Introduction of power electronics in traction power supply fixed installations

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Abstract
After an explanation of the requirements related to power supply fixed installations, it is shown how today power electronics offers reliable solutions in competition with classical electro technical implementation strategy. These power electronic devices make it possible to avoid heavy installations, and allow a better use of the infrastructure, e.g. traffic increase. Examples of installations are shown, be it in dc or ac electrification systems.

1. Present situation of use of power electronics in railways
In the railway world, power electronics is particularly used in the domain of rolling stock. Converters of traction units are well known. For decades, their evolution is impressive and demonstrates that the world of new components is perfectly adapted to the needs of electric traction.
From the first ignitron, to the present IGBT’s, five decades of research have led to such a progress in terms of power, quality of the wave and in convergence to one of the power factor. IGBT’s have allowed managing power in three phase asynchron motors which was difficult and costly to be made with GTO’s.
But, today, seen from the power supply fixed installations side, power electronics is used very seldom, except for rectifiers. On board of a traction unit, need of variable speed, very small room, absence of three phase network made it difficult to use and drive three phase motors with conventional electro techniques. To solve this, power electronics was especially well adapted. These arguments are not valid for on site installations. No necessity to have variable voltage to manage motors, large available surfaces, has not shown necessity to use these systems. Moreover, classical systems present lower investment and life cycle costs compared with complicated power electronics systems which need a constant surveillance. Nevertheless, due to evolution of conditions - technical, environmental and financial - to be met in the field of connexion to the three phase grid, or due to quality of power supply in terms of level of voltage in the overhead line, reliability and availability, it had become interesting to introduce power electronics on site.

2. Power electronics within traction fixed installations
   a. General
The power supply systems used in Europe demonstrate the historical evolution of electro techniques since the beginning of the 20th century. DC systems were used, allowing rotating machines to convert ac to dc, and dc was directly usable by the traction units equipped with dc motors. AC 16, 7 Hz needed a direct power generation in this frequency or a conversion from 50Hz through rotating machines, but the traction units could absorb this 16,7Hz energy with dc direct motors. In the 50’s, it became possible to rectify current on board, as well as to rectify current in substation by the use of the first diodes. It allowed a substantial increase of the power of sub-stations. AC 50Hz electrification can pick up energy from the mains with a very simple, reliable and efficient diagram.

   b. Requirement of traction power supply
Traction power supply has some important constraints: structurally, it is a system with one active conductor wire and rails for return current. Electrically, with the requirements coming from power suppliers, there is a necessity to reduce strongly any disturbance in terms of quality of
the electrical wave: harmonics, phase unbalance, flicker: a perfect consumer is wished! On the other hand, trains are moving and the impedances seen upstream by a traction unit change at any moment. Also, harmonics generated by traction units will also flow through variable impedances creating a risk of instability of the network with over voltages as a consequence. As a matter of fact, any fixed system working with power electronics will have to be assessed towards EMC, particularly against track circuits for signalling purposes. With all these requirements, it is always possible to fulfill them by implementing classical electro technique solutions such as increasing the short circuit power by building new HV transmission lines, new sub stations. But often, such hard and costly installation would be oversized with the effective need and therefore power electronics will offer an adjusted solution. This participates to a reduction of the impact on the environment if it avoids new construction of HV lines and substations. Next paragraph will describe the functions that power electronics can offer. Figure 1 shows where power electronics can be used in a power supply system.

Figure 1: power supply systems and possible use of power electronics

**c. Main components used**

The table 1 hereafter shows what the properties of semiconductor valves used for fixed installations.

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3. DC electrified network applications

a. Rectifiers

Since the diodes are implemented on a large scale in rectifiers in dc sub-stations, it has been demonstrated that they are very reliable with a low life cycle cost.

In order to reduce the harmonic content of the current on the primary side, the phase index of the rectifier can be increased.

b. Inverters

When trains regenerate, it may be interesting to send back energy to the mains. With dc electrification, this needs a converter with inverter function. Such inverters are costly, and generally the regenerated power is consumed by other trains.

c. Switchgear

Breaking a dc current is always a difficult task. Until now, electromechanical circuit breaker are on the market. Some example of very high speed breakers have been built, with interesting characteristics such as a breaking time close to 2 ms. This was possible through the switching on of a thyristor in a circuit.

d. Electronic “autotransformer”

DC electrified networks need numerous substations and the voltage drop in the traction circuit is significant. In case of increase of power demand (increase of headway, traffic, speed), it becomes difficult or expensive to implement the necessary and additional installations such as substations.

With power electronics, implementation of new converters that allow voltage conversion makes it possible to increase power transmission from the substation to the trains. This may avoid the

<table>
<thead>
<tr>
<th>Voltage drop</th>
<th>Diode</th>
<th>Thyristor</th>
<th>GTO</th>
<th>IGBT</th>
<th>IGCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 V (4000A)</td>
<td></td>
<td>3 V (4000A)</td>
<td>3 V (4000A)</td>
<td>5 V (600A)</td>
<td>2 V (4000A)</td>
</tr>
<tr>
<td>Working frequency</td>
<td>50 Hz</td>
<td>50 Hz</td>
<td>&lt; 500 Hz</td>
<td>&lt; 2000 Hz</td>
<td>&lt; 2000 Hz</td>
</tr>
<tr>
<td>Command</td>
<td>/</td>
<td>Current</td>
<td>Current</td>
<td>Voltage</td>
<td>Current</td>
</tr>
</tbody>
</table>

Table 1: main characteristics of valves
construction of a new substation, as well as new high voltage transmission lines. It therefore participates to the energy efficiency and sustainable development policy. The technical research consists, very simply, in implementing on the fixed side of the railway system what is already in service in traction units: e.g. converters of locomotives which allow the reversible “transformation” of 1,5kV dc into 3kV dc. Of course, it is not only a simple adaptation, it is a research taking into account the latest semi conductors evolution, and the requirements from the infrastructure side which are different from the one of rolling stock.

