

Techno Economic Assessment of an HTS Busbar System

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Hi-SCALE



Content

- I. TMS Paper
- II. Magnetic Compensation: Why?
- III. DC Connection Between Potline and Power Plant/Grid
- IV. Conclusion

I. TMS Paper

Where can HTS be utilized?

With simplified, slightly altered calculations



Superconductor Busbars—High Benefits for Aluminium Plants

Wolfgang Reiser, Till Reek, Carsten Räch, and Daniel Kreuter

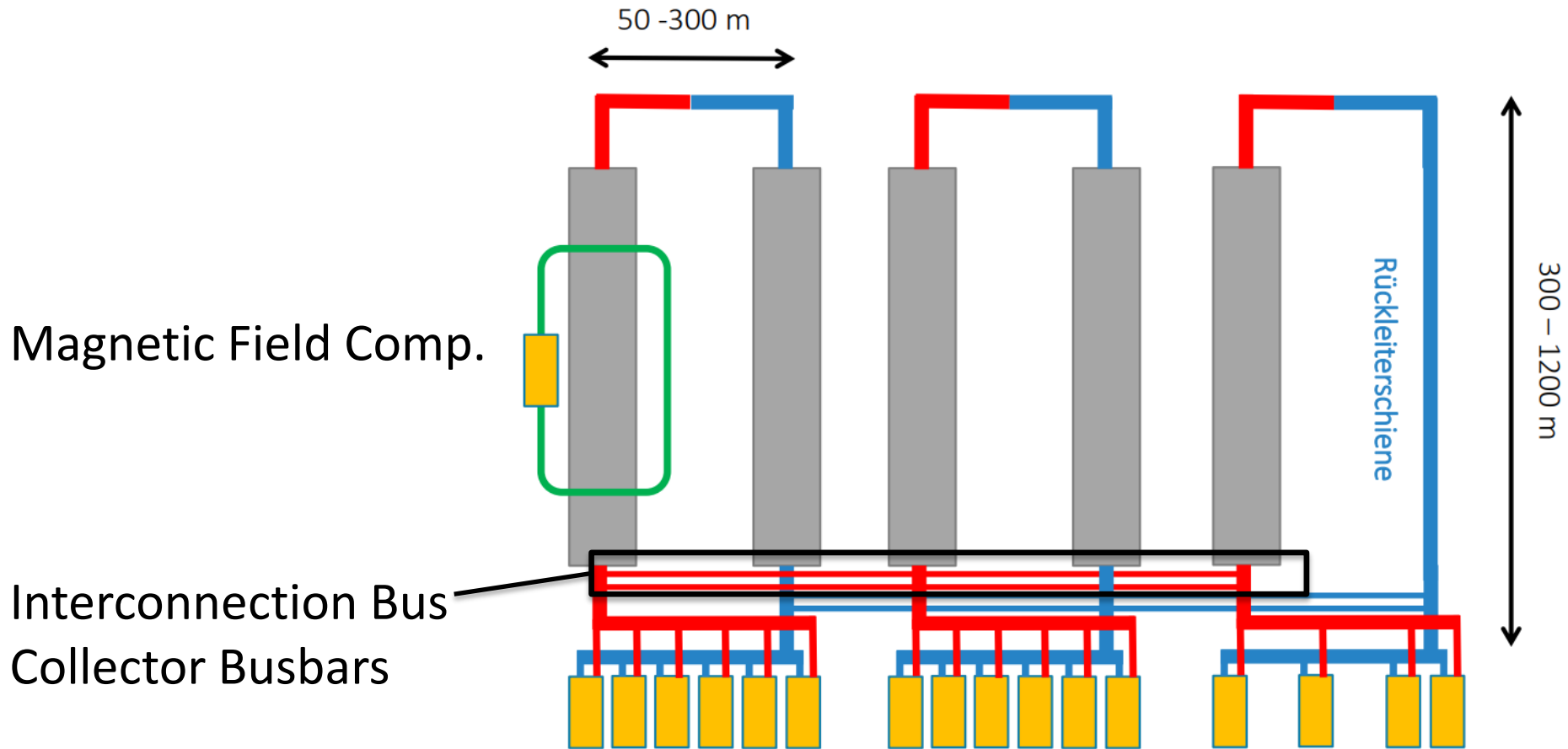
Abstract

Superconductor busbars have reached industrial readiness. Superconductors are conducting direct current with extremely high densities of more than 50 kA/cm^2 with zero losses. Due to

