

10.1 Dynamic Topology

The complete system is composed of a deformable circuit between the energy supply by the sub-station and the train. The sub-station supplies energy at a voltage level adapted at the use possibility for a traction engine, it receive it at other characteristics, adapted at transport, from production site.

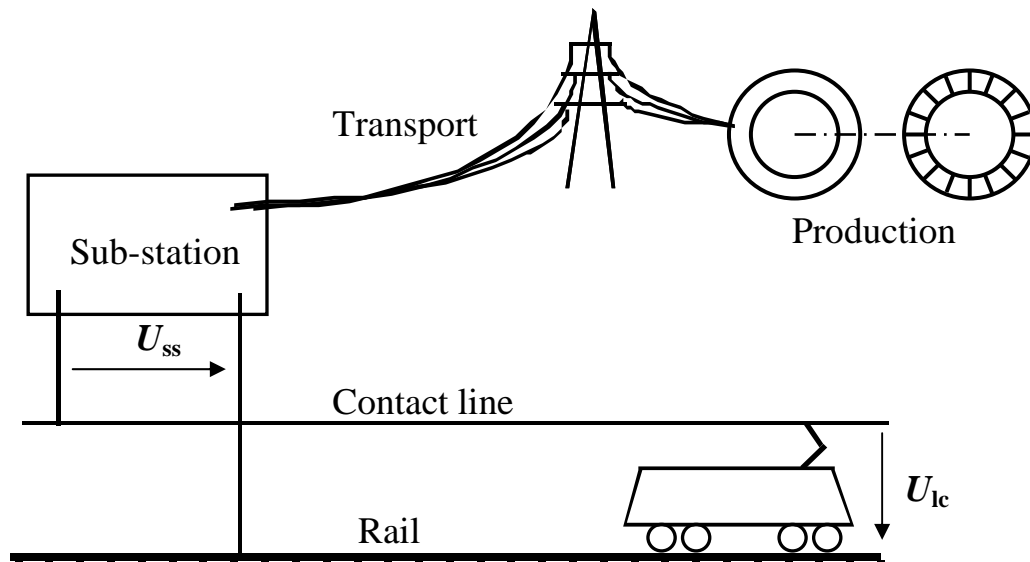


Fig. 10.3 Schematic disposition of electric traction.

10.2 Traction circuit constitution

The traction circuit is composed of two very different conductors:

1. The contact line isolated from supports, with a well known characteristics at construction.
2. The rails and surrounding field where current is divided on undetermined manner.

However, it is possible to draw a simplified schema considering all impedances.

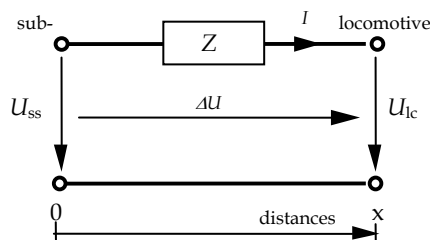


Fig 10.4 Traction circuit: simplified schema.

As impedance Z , for a specified type of construction, depends on distance, it is often spoken of linear impedance. Typical values of contact lines have been calculated for tracks with standard traffic; for ground conductor, mean values were chosen. Please note that the track construction needs careful dispositions in order to guarantee the electric continuity in sort of the main part of current passes through rails.

	Linear impedance [Ω/km]	
	Single track	Double track
1,5 kV=	0,07	0,05
3 kV=	0,08	0,06
15 kV 16,7 Hz	$0,08 + j 0,13$	$0,05 + j 0,08$
25 kV 50 Hz	$0,13 + j 0,35$	$0,09 + j 0,21$

Fig. 10.10 Linear impedances for typical lines.

The voltage effectively usable by the traction engine is one delivered by the sub-station, from which the voltage drop is subtracted. This voltage drop depends on the distance from the sub-station and from the intensity of the current asked by the traction engine. Not all lines are supplied by a single sub-station, but in particular indirect current, one section of length d can be supplied at both ends.

