Current Topologies of Traction Substations for 25kV Railway Electrification

Martin Pittermann
Department of Power Eletronics and Machines
University of West Bohemia
Pilsen, Czech Republic
pitterma@fel.zcu.cz

Vojtech Blahnik
Regional Innovation Center for Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
lucke@fel.zcu.cz

Milos Straka
Regional Innovation Center for Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
strakami@fel.zcu.cz

***Abstract*—The paper is focused on AC railway traction system 25kV / 50Hz (respectively 60Hz). Currents progress at fields of power electronic allows to use semiconductors converter as a part of traction substations. It brings more advantages for operation modes of TSS (symmetrization, compensation, filtration, TSS cooperation, recuperation, etc.). The most promising topologies are described in the second half of the paper. The main benefit of the paper is comparison of TSS selected topologies.**

***Keywords*—AC traction substation, power converters, electrical railway topologies**

I. Introduction

Nowadays are exclusively electrical railways with voltage level 25kV / 50Hz under the construction in most of Europe. This trend is due to the modernization of the old electric railway due to the potential of using modern high-speed electric vehicles and vehicles achieving higher performance for passenger and freight transport. [1] Many TSS topologies with different characteristics can be used to power this infrastructure.

The operation of TSS must fulfill at the point of common coupling appropriate parameters determined by provides of the distribution grid, under the threat of penalty. For this reason, it is necessary to take care about symmetrization compensation, filtration and another problem of the railway. TSS topologies are diverse in term of use of neutral section somewhere in the traction section, operation of TSS in case of fault and so on. Complexity of whole topology determines reliability of devices and at the same time goes hand in hand with price.

II. Classification of TSS for 25kV / 50Hz

One of possible classification how to sort of TSS is shown in Fig. 1. The basic dividing is with or without a power electronics. Another dividing is in terms of topology and properties. The topologies are discussed in individual chapters.

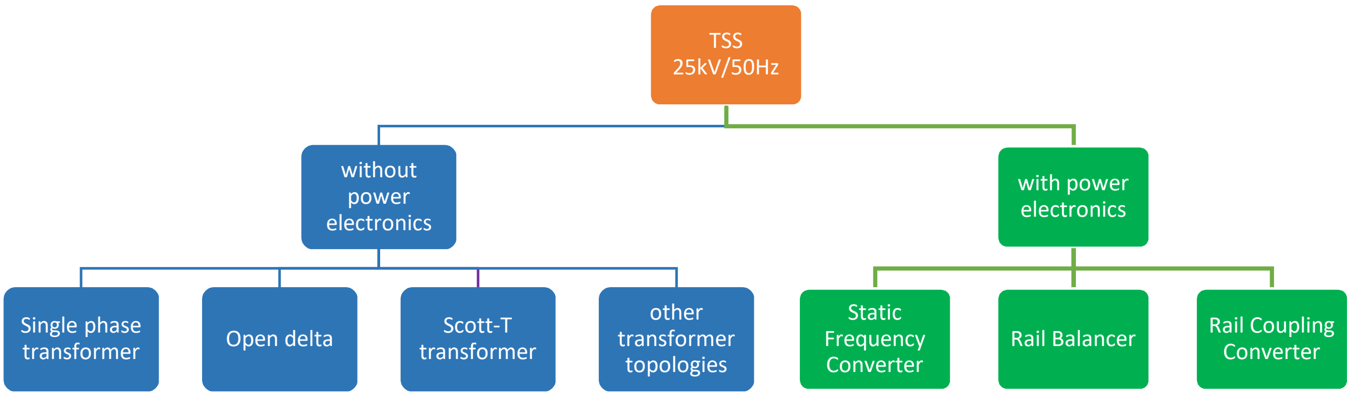

Fig. 1: Classification of TSS for 25kV / 50 Hz system

III. Topologies without Power Electronics

A. Single phase transformer

Single phase transformer shown in Fig. 2, is the most basic and simplest topology used for railway infrastructure powering. The transformer is connected to line to line voltage is robust low-cost topology. This connection is used in TSS which catenary ends. Due to the nature of the connection, it is not possible to gain symmetrical three phase consumption. Compensation and filtration of harmonics of higher order has to be done by an additional device.