Keywords

Aluminium • Superconductor • Busbar • Efficiency

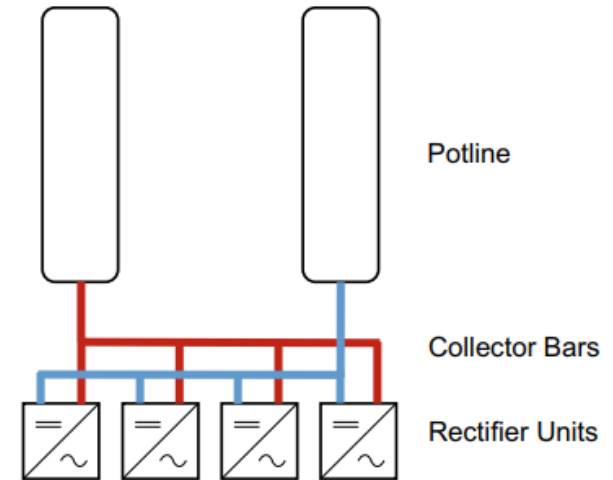
Where can HTS be utilized?



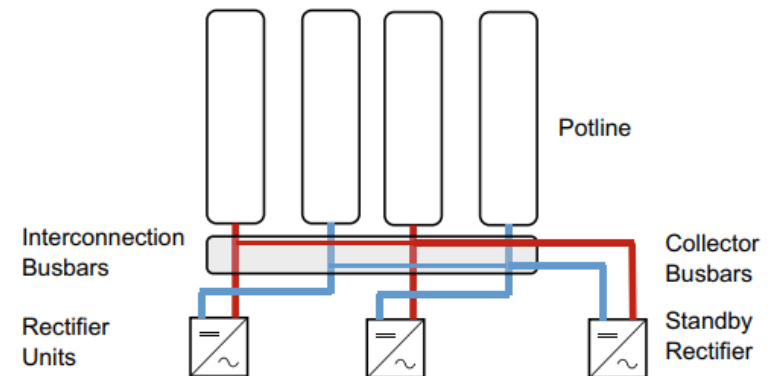
[1] earth.com/earthpedia-articles/aluminum

Where can HTS be utilized?

- Lets look at the cases:
 - Case 1: Collector Bars



- Case 2: Interconnection Bus



Where can HTS be utilized?

- Lets look at 3 cases:
 - Case 3: Magnetic Field Compensation
 - Case 4: Interconnection Bus