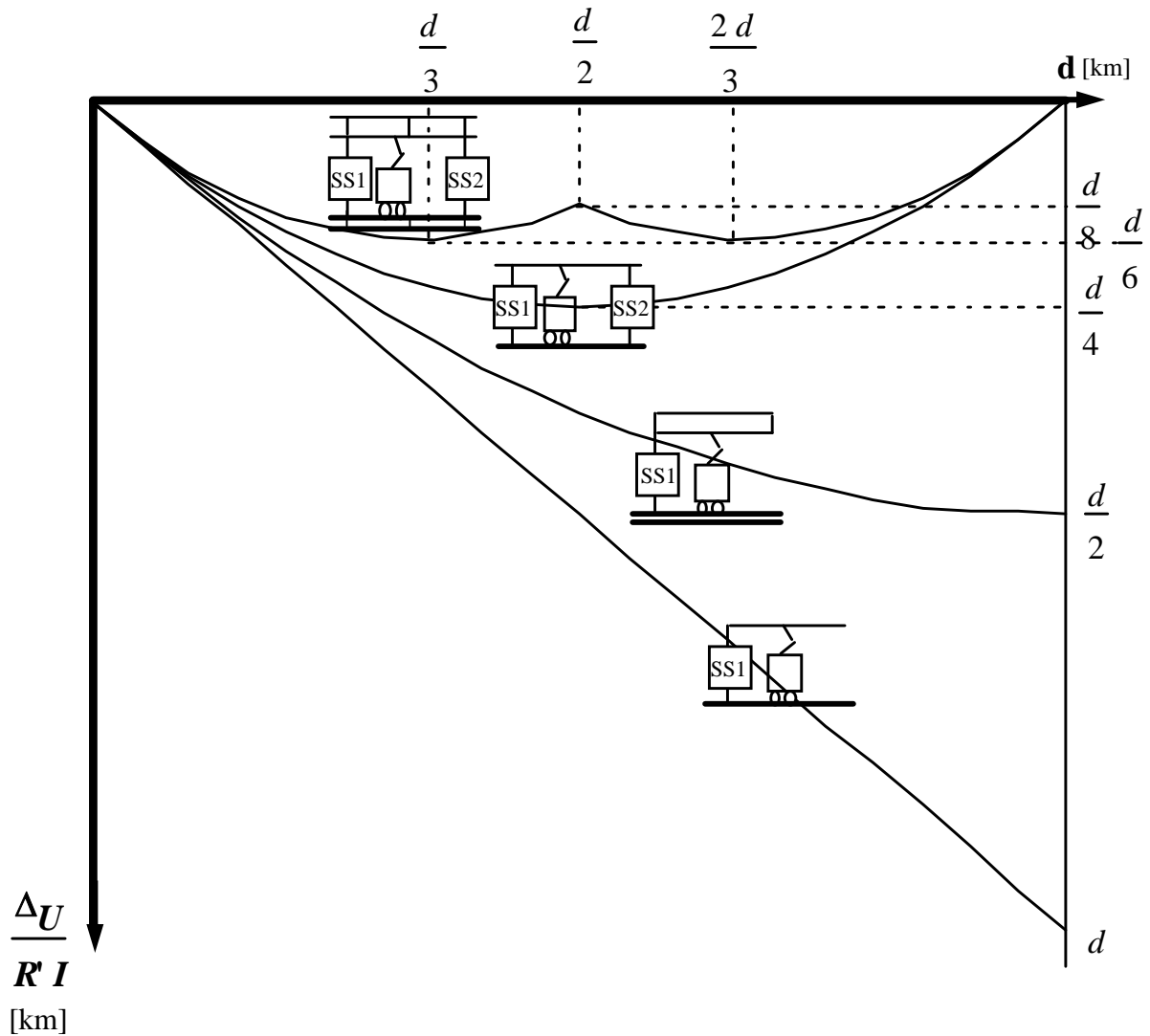


Fig. 10.17 Relatives tension drops on line.