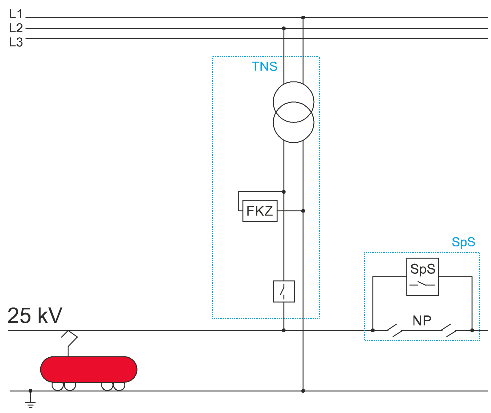

Fig. 2: Single phase transformer

ISBN 978-80-261-0973-0, © University of West Bohemia, 2021

B. Open delta configuration

The open-delta configuration (known as V/V configuration) is currently commonly used for 25kV/50Hz in the Czech Republic. This topology is based on two single phase transformers connected to two different line to line voltages as shown in Fig. 3. Each of these transformers supplies a different traction sections, which are separated by neutral section (NP) to avoid of circulating current. For the same case are installed neutral section in the middle of traction section to which is switching station (SpS) parallelly. Switching station is there for case, when supply transformer is shut down for a reason. A necessary part for this topology filtration and compensation device (FKZ) takes care of the reactive power of the load and harmonics of higher order.

The main advantage of this connection is simplicity, high efficiency due to transformer losses only and low purchase price. The disadvantage is asymmetrical current consumption of the distribution power grid and compensation is available with an additional device only same as well as a filtration of harmonics of higher order. Symmetrical currents are ensured if certain requirements are met.

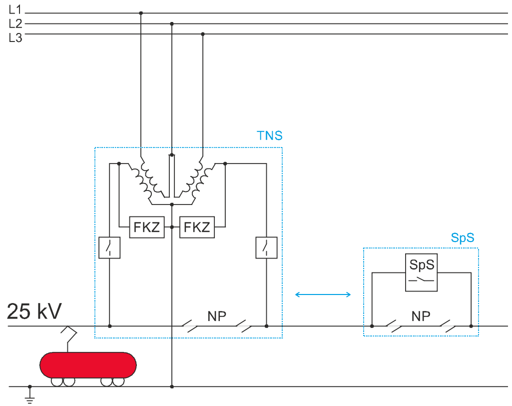

Fig. 3: Open delta configuration

C. Scott-T transformer

Fig. 4 shows a Scott-T connection which is transformer with special winding construction used to transform three phase system into two phase system. Each of the secondary winding feeds a different traction section. When the loads are equal on the both sections, it is handled symmetrical consumption from the distribution power grid. For compensation and harmonic of higher order filtration is necessary to use additional device.

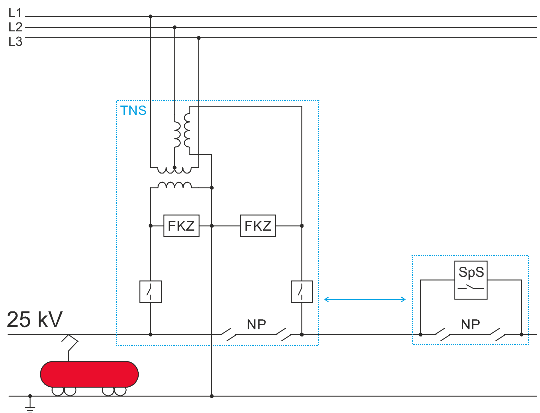

Fig. 4: Scott-T transformer

D. Other transformer topologies

Other transformer topologies used in traction substations, has a special winding construction creating from a three phase system a two phase orthogonal as mentioned Scott-T transformer. Between those topologies are for example Woodbridge, Le-Blanc, Roof-delta or Impedance matching. [2][3]

IV. Topologies with Power Electronics

A. Static Frequency Converter

The SFC topology of TSS enables cooperation with others TSS even with different topologies. Thus, this topology allows the use of a continuous catenary as shown in Fig. 5. The main advantage of this topology is ability of compensation of reactive power of the load and filtration of harmonics of higher order without another additional devices. Thanks to active rectifier on the input of device (AFE – active front end) is handled symmetrical current consumption from the distribution power grid and enabled controlled bi-directional active power transfer (in case of recuperation possibility).