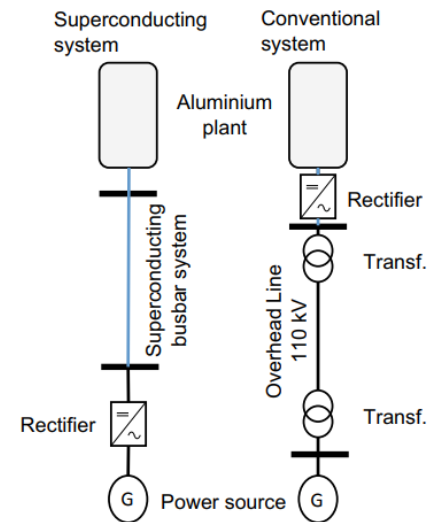
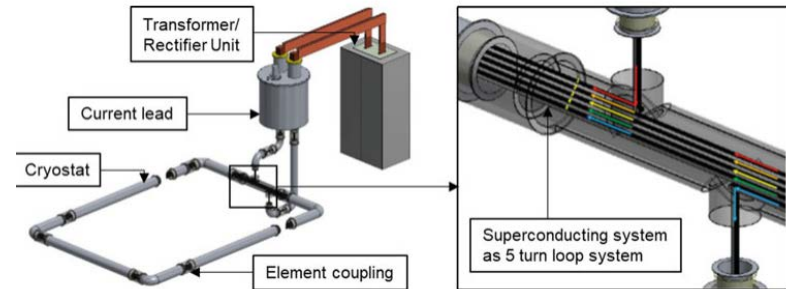
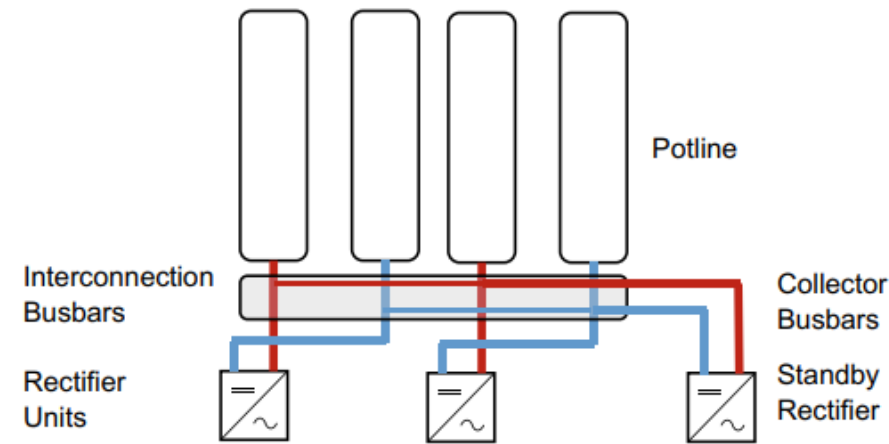


Fig. 5 Superconducting DC/overhead line connection between power source and potline. (Color figure online)

Case 2:

- Interconnection bars connect multiple potlines
- Facilitates an even electrical load
- Less current than case 1 (50 kA compared to 400 kA)
- Longer distance than case 1 (1,000 m compared to 415 m)
- How will this affect the overall **CAPEX/OPEX?**



Case 2:

Case 1: (Collector Bars)

Case 2: (Interconnection Bars)