10.2 Constitution

The sub-stations and the contact line are linked by contactors, to permit different structures of traction circuit. If the parallel coupling of direct-current sub-stations don't get problems, in single-phase, the parallel coupling is only possible if both sub-stations have exactly the same phase.

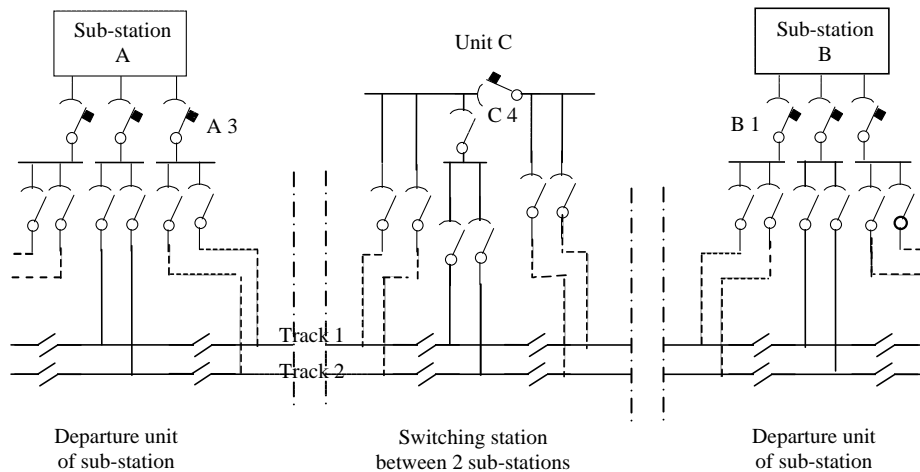


Fig. 10.46 Coupling of two sub-stations

To reduce the linear impedance in single-phase, a dual voltage is chosen in many times, with autotransformers in line.

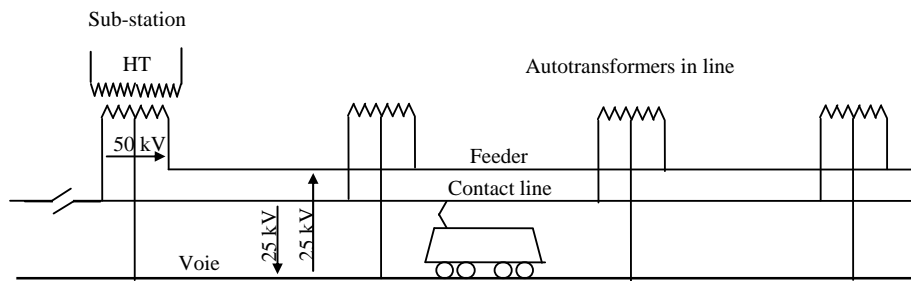


Figure 10.48 Double single-phase power supply.

	Distances between sub-stations [km]	Power per sub-station [MVA]
Direct current 1500 V	8 to 14	3 to 12
Single-phase 16,7 Hz 15 kV	30 to 60	10 to 30
Single-phase 50 Hz 25 kV	30 to 60	10 to 30
Single-phase 50 Hz 2 x 25 kV	40 to 90	30 to 60

Tableau 10.52 Intervals and powers of sub-stations depending of systems

The transformer defines the nominal power what furnish a sub-station, it can be overlade for a short time (for ex. $200\% * P_n$ during 2 minutes). For direct-current sub-stations, the overload will be limited by the maximal current of the rectifier.

10.3 Power supply

The single-phase contact lines are supplied from the general three-phase grid (fig. 10.52a) through sub-stations three-phase – single-phase who step down voltage. Care is taken on the best load equilibrium of the three phases on the general grid by the sub-stations who follow each over on a line.

The direct-current contact lines are also supplied from the general three-phase grid (fig. 10.52c) through sub-stations transformer and three-phase rectifier. At the beginning of electric traction, it were found direct current power plant who supply directly the contact line.

