UNDERGROUND DISTRIBUTION NETWORKS IN URBAN HISTORICAL AREAS: 
THE CITY OF ROME

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INTRODUCTION

The paper gives an overview about technical and practical 
problems in installation of electric distribution underground 
cables at low, medium and high voltage in the city of Rome, 
Italy. It shows as technical standards and legal requirements 
makes building works in the urban historical area very costly 
and difficult to carry out because of the constraints they have 
to comply with.

GENERAL INFORMATION

Rome is a large city having a millennial history and special 
features such as a subsoil very rich of archaeological remains, 
lots of valuable buildings of several epochs, many protected 
natural areas. Its territory measures 1,280 km² and makes it 
the largest town in Europe. It has about 3 millions of resident 
population and high number of tourists and visitors are 
temporarily hosted in the municipal area all the year round, 
also because of being the world centre of Christian religion. 
The demand of electricity in 2003 reached 10,200 GWh, the 
peak of power being of 2,000 MW. The total number of 
customers is greater than 1.5 millions; about 2,400 customers 
are connected to medium voltage network.

In the last decade energy consumption has been increasing at 
rate of 3-4 %. The city is still expanding with the construction 
of new districts and the retraining of old ones. At the same 
rate, the power demand could reach 3,000 MW in the year 
2015.

DISTRIBUTION NETWORKS

Electricity distribution is carried out by means of three 
networks at different voltage level:
− 150 kV system, connecting national transmission grid to 
primary substations (where HV/MV transformation and 
voltage regulation is performed);
− 20 kV system, that is the network connecting secondary 
substation (MV/LV transformation) and customer with 
rated power greater than about 100 kW;
− Low voltage system, three phase 380/220 V and, in the 
historical centre, 220/125 V (for single phase customers 
it is utilized mainly as phase to phase).

Fig. 1 shows the general schemes of HV and MV network. MV system is operated only as radial circuit and has neutral point insulated from ground. HV is operated as connected system or radial. Fig. 2 shows a primary substation scheme. Main data about electricity distribution networks in Rome are detailed in tables 1 and 2. One can see the quantity of MV and LV underground lines is around 90 %.

TABLE 1 – Total length of electric lines (km) (end 2003)

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>Underground lines</th>
<th>Overhead lines</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>216</td>
<td>412</td>
<td>628</td>
</tr>
<tr>
<td>MV</td>
<td>8,330</td>
<td>725</td>
<td>9,055</td>
</tr>
<tr>
<td>LV</td>
<td>13,306</td>
<td>1,730</td>
<td>15,036</td>
</tr>
</tbody>
</table>

TABLE 2 – Primary and secondary substations (end 2003)

<table>
<thead>
<tr>
<th>Substations (n)</th>
<th>67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary substations (n)</td>
<td>12,101</td>
</tr>
<tr>
<td>HV/MV transformers (n)</td>
<td>166</td>
</tr>
<tr>
<td>Total power HV/MV (MVA)</td>
<td>5,700</td>
</tr>
<tr>
<td>Total power MV/LV (MVA)</td>
<td>4,200</td>
</tr>
</tbody>
</table>

STANDARDS IN FORCE ABOUT CABLE INSTALLATION

Cable laying in ground must comply with national standards, 
local municipal regulations and legal requirements. All 
together, these rules form severe constraints making cable 
laying in Rome hard to carry out and more expensive in 
comparison with similar works in other towns.
The main standard in force in Italy about cable lines is CEI 11-17, which states in detail laying modalities, minimum distance from other services, precaution against fire propagation, etc. It also prescribes minimum depth for cables laid directly in soil, as shown in table 3 (the table refers to rated voltage utilized in Rome).