Research which has been done until now show that voltage drop is strongly reduced by 2 for the equivalent traffic [2]. The converter is equipped with IGBT in a structure described in figure 2 above and represented in figure 3:

![Figure 2: Example of an «electronic « autotransformer »](image)

This prototype has demonstrated that it was feasible that IGBT’s can be cooled with a caloduc, which provides a significant reduction of cost through simplification of cooling system avoiding a pump and water circuit.

![Figure 3: layout of equipment](image)
4. AC electrified network applications

a. Balancer and active filtering

Supplying single phase circuit from a three phase network has always been subject to power limitation, generally with single phase energy lower or equal than 1% of the three phase short circuit power. This leads to connect the railway sub station to higher voltage network, where connexion on lower voltages would be enough if the power consumption would be balanced on the three phases.

On the French National Rail Infrastructure, in order to allow an increase of traffic and avoid the construction of a new line, RFF and SNCF, with RTE power supplier, implemented a balancer supplied by ABB Sweden. Its function is to balance on a 500 MVA short circuit power network a single phase of 17 MVA with a maximum residual unbalance of 1%. The equipment, called SVC light, first application for railway, is equipped with 120 IGBT’s and is water cooled. It’s performance allows also active filtering up to harmonic rank 9. Figure 4 shows, through measurement, the effect of balancing the single phase load. Figure 5 shows, through measurement, the effect of active filtering. Figure 7 shows the IGBT’s with water cooling system. Figure 8 gives an overview of the device.

Figure 4: measurement of the effect of balancing (left without balancer; right with balancer)
Figure 5: measurement of the effect of filtering (left without active filtering; right with)

Figure 6 shows the harmonic content generated by the balancer, in function of the forbidden area of the track circuit. Studies, setting of the command of IGBT’s and measurement have demonstrated that track circuit are not influenced

Figure 6: current in track circuit (over blue line: forbidden zone)
Figure 7: IGBT’s

Figure 8: the Evron Balancer (France)

Figure 9 gives currents in each 90kV phase without load balancer (above) and with it (below).
b. HVB or SVC

Recent research programs in Europe have allowed implementing a so-called High Voltage Booster “HVB” or SVC. Its function consists in compensating voltage drops in the Overhead line – rails loop by a controlled injection of reactive energy. In France and Great Britain, some units are installed and many projects plan to do so. It also avoids construction of new substation and allows an optimization of the traction energy system [3].

The HVB device is a continuous reactive power compensator and consists of three branches: the thyristor controlled reactor (TCR), the third harmonic filter and the low pass filter. The capacitor banks of the filters provide the fixed leading VAR supply while the TCR provides the required lagging VAR supply. The TCR branch includes the two main air-core reactors that provide the rated lagging VAR supply, the thyristor valve that controls the amount of the lagging VAR supply.

The introduction of Static Var Compensation (SVC) technology improves the voltage profile seen by trains on existing and new railway electrification infrastructures, avoiding the installation of a new sub-station. Why? Because the connection of VAR compensation systems can help increasing the traffic capacity of the line, by increasing the active power that flows on the system. The connection of a VAR compensator can limit the reactive power flow in some parts of the system, compensating the voltage drop that the trains produce. In the same way, if the reactive power is produced locally by the compensator, the substation transformer will be able to handle more active power, permitting a traffic increase in the line. [4]

The simple design combined with the availability of the components, are now, a relevant solution for the railway applications Figure 10 shows the effect of the HVB with an increase of on line voltage by 2,3kV.
Evolution of power electronics lead to smaller installations with less losses and noise: reduction of costs and sustainable development are in the heart of research in that domain. Next HVB will be based on use of IGBT’s with a poor and high a frequency harmonic generation avoiding implementation of a filter. Figure 11 shows the HVB implemented in UK and then near Paris in Villenoy.

Figure 10: impact of a HVB on overhead line voltage

Figure 11: HVB in Chathill (UK)
c. **AC Converter 50Hz – 16,7Hz**

For the purpose of supplying tests tracks in the Technicentre Est Européen (workshop of the TGV Est train sets), a 1MVA converter 50Hz / 16, 7 Hz has been implemented. Its technology is based on IGBT's water cooled. This application of power electronics has allowed to supply in 15kV 16, 7 Hz from the 25kV 50 Hz single phase network.

d. **AC static switchgear**

Recent research has shown that it is possible to replace a classical circuit breaker with a unit using power electronics, IGBT or IGCT's. The main advantage will consist in the ability to switch off a traction or short circuit current very quickly without any mechanical stress and an infinite number of times. Application could be observed where switching is necessary at each train passage. An application is also a current limiter device [1]

e. **High power frequency converters**

These devices, built especially to supply 15kV 16, 7 Hz overhead lines from 50Hz three phase network are used in countries electrified with this power supply system.

5. **Potential for implementation, impact on railway business**

The railway market for such devices is particularly important. If technical success is proven, the cost of devices, in terms of LCC, has to be determined and industry has to take it into account, in order to have competitive solutions compared with “classical” electrotechnic solutions. The market will emerge as the result of experiment. This is what is happening in France with HVB’s, where after a test of a first prototype, new units are being installed. Other projects will also benefit from the implementation of these systems. Generally speaking, in all countries of Europe and the world, there is a need of systems that allow a better use and an optimization of the electric traction infrastructure. The systems described here above give answers which allow an increase of traffic, less high voltage transmission line, less substations and participate therefore to sustainable development. It has then a direct impact on the railway business by allowing required increases of traffic.

**References**