The single-phase contact lines at special frequency can be supplied from a single-phase grid and single-phase power plants (fig. 10.52b) through sub-stations with single-phase transformers, or from the general three-phase grid (fig. 10.52d) through frequency converter sub-stations or par through a combination of both modes.

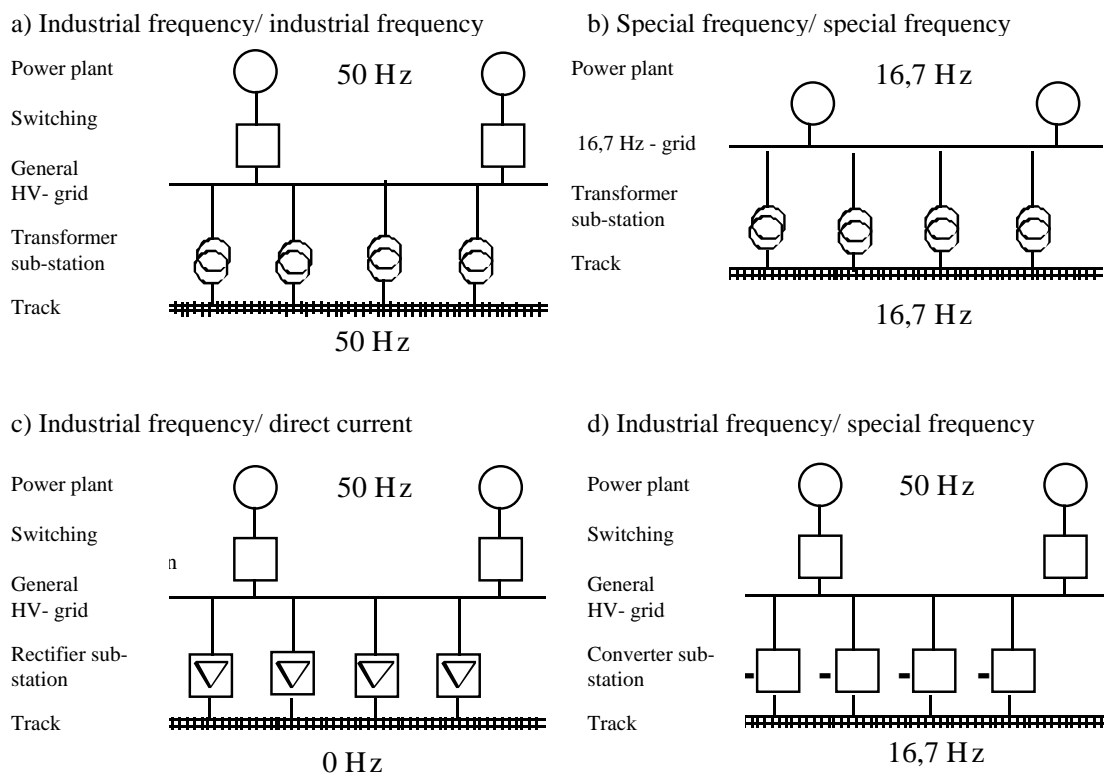


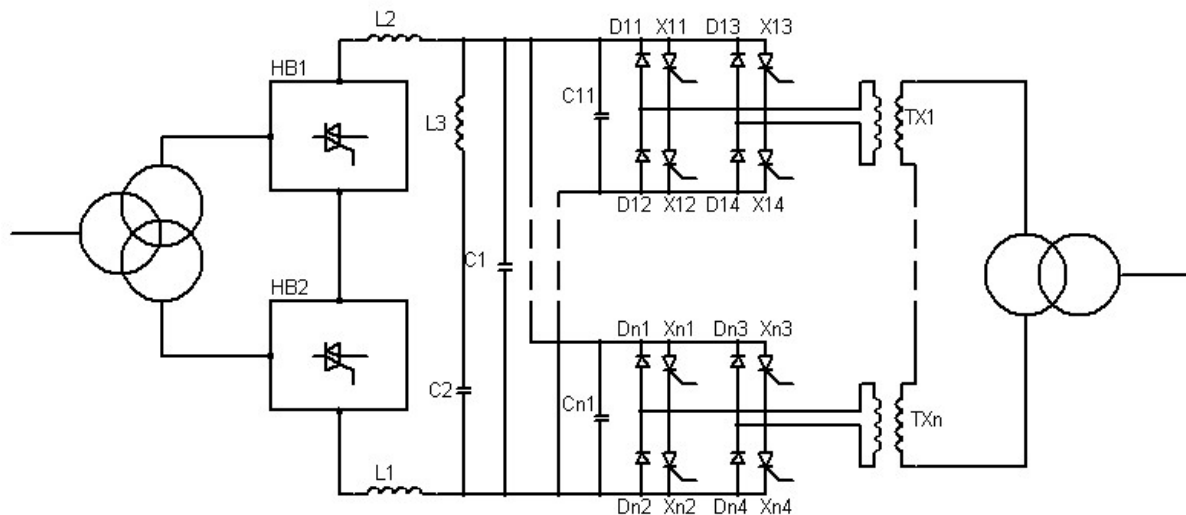
Fig. 10.53 Different power supply possibility.

For frequency conversion, rotating converters were first used: rigid for special frequency without own production, weak for ones with an own supply. Now, static frequency converters are used, with intermediate continuous voltage circuit (U-converter). So on three-phase side as on single-phase side, elementary converters are installed in cascade, in order to guarantee a low harmonic factor from chopper frequency. First implementations used GTO (CFF: Giubiasco) [122]. The recent realizations use IGCT (DB: Bremen) [123] who permitted less conduction losses, – 25 % , a reduction in a factor 5 to 6 of the gate-unit power and commutation time reduced in factor 6 to 8. These commutation times are similar as ones of IGBT, who have greater conduction losses. The structure of a IGCT is comparable at one of a IGBT of same range, this permit quantity gain in the productions costs.

These equipments are reversible.

Such equipments are also thought between three-phase 50 Hz and single-phase 50 Hz [147]. For a moderate buying cost supplement compared to simple transformers, the using costs are reduced:

