chemicals for the Heavy Industries Segment at Schneider Electric. He graduated from the University of Chemical Engineering and Process (ENSIC) in Nancy, France, in 2010. He is a recognized industry expert with 15 years' experience with plants operators and process licensors in Oil Refining & Petrochemicals, driving process technical support, energy efficiency, decarbonization projects and commissioning of new process units globally. In his current role, he advises the industry on the most efficient ways to decarbonize and optimize operations, especially around the electrification of their processes and assets. He has authored several technical papers on industrial processes electrification and sustainability.
damien.feral@se.com