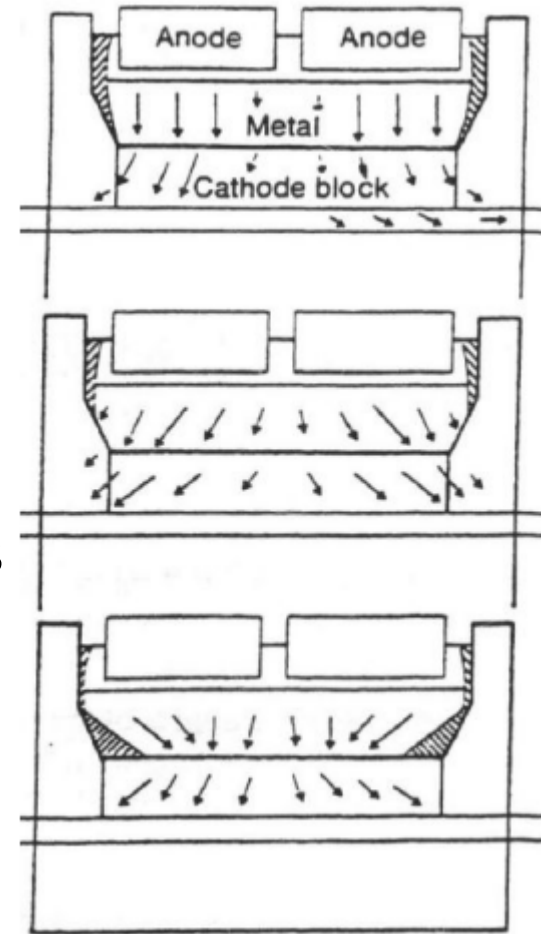
	Al busbar	SC busbar			Al busbar	SC busbar	
Nominal current	400		kA	Nominal current	50		kA
Conductor current density	0.06	50	kA/cm ²	Conductor current density	0.06	50	kA/cm ²
Conductor cross section	6,667	8.0	cm ²	Conductor cross section	833	1.0	cm ²
Conductor mass per meter	1,800	7.0	kg/m	Conductor mass	225	0.9	kg/m
System mass incl. supports & fixation	2,500	60	kg/m	System mass incl. supports & fixation	320	36	kg/m
Overall length	415		m	Overall length for 2 phases	1,000		m
Total mass (incl. LN2 for SC)	1,037,500	24,900	kg	Total mass (incl. LN2 for SC)	320,000	36,000	kg
Total electrical resistance	0.022		mΩ	Total electrical resistance	0.429		mΩ
Temperature rise above ambient	40		K	Temperature rise above ambient	40		K
Conductor temperature at nominal current	80/353	-203/70	°C/K	Conductor temperature at nominal current	80/353	-203/70	°C/K
Voltage drop at nominal current	8.9	0.3	V	Voltage drop at nominal current	21.4	0.3	V
Busbar power losses	3,557	120	kW	Busbar power losses	1,071	15	kW
Electrical power for SC cooling machines		820	kW	Electrical power for SC cooling machines		141	kW
CAPEX	6,200	17,000	k€	CAPEX	1,920	5,680	k€
Energy costs	50		€/MWh	Energy costs	50		€/MWh
Full load hours per year	8,640		h	Full load hours per year	8,640		h
Operating energy (Losses + machines)	30,700	8,100	MWh/year	Operating energy (Losses + machines)	9,300	1,300	MWh/year
OPEX	1,535	405	k€/year	OPEX	465	65	k€/year
Payback period	Base	9.6	Years	Payback period	Base	9.4	Years
TCO (Total cost of ownership over 10 years)	21,550	21,050	k€	TCO (Total cost of ownership over 10 years)	6,570	6,330	k€
TCO (Total cost of ownership over 25 years)	44,575	27,125	k€	TCO (Total cost of ownership over 25 years)	13,545	7,305	k€
TCO (Total cost of ownership over 40 years)	67,600	33,200	k€	TCO (Total cost of ownership over 40 years)	20,520	8,280	k€