- No penalties to pay at the energy supplier for consumption asymmetry.
- Harmonics absorbed through filters on the intermediate circuit.
- Reactive power furnished by the intermediate circuit.
- Voltage level is controlled at upper allowed value if sub-station supply power and at lower one if it absorb power.



Transformer 3-phase 50 Hz	Converters	Intermediate circuit	Converters in parallel	Transformers at serie secondaries	Transfo. 16.7 Hz
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Fig. 10.62 Static frequency converter.

For the direct-current lines power supply, rotating machines and mercury rectifiers are no more used today. In general, single-direction diode rectifiers are used.

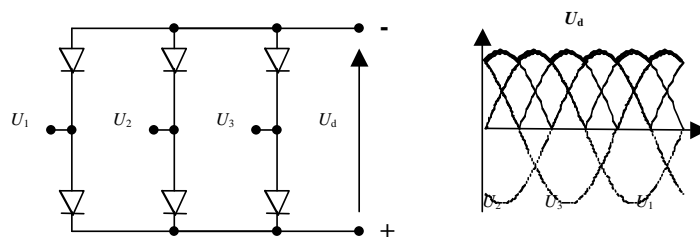


Fig.10.64 Three-phase rectifier.

In single-phase, we have seen than linear impedance is complex (fig. 10.10). This causes that the available voltage for the traction engine is lower than at sub-station output, but it is also shifted in phase (fig.10.69a). In place of reducing sub-station intervals, with great costs, capacitor rack can be implemented on line, in series with contact line (RhB, NSB, fig. 10.69b) or in parallel SNCF, fig. 10.69c). Not only the voltage at contact line is better, but also the reactive power, who is supplied by the sub-station is lower: the phase difference φ_{ss} between voltage U_{ss} at sub-station and the furnished current I is lower.