**TABLE 3** – Minimum laying depth according with CEI 11-17 (meter)

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>Public streets</th>
<th>Private areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 kV</td>
<td>1.20</td>
<td>1.00</td>
</tr>
<tr>
<td>20 kV</td>
<td>0.80</td>
<td>0.60</td>
</tr>
<tr>
<td>380/220 V</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

However municipal regulations states that cables under public streets must be laid at depth not less than one meter, measured from the top of protection tile to ground surface. Tile or slab mechanical protection of cable is prescribed in case cable has no armour, as it is usually. Such regulations states detailed technical and procedural rules concerning works of cable laying in soil; in particular, if cables are laid in trench, the minimum width of trench must be 0.60 m.

Practically, because of the local regulations and other reasons, cable laying deepness usually adopted are those shown in table 4.

**TABLE 4** – Laying depth adopted in Rome (meter)

<table>
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<td>1.00</td>
</tr>
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</table>

Moreover the national law 36/2001, taking aim at health protection of people against ELF magnetic field, must be considered in design cable routes in proximity of civil buildings. The law states that magnetic induction in spaces where people could stay longer than 4 hour a day must non exceed 3 \( \mu T \), intended as median of the values in a period 24 hours long.

**AUTHORIZATION TO INSTALL AND OPERATE LINES**

The construction and operation of MV and HV electrical lines, both overhead and underground, are subject to special authorization by provincial administration. Authorization is issued at the end of a complex procedure that can take a long time to be completed, as a large number of public agencies, boards, authorities, etc. must be consulted. Sometimes authorization could be denied, and hence an alternative project have to be considered.

For example, in case the line route crosses areas containing archaeological finds, or even that is simply suspected, national office for monuments an fine arts must be asked in order to obtain approval. Similar permission must be asked to protection environment authority in case route line crosses natural parks or streams, etc. Further permissions are required whenever line intersects railways, others underground services, etc. A long period of time is often necessary to obtain all approvals, permits, etc.; sometimes it takes much more time to obtain authorization in comparison with time requested for manufacturing cable and lying it.

**MODALITIES OF CABLE LAYING**

The most common technique to lay cable directly in ground consists in excavating trenches, whose standard normal sections are shown in fig. 3 for HV, MV and LV cables.

![Fig. 3 – Examples of vertical sections of trenches for HV, MV, LV](image-url)

The sections 2.1 and 2.2 are just indicative since the number of cables in the same trench may vary from 1 to 4, depending on the overall design of the network and choices about work planning; besides, the cables may be only MV or mixed MV and LV.

The spacing between single core cables (HV network) or multi core cables (MV and LV) must be large enough to ensure effective current carrying capacity is not less than expected value.

Cable route is usually drawn along public streets and located under sidewalk or carriageway, depending on the presence of other pipes or cables or sewer systems. Rarely line route crosses private terrains.

The technique above mentioned has revealed fully satisfactory as it allows laying conditions to be easily controlled (cables spacing, type of soil, depth of laying, filling materials, etc.). However this technique is costly, mainly because of high global costs of digging and refilling of trenches, and restoration of road paving. The total cost of civil works per unit length is much greater than cost of cable, its accessories an laying operations in open trench. Furthermore, digging works causes troubles to motor traffic and human activities and then people often opposes to such initiatives.

On the other hand, trench technique allows cable drum length up to 250 m to be pulled easily in site. In case of HV cables...
the drum size may reach 500 m, if the route has no many turns.

A different modality of cable laying is the “microtunnelling” technique. It has been gaining in utilizing in the last years and consists in making an horizontal hole in soil, at deepness between one and 2 meters, by means of a special driven machine allowing path to be controlled; then the excavating head is driven back pulling the cable in site. The main advantages of this technique are two: (a) it allows to avoid breaking of the road paving; (b) the cost of civil works is less than cost of trench excavation (if only one or two cables have to be laid along the same route). On the other hand, this technique cannot be utilized if the underground contains many other cables or pipes. However, nowadays new devices for radar investigation of soil are available and they enables existing services to be found and located with sufficient detail. In recent works carried out in Rome the tunnelling technique has been applied as an alternative to trenching with good results. Sometimes both the techniques, trenching and tunnelling, are applied together in the same route, the former in the parts where many cables or pipes are already present, the latter in the remaining parts. A disadvantage of this method consists in the increasing of the number of cable joints. The design of the cable line should aim to arrange for the distance between two successive joints is not less than 100 m.