Undeniable disadvantage of the topology, is that in case of fault one of component it has to be whole TSS shut down. The purchase price is significant in compare to other topologies due to necessary of dimensioning to full through power and duplication of transformer and semiconductor converters. ABB company deployed this topology in Wulkuraka, Australia or transportable variant in Oslo, Norway. [4][5] Siemens offer this topology named as Sitras SFC plus operated in Germany, Austria, Switzerland and Sweden. [6]

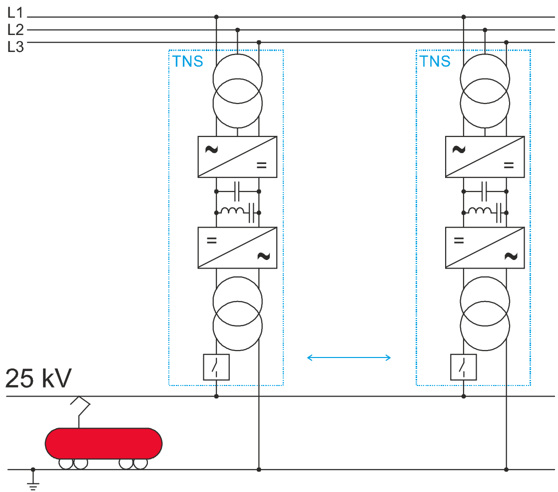

Fig. 5: Static Frequency Converter

B. Rail balancers

Sitras® RAB plus (Fig. 6) is one of the active balancers used to symmetrize the power of a single-phase load to a three-phase symmetrical load. The rail configuration is a semiconductor variant of Steinmetz triangle used to symmetrize a single-phase load. Instead of a passive component, three multilevel semiconductor converters are used, which are able to change their impedance character in individual branches through the control structure. [7]

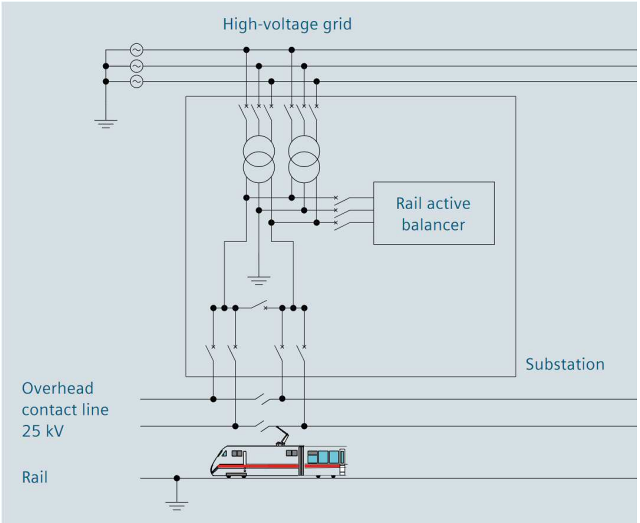

Fig. 6: Sitras RAB plus configuration

SVC (Static Var Compensator) serves, as the name suggests, to compensate of reactive power similar as the RAB, but using passive components. [8] Semiconductor devices can be used to turn passive or phase-controlled components on and off. [9] Fig. 7 shows the use of SVC for Channel Tunnel, where phase control is used of reactors. [10]

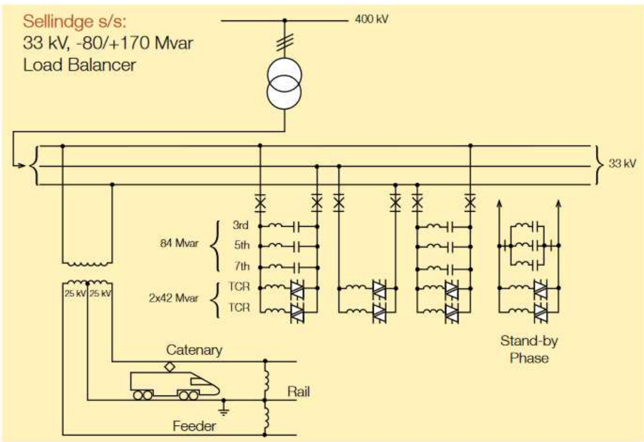

Fig. 7: The Channel Tunnel (picture was taken from [10])