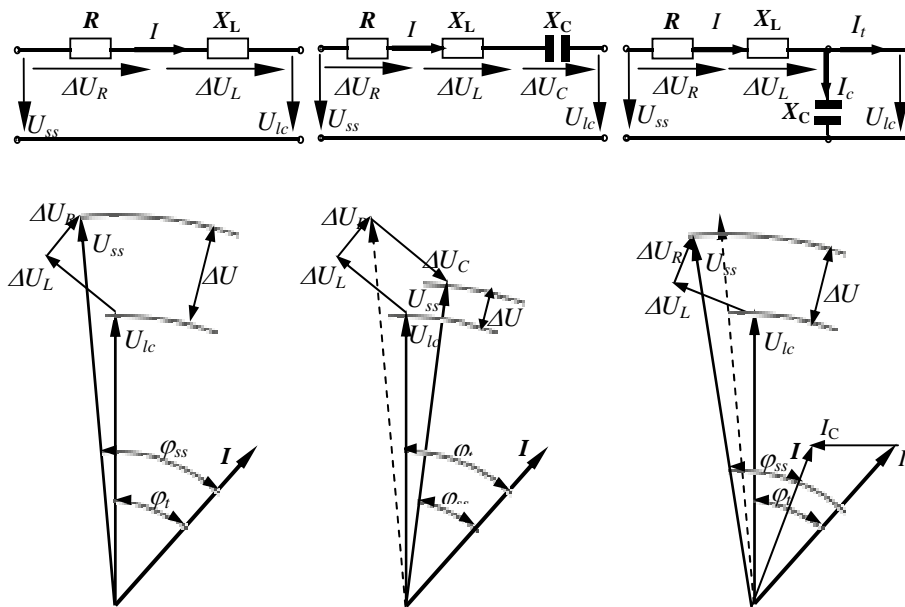


Fig. 10.69 Voltage drop compensation on single-phase by capacitor.

Better than using passive components who helps only on certain parts of lines for certain load cases, we use today static voltage compensators (SVC) who combine batteries of selfs et capacitors with semiconductors controlled by a software who survey in real time voltages and currents at contact line. The impedance value can be adapted at the real load condition at contact line.

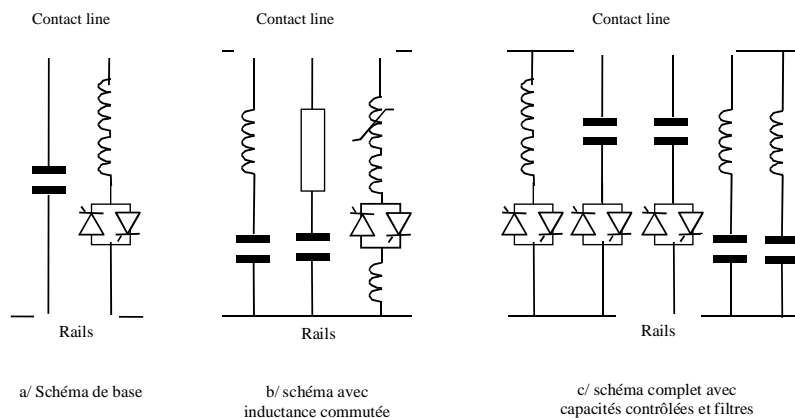


Fig. 10.71 Static voltage compensators for reactive power.

The direct-current sub-stations are considered as real voltage sources adjusted for U_0 , with an internal resistance R_i and conceived for a nominal current I_{ssn} . They may be shortly overloaded.

$$U_{ss} = U_0 - R_i \cdot I_{ss} \tag{10.75}$$

$$I_{ss2h} = 1,5 \cdot I_{ssn} \quad I_{ss1min} = 3 \cdot I_{ssn} \tag{10.76}$$

In single-phase, internal impedance has to be considered. They may be shortly overloaded.

$$I_{ss15min} = 1,5 \cdot I_{ssn} \quad I_{ss5min} = 2 \cdot I_{ssn} \tag{10.77}$$