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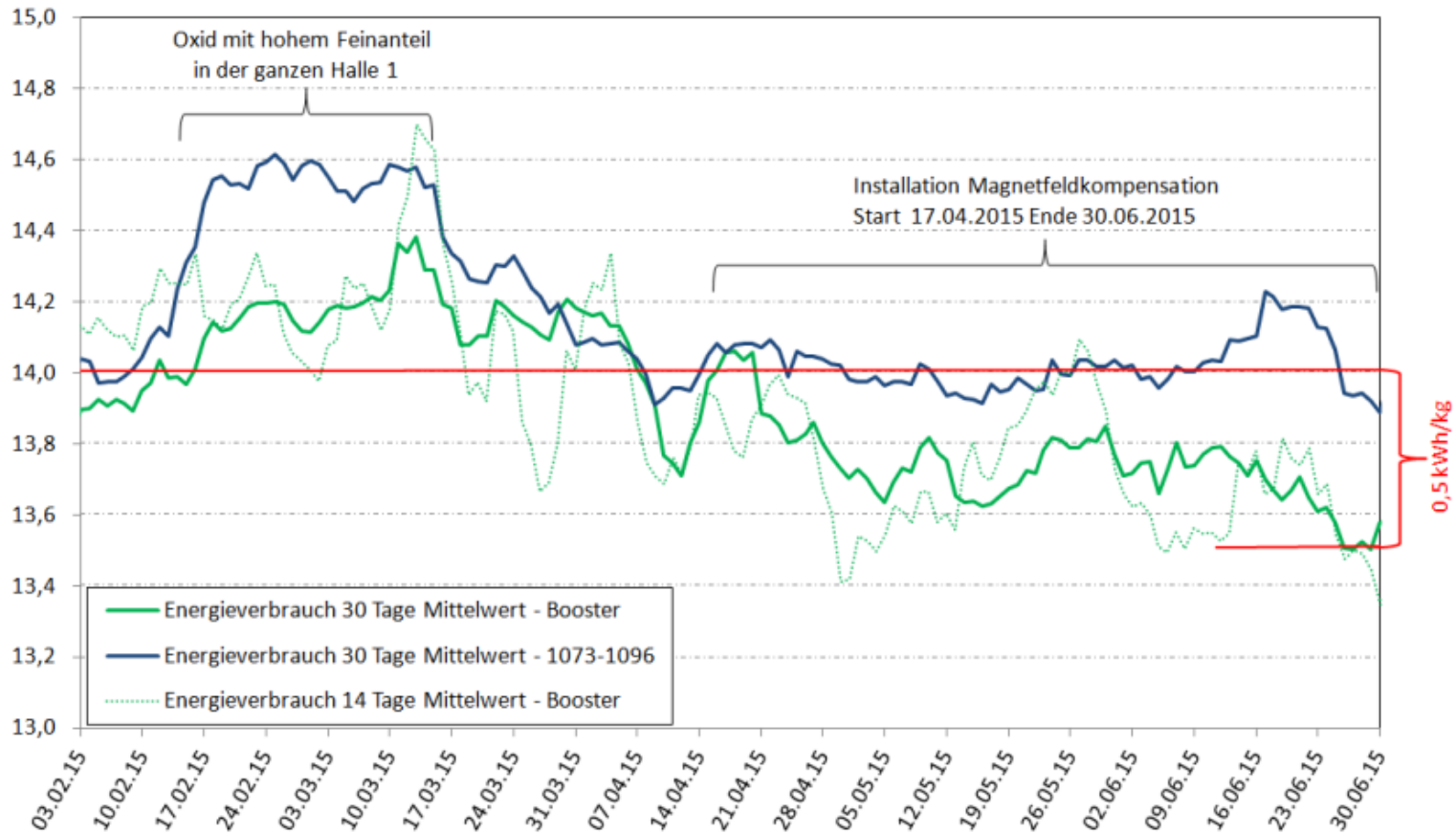
II. Case 3: Magnetic Compensation

Magnetic Field Compensation – Why?

- High currents cause high magnetic fields!
- This causes the Al in the smelter to magnetize and coalesce
- The current distribution in the smelter changes (depicted by arrows)
- Increasing the resistance of the smelter..
- ... which increases the losses



Magnetic Field Compensation – Why?



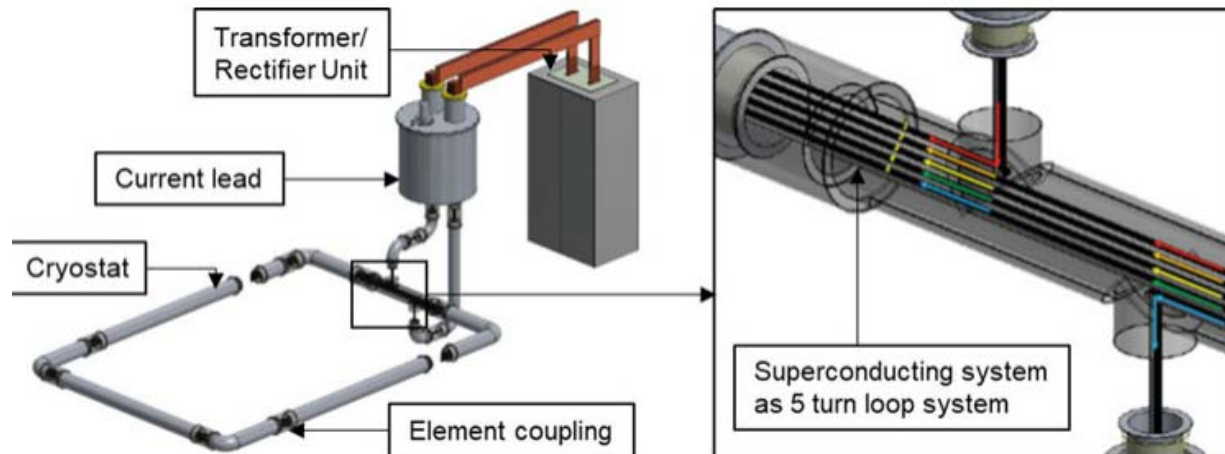
Düssel, Roman. Entwicklung eines Regelungskonzepts für Aluminium-Elektrolysezellen unter Berücksichtigung einer variablen Stromstärke und eines regelbaren Wärmeverlusts