C. Rail Coupling Converter

Rail coupling converter are mainly used in railway for power transfer between adjacent sections. The basic of most topologies is the same. A back to back topology allowing the transfer of power from one section to another, where is consumed by a traction vehicle or stored to an accumulation component in a DC-link. The topology allows with the power transfer the current balancing or filtration of harmonics. Depending on the type of power supply, the transformer can also serve as a backup power supply for the section that cannot be supplied directly by the transformer in a fault. [11] [12]

V. Advanced Rail Balancer

Advanced rail balancer contains a common three-phase transformer with three branches of semiconductor converters connected to a triangle and to line-to-line voltage and Phase Shifting Device. PSD done by PST or Serial Line Conditioner shown in Fig. 8. Each converter branch is composed by a n number of CHB. This topology is based on Steinmetz method of symmetrization. [13] By the converters we are controlling the currents flow through them so the currents flow the distribution power grid are the same in phase with its line voltage. The Phase Shift Device handle the cooperation with neighbors TSS without a necessary of neutral section in the traction section. By the PST we are also able to control the currents flows from the individual TSS feeds a load.

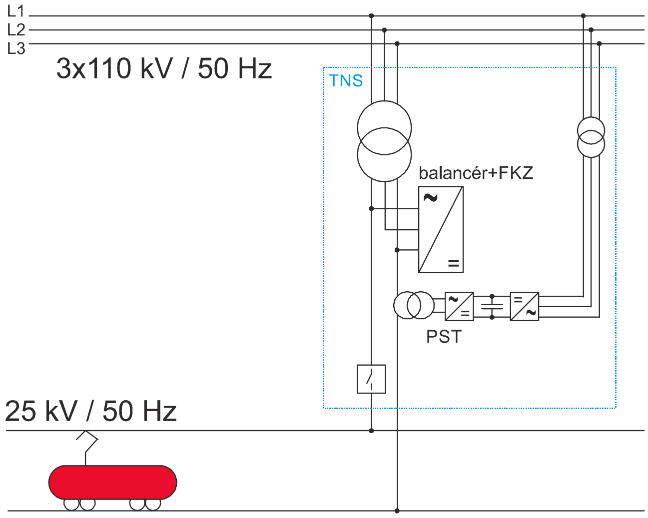

Fig. 8: ARB topology

VI. Compararison

The presented topologies are compared from several point of view:

- Symmetrization - evaluation of the grid currents symmetry
- Compensation - evaluation of reactive power compensation possibility
- Filtration - evaluation of filtration of harmonic components possibility
- Neutral section - comparision in terms of use of neutral section (possibility of continuous catenary use). This aspect is divided to two options: neutral section near of TSS and neutral section between two TSS (with switching station)
- Fault operation - evaluation of TSS operation in case of failure of the semiconductor converter. The emergency operation capability is awarded by "-" and necessary the TSS disconnection by "- -".
- Reliability - reliability assessment is related to the complexity of the entire TSS device. We assume lower reliability of semiconductor converters against transformers
- Economic costs - Aspects covered under this point include: acquisition costs, maintenance costs, life and environmental disposal costs

TABLE I. Comparison of individual topologies

	Symme-trization	Compen-sation	Filtration	Neutral section		Fault operation	Reliability	Economic costs
				Between TSS	Near TSS			
1p TR	- -	-	-	- -	+ +	0	+ +	+ +
Open delta	-	-	-	-	- -	+	+ +	+ +
Scott-T	0	-	-	0	--	0	+	+
SFC	+ +	+	+	+ +	+ +	--	- -	- -
RAB 1s	+ +	+	+	0	-	-	0	0
RAB 2s	+	+	+	-	- -	-	0	0
SVC 1s	+ +	+	+	0	-	-	+	0
SVC 2s	+	+	+	-	- -	-	+	0
RCC	+ +	+	+	+	-	-	- -	-
ARB	+ +	+	+	+ +	+ +	-	-	-

VII. CONCLUSION

The paper provides an overview and comparison of commonly used topologies with advanced TSS topologies for the 25kV, 50Hz electrical railway system. The primary properties of the selected TSS topologies that were assessed are listed in TABLE I.

Nowadays, an SFC topology is often preferred, which has good behavior in terms of symmetrization, compensation, filtering, and the need of a neutral section. However, the complexity of the system also brings a disadvantage in the form of lower reliability, high purchase price.

