High-voltage direct current transmission lines

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***Abstract* – this article treat about HVDC (high-voltage direct current) technology. In history of energy transmission, crucial moment was "War of Currents" in XIX century . From conflict between supporters of AC and DC was winning Nikola Tesla. In effect, the most popular way to transmission energy are AC transmission lines. Despite many advantages of AC transmission, in some conditions better is DC transmission, which demand presence of high-voltage. The serious acceleration in development of this technology was 1954 when was built the first such system. Since those time, HVDC has developed very intensive, and will be very important technology in problem of transmission energy.**

I. INTRODUCTION

Power does not rely only from voltage, but is equal of voltage times current.

$$P=UI \tag{1}$$

For a given power a low voltage require a higher current and a higher voltage requires a lower current. However, since metal conducting wires have a certain resistance, some power is wasted, and transfer as heat. The power losses in a conductor are proportional to the square of current and resistance of conductor.

$$P=RI^2 \tag{2}$$

Power is also proportional to voltage, so for given power level, higher voltage let decrease a current level. Higher level of voltage, give us also lower power loss. Power loss can be also reduced by decreasing resistance e.g. by increasing diameter of conductor, but it's demand higher economical costs.

High voltage transmission is used to reduce lost of power, but it cannot be used for lightning system and supplying motors. High voltage level has to be adjust to receivers. In AC are using transformers which decreasing or increasing voltage to required level. In DC does not exist such possibility. In those technology manipulation is possible for more complicated way. To changing a level of voltage are used electronic devices as mercury arc valves, semiconductors devices, thyristors, insulated-gate bipolar transistors (IGBTs), high power capable MOSFETs (power metal–oxide–semiconductor field-effect transistors) and gate turn-off thyristors (GTOs).

In AC voltage conversion is simple, and demand little maintenance. Further three-phase generator is superior to DC generator in many aspects. Those reasons causes that AC technology is today common in production, transmission and distribution of electrical energy. However alternative current transmission has also drawback which can be compensate in DC links. It's the main reason why DC technology is chosen instead AC:

- inductive and capacitive elements of lines put limits to the transmission capacity and transmission distance
- is not possible transmission between two points of different current frequency

Therefore electrical engineers research and applied DC technology which doesn't have such limitation.

II. HISTORY

The first transmission of direct current was in 1882, distance was 50 km long (distance between Miesbach-Munichbut) and voltage level was only 2 kV. DC transmission was developed by Rene Thury. This scientist created own method, which based on series-connected generator and was used in practice by 1889 in Italy. System based on Thury's idea transmitted 630 kV at 14 kV over distance 120 km. The next important

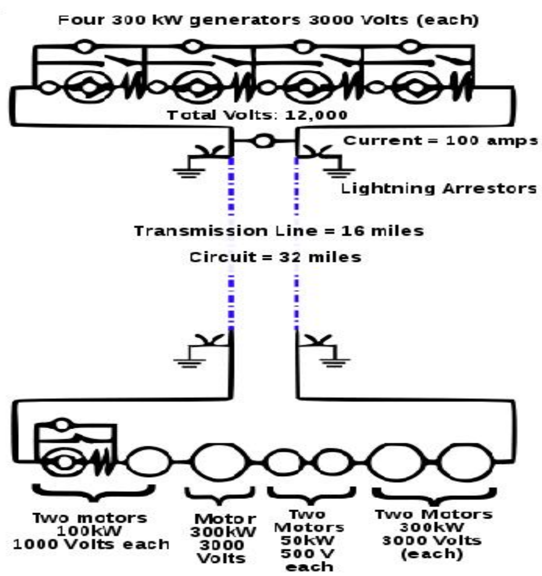

Figure 1. Scheme of Thury's installation from 1889.

project was line Mountiers-Lyon in France which was working between 1906 until 1936. Mountiers power plant had eight generators which was connected in series. Line of Mountiers-Lyon connected hydroelectric power plant, transmitted 8600 kW, had 200 long kilometers and voltage between two poles was 150 kV. In sum was built fifteen similar systems. Other systems worked at up to 100 kV DC, and was using to 30s'. Economical and technical low efficiency caused that Thury's systems was withdrawal, but despite those reasons – it was little commercial success.

The next era, was attempts with mercury arc valve. The first such technology was put in 1932 by General Electric, which tested mercury-vapor valves in 12 kV DC line. System could convert current from 40 Hz to 60 Hz frequency. This installation worked in Mechanicwille, New York. In 1941 existed underground DC (with mercury arc valves) connection in Berlin, but due to war project was never completed.

Crucial moment in development of HVDC was in 1954. This moment began era of static mercury arc valve. This system was created by ASEA and connected Sweden with island Gotland. Up to 1975 had used technology based on solid-state devices. From this time to 2000 had been lasting era of thyristor valves. Future probably will belong to commutated converters.

III. COMPOTENTS AND RECTYFING/INVERTING SYSTEMS

HVDC using mercury arc rectifiers but the most modern way are thyristors. Thyristor is a solid- state semiconductor, similar to the diode, but has particular property in control of AC cycle. The insulated-gate bipolar transistor (IGBT) is simpler and cheaper way of control.

Fig 2. Simplification scheme of HVDC transmission

Rectifying and inverting systems usually use the same devices. *At the AC end a set of transformers, often three physically separate single-phase transformers, isolate the station from the AC supply, to provide a local earth, and to ensure the correct eventual DC voltage. The output of these transformers is then connected to a bridge rectifier formed by a number of valves. The basic configuration uses six valves, connecting each of the three phases to each of the two DC rails. However, with a phase change only every sixty degrees, considerable harmonics remain on the DC rails. An enhancement of this configuration uses 12 valves (often known as a twelve-pulse system). The AC is split into two separate three phase supplies before transformation. One of the sets of supplies is then configured to have a star (wye) secondary, the other a delta secondary, establishing a thirty degree phase difference between the two sets of three phases. With twelve valves connecting each of the two sets of three phases to the two DC rails, there is a phase change every 30 degrees, and harmonics are considerably reduced.[1]*. In elements which take share in conversion, are applied filters which limit harmonic in DC cycle.

IV. CONFIGURATIONS

In the most popular configuration - monoplar, one terminal of rectifier is connected with the ground. Second terminal with potential another than ground, is connected with transmission line.

Current flows in the earth between electrodes two stations when not metallic conductor is installed. It's a single wire earth return type of configuration. If not exist return conductor, configuration may gives such problems:

- corrosion because long underground objects (e.g. pipelines),
- submerged return electrodes may participate in chemistry reaction
- unbalanced current may disturbed magnetic field and influent on navigations ships equipment.

Presence of return wire can eliminate such effects. Those line has to be connected between two ends of monopolar transmission line. Second conductor is applied in depending on economical, technical and environmental factors. In the future will spread bipolar systems. *Modern monopolar systems for pure overhead lines carry typically 1500 MW. If underground or underwater cables are used the typical value is 600 MW.[2]*

The next system is bipolar transmission. In this configurations, is used two wires with the same potential as ground, and opposite polarity. Costs of this line is higher than monopole, but despite economical aspect bipolar system