Magnetic Field Compensation – How?

- Magnetic fields cannot be blocked, only redirected!
- The solution is to generate a counter-acting magnetic field...
- ...through a separate current
- Conventional compensation busbars are installed the pots in a hot and tight environment around the smelters
- This results in additional assembly difficulties and therefore additional costs

Magnetic Field Compensation – How?

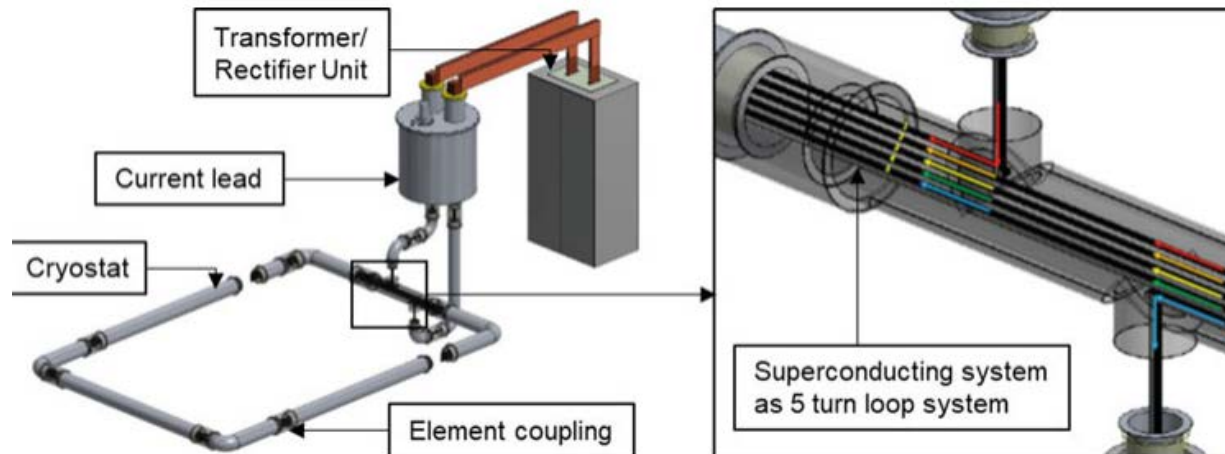
- Due to the small size of HTS busbars, these difficulties can be reduced
- Contrary to aluminum busbars, a HTS loop can be created inside the cryostat



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Magnetic Field Compensation – How?