A further technique is the so called “multifunction underground structure”, that is a tunnel in which different services can be laid (distribution cables, public lighting cables, traffic light cables, water pipe, telecommunication cable, etc.). There are two types of such structures: ducts and galleries. The first one type has lower cost, but it is not accessible (Fig.4); hence civil works become necessary to add new cables or remove the old ones. Gallery is a very flexible structure, since personnel can enter it for adding or removing cables in any moment.

On the other hand galleries are very expensive and their construction may result very difficult because of existing services; generally the initiative to build up a new gallery or tunnel is issued by local government, which ask public companies to share the expenses. The gallery must be considered a framework and hence it is important that a subject is appointed as supervisor for operation and maintenance. The most common trouble is that with time public companies could omit to remove out-of-date pipes or cables; that could result in saturation of capacity and security risk. In Rome are now existing about 150 km of galleries. That means cable laying often requires excavation along streets to be carried out. Since 1999 there is a recommendation of the Italian Government to build up multifunction galleries or ducts during the development of new districts or of the transformation projects in existing urban areas.

**TYPES OF CABLES**

The 150 kV grid has been developed up to 1980 using single core oil-filled cables and, since then, EPR insulated cables with lead sheath and copper stranded conductor 1,000 mm². From 2000 on cables with aluminium conductor 1,600 mm² EPR insulated with copper wire sheath are used. The latter is less expensive (about 40%) and its use so far has been revealed very valid. No one internal fault has occurred in the last decade in EPR insulated cables. Drum length of these cable may ranges from 300 to 500 m; however the routes has often many turns and humps so that drum length rarely may exceed 350-400 m.

To develop 20 kV network, at present 3-core aluminium cables, 185 mm², EPR or XLPE insulated, are usually used. The cable is formed by stranding three single core cables (it is also named “visible spiral” type). Cables of similar design, with copper conductor 150 mm², copper tape sheath and special external protective sheath to avoid fire propagation are used only exiting from primary substations, whereas many cables are necessarily installed in group. Recently a new type of cable has been developed, the so called “protected against impact”; it can be installed directly in ground without mechanical protection, by means the microtunnelling technique.

Low voltage network is formed by feeders, connecting contiguous secondary substations, and lateral lines connecting customers (single or groups). The feeders are built with 4-core cables 3×150+95 mm² or 3×95+50 mm², EPR insulated. Similar cables, but having sections 3×50+25, 4×25, 4×16 mm², depending on the connected load, forms lateral lines.

**INSTALLATION PRACTICAL PROBLEMS**

At present, owing to the large number of existing services in ground and the extent of archaeological areas, cables must be laid mainly in trench. In that case, before starting excavation works, careful investigation of subsoil is mandatory in compliance with local regulations, in order to identify other cables, pipes, etc. Investigations by means of radar or preliminary excavations may be required. Public utilities generally may provide maps of own networks in ground, but such maps can’t give complete information because of scale, precision, updating, etc. For example, preliminary excavation is always carried out to ascertain 150 kV joints may be installed (as cross-bonding technique is normally applied to

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**Fig. 4 – Example of multifunction duct**

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When the presence of archaeological findings are expected, designing cable lines: the detailed identification of the route. Ground investigation allows to perform the first step in line route is very important to determine drum length). Then excavation are generally performed in the presence of archaeologists charged by office for monuments and fine arts. Sometimes archaeological findings are not important (in opinion of the archaeologists) and hence a solution may be agreed to allow works go on. Other times the discovery may be important, and archaeologists may decide to make a thorough investigation, for example by enlarging trench or increasing its depth. Changes in the project may be necessary and so installation requires more time and extra cost to being completed.