The main disadvantage is the inability to work in case of failure of one part of the SFC chain. Due to the ARB configuration is more than comparable because it retains the benefits of SFC, but in the event of a balancing unit failure, it is possible for TSS to still run and buy it at a lower price. For these reasons, the topology is currently being developed in the Czech Republic.

ACKNOWLEDGMENT

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the project OP VVV Electrical Engineering Technologies with High-Level of Embedded Intelligence CZ.02.1.01/0.0/0.0/18_069/0009855 and under project SGS-2021-021.

REFERENCES

[1] A. Steimel, Electric traction - motive power and energy supply: basics and practical experience, 2nd edition. München, germany: DIV Deutscher Industrieverlag GmbH, 2014. ISBN 978-3-8356-7257-4

[2] H. Morimoto, T. Uzuka, A. Horiguchi and T. Akita, "New type of feeding transformer for AC railway traction system," 2009 International Conference on Power Electronics and Drive Systems (PEDS), 2009, pp. 800-805, doi: 10.1109/PEDS.2009.5385659.

[3] M. Tanta, V. Monteiro, T. J. C. Sousa, A. P. Martins, A. S. Carvalho and J. L. Afonso, "Power quality phenomena in electrified railways: Conventional and new trends in power quality improvement toward public power systems," 2018 International Young Engineers Forum (YEF-ECE), 2018, pp. 25-30, doi: 10.1109/YEF-ECE.2018.8368934.

[4] ABB. (2016) Static frequency converter supports 50 Hz rail network. (Application Note 3BHS987050 E01) Retrieved from ABB website: https://search.abb.com/library/Download.aspx?DocumentID=3BHS987050%20E01&LanguageCode=en&DocumentPartId=&Action=Launch

[5] ABB. (2018) Modular and transportable static frequency converters (SFCs). (Application note 3BHS987016 E01) Retrieved from ABB website: https://search.abb.com/library/Download.aspx?DocumentID=3BHS987016%20E01&LanguageCode=en&DocumentPartId=&Action=Launch

[6] Siemens. (2018) Sitras SFC plus static frequency converter (Product information No.A6Z00016046063) Retrieved from Siemens website: https://assets.new.siemens.com/siemens/assets/api/uuid:34846022-3f14-41de-ad46-d4c66a3e004c/siemens-sitras-sfcplus-pi-en.pdf

[7] Siemens. (2018) Sitras RAB plus rail active balancer (Product information No.A6Z00036124075) Retrieved from Siemens website: https://assets.new.siemens.com/siemens/assets/api/uuid:4c1373d1-898d-48f1-9f8a-a4471820470b/siemens-sitras-rabplus-pi-en.pdf

[8] Siemens. (2018) Sitras RVC plus mobile rail VAR compensator (Product information No.A6Z00036124075) Retrieved from Siemens website: https://assets.new.siemens.com/siemens/assets/api/uuid:5033ab7e-5fac-4530-9328-15cc033803ab/siemens-sitras-rvcplus-pi-en.pdf

[9] K. Vaclav and S. Bohumil, "Effect of filter and compensation unit in the traction power supply at extreme distortion," 2013 International Conference-Workshop Compatibility And Power Electronics, 2013, pp. 7-12, doi: 10.1109/CPE.2013.6601120.

[10] ABB. (2010) SVCs for load balancing and trackside voltage control. (Product information) Retrieved from ABB website: https://library.e.abb.com/public/c9f996d4f6c5c601c12570c9004b1754/A02-0196%20E%20LR.pdf

[11] M. Tanta, J.G. Pinto, V. Monteiro, A.P. Martins, A.S. Carvalho, J.L. Afonso, "Topologies and Operation Modes of Rail Power Conditioners in AC Traction Grids: Review and Comprehensive Comparison," *Energies* 2020, *13* (9) : 2151. https://doi.org/10.3390/en13092151

[12] B. Chen, C. Zhang, W. Zeng, C. Tian and J. Yuan, "An electrical-magnetic hybrid power quality compensation strategy for V/V traction power supply system," 2014 IEEE Energy Conversion Congress and Exposition (ECCE), 2014, pp. 3774-3779, doi: 10.1109/ECCE.2014.6953914.

[13] V. Blahnik, M. Pittermann, M. Straka, "Operating States of Load Balancer for AC Traction Substation Based on CHB Topology", 19th IEEE-PEMC, Gliwice, Poland 2021