- The additional turns increase the resulting magnetic field, similarly to an inductor
- By using 5 turns, we can reduce the operating current by a factor of 5!
- Reducing the needed power



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Magnetic Field Compensation

- Resulting benefits:
 - Reduced compensation current
 - Increased space efficiency in an already crowded industrial space
 - No additional heat is introduced
 - Minimal interference with the smelters

Magnetic Field Compensation

- CAPEX rough order of magnitude:

Needed:		Unit Price	
1	HTS	50	€/kA/m
2	Cryostat	500	€/m
3	Current Lead	2,500	€/kA
4	Cooling Machine	100,000	€/kWcool
5	Connectors, Supports, Control..	300,000	€/system
System Parameters			
a	Current	40	kA
b	Length	500	m
c	Electric Power for Cooling Machines + Losses	43	kW
d	HTS Mutual Magnetic Factor	1.5	
e	Number of current leads	1	
f	Heat Losses per m	0.002	kW/m
CAPEX Calculation			
	HTS	1,500,000	$1 \cdot a \cdot b \cdot d$
	Cryostat	250,000	$2 \cdot b$
	Current Lead	20,000	$3 \cdot a \cdot e / 5$
	Cooling Machine	100,000	$4 \cdot b \cdot f$
	Supports	300,000	5
	Total	2,170,000	

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Magnetic Field Compensation – How?

	Al busbar	SC busbar	
Nominal current	40		kA
No of turns	1	5	
Conductor current density	0.06	50	kA/cm ²
Conductor cross section	667	0.8	cm ²
Conductor mass	180	0.7	kg/m
System mass incl. supports & fixation	250	20	kg/m
Overall length of the MFC loop	500		m
Total mass (incl. LN2 for SC)	125,000	10,000	kg
Total electrical resistance	0.268		mΩ
Temperature rise above ambient	40		K
Conductor temperature at nominal current	80/353	-203/70	°C/K
Voltage drop at nominal current	10.7	0.2	V
Busbar power losses	429	8	kW
Electrical power for SC cooling machines		43	kW
CAPEX	1,250	2,200	k€
Energy costs	50		€/MWh
Full load hours per year	8,640		h
Operating energy (Losses + machines)	3,700	400	MWh/year
OPEX	185	20	k€/year
Payback period	Base	5.8	Years
TCO (Total cost of ownership over 10 years)	3,100	2,400	k€
TCO (Total cost of ownership over 25 years)	5,875	2,700	k€
TCO (Total cost of ownership over 40 years)	8,650	3,000	k€

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III. Case 4: DC Connection between Potlines and Power Plant/Grid

HTS DC-Transmission vs. Conventional AC

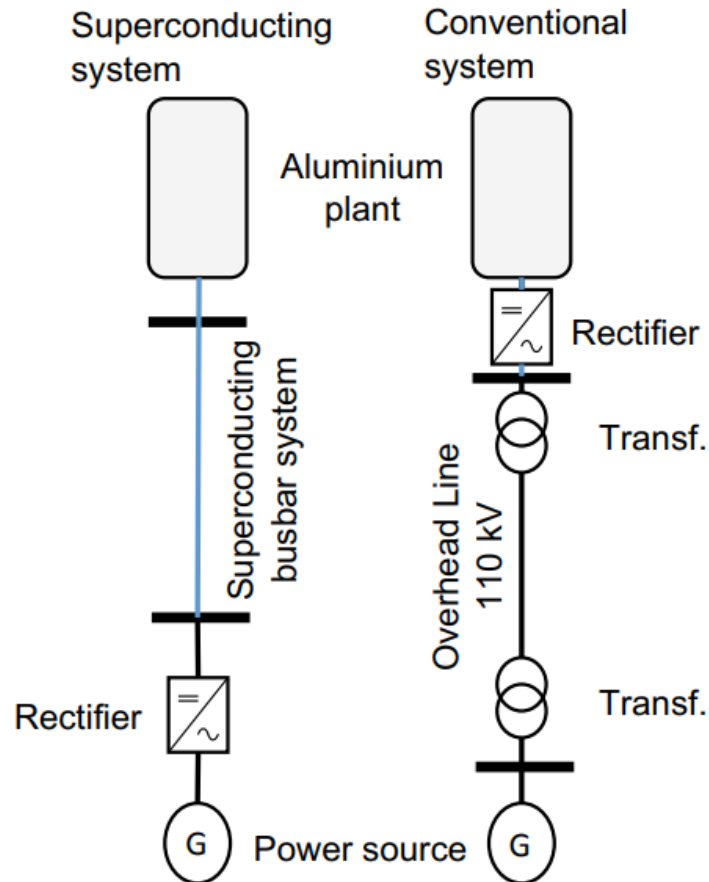
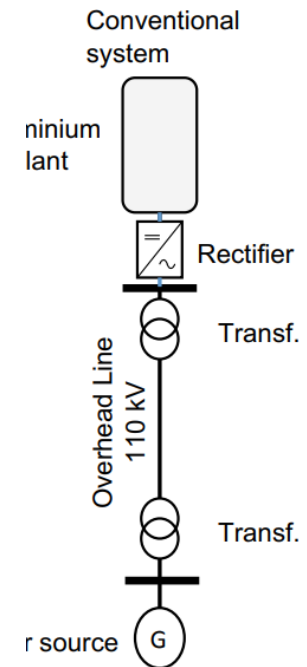