Another important feature of trenching regards road paving. Up to 1996 refilling of trenches was made by special sand mixed with cement, but this technique, though carried out with care, could give rise to subsidence of the soil surface in a short time. Therefore the Municipality of Rome developed, with the collaboration of University, special refilling materials that have effectively solved such a problem. In fact new materials are similar to a concrete having a low content of cement; moreover, such materials may be easily crumbled. So, from 1997 on the use of new refilling mixes is mandatory. However, their cost is considerably higher than previous ones. In accordance with municipal regulation, all the service utilities must provide for the restoration of road paving, that may be of several types. In the central areas a lot of roads have special paving formed with marble slabs or little cubic stones; sometimes such paving is based on a reinforced concrete floor slab. Naturally, original road surface can’t be changed and then also the restoration of paving may become costly.

At last we notice that, in order to limit disturbances to traffic and population, and to avoid to dig trenches on just restored paving, the Municipality of Rome calls all the service utilities to prepare the annual plan of all the works integrated with a 4 months operational plan. The plan don’t include short connections of single customers.

**COSTS OF UNDERGROUND CABLES**

The unit cost of underground cable lines is considerably higher in comparison with equivalent overhead lines and that is in itself relevant as the latter aren’t allowed in urban areas. The unit cost of a medium voltage cable is about double with respect to overhead line with the same rating. The unit cost of HV cable lines is about 7 times greater than overhead ones. The medium unit costs of cables directly laid in ground by trenching are shown in table 5, in terms of percentage components.

The cost of building works depends on many factors such as type of paving and subsoil, existing services, medium depth of the trench, archaeological finds, motor traffic, width of the road, etc. So, they may vary considerably from a project to another. The local taxes consists essentially of two items: (a) temporary occupancy of the public area; (b) restoration of paving, that is a special local tax that public utilities owe to Municipality to enable periodical rebuilding of road paving can be made.

**TABLE 5 – medium costs of underground cable lines**

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>Cables and accessories</th>
<th>Building works</th>
<th>Local taxes</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 kV</td>
<td>27 %</td>
<td>37 %</td>
<td>25 %</td>
<td>11 %</td>
</tr>
<tr>
<td>20 kV</td>
<td>38 %</td>
<td>42 %</td>
<td>10 %</td>
<td>10 %</td>
</tr>
</tbody>
</table>

At present innovative techniques and standards are considered in order to minimize costs and duration of the cable installations in trench; on the other hand, the refilling of the trenches and the reinstatement of road paving should be correctly performed. An advantageous initiative consists in reduction of the minimum deepness and width of the trench, to minimize the volume of excavated material ad duration of building works. Moreover the excavated soil could be recycled as refilling material after a suitable treatment. Public utilities and municipal office are considering such opportunities.

**HV/MV AND MV/LV SUBSTATIONS**

Primary substations may be of two types, with reference to HV section: air insulated or gas insulated. The first one type is cheap and relatively simply to build up and operate. The gas insulated type is more expensive and complex, but it requires less space and this is essential in urban areas. Most of the primary substations built up or renovated in the last decade are of gas insulated type and entirely installed inside buildings; some of them are housed in underground structure and relative construction resulted very costly, but no alternatives were available. At times existing valuable buildings were adapted in order to house electrical equipment, but without change outward appearance, because of legal requirements in defence of monuments an fine arts. The layout designs of such substations may be quite different one from another; moreover they results in very peculiar an challenging projects. For example, a primary substation is housed in a building having six levels; the power transformers (3×25 MVA) are at third flat and relative heat exchangers of the refrigerating systems are on the top of the building; in such multilevel plant the design of cable route inside building is a relevant feature of the whole project.

Secondary substations are easier to build, thanks to relatively little dimensions. In fact such substations are housed in a room about 4×3 m. Electric scheme is relatively simple, as only one transformer is usually installed, whose rated power never exceed 630 KVA. In the new districts each cabin is always installed in a separate building purposely designed. In the historical area the rooms are usually incorporated in buildings. A large number of such rooms are located in underground and have access through a trapdoor. In case the substation rooms are located inside buildings, specific environment problems must be considered, such as heating, vibrations, noise, electromagnetic field produced by equipment.