Fig. 5 Superconducting DC/overhead line connection between power source and potline. (Color figure online)

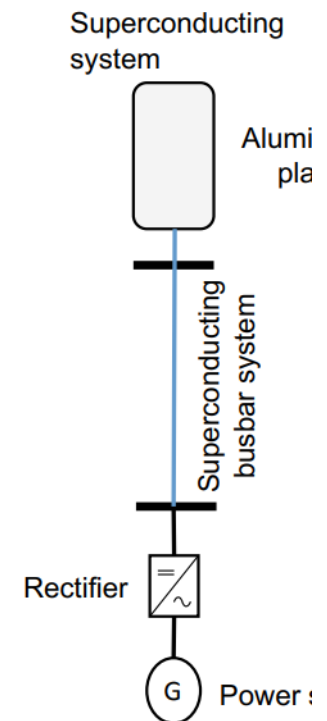
Conventional Overhead Line

- Power is provided either by grid connection or a power plant
- The distance can be several 100 ms ranging to multiple kms.
- To keep transmission losses low, a higher voltage is needed ...
- ...which results in two transformers...
- ...and an overhead line



HTS System

- Since HTS have no ohmic losses, we don't need to worry about transmission losses
- A DC transmission from the power source to the aluminum plant is possible...
- ...without the need for transformers
- No costly overhead lines are needed either
- Due to the small size of the HTS system, less construction is needed
- DC transmission also incurs no reactive power



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Case 4: Results

	Overhead Line	SC busbar	
Nominal power	400		MVA
Length of connection	1,500		m
System configuration	Transformer/Overhead Line/Transformer	SC busbar	
Nominal voltage	AC 110	DC 1.25	kV
No of phases	3	2	
Nominal current	2.1	160	kA
Conductor current density	0.1	50	kA/cm ²
Conductor cross section	21.0	3.2	cm ²
Resistance of 1 Phase OH-Line at 80 °C	15.5		mΩ
Power Losses OH-Line, 3 Phases	230		kW
Transformer efficiency	99.6%		
Power losses two transformers	0.8%		
Power losses two transformers	3,200		kW
Voltage drop of SC Busbar		0.3	V
Busbar power losses	3,430	96	kW
Electrical power for SC cooling machines		696	kW
CAPEX	18,000	22,100	k€
Energy costs	50		€/MWh
Full load hours per year	8,640		h
Operating energy (Losses + machines)	29,600	6,800	MWh/year
OPEX	1,480	340	k€/year
Payback period	Base	3.6	Years
TCO (Total cost of ownership over 10 years)	32,800	25,500	k€
TCO (Total cost of ownership over 25 years)	55,000	30,600	k€
TCO (Total cost of ownership over 40 years)	77,200	35,700	k€
<i>Special case at 500 m distance</i>			
CAPEX	14,000	13,400	k€
Energy costs	50		€/MWh
Full load hours per year	8,640		h
Operating energy losses	28,200	6,000	MWh/year
OPEX	1,410	300	k€/year
Payback period	Base	CAPEX LOWER	

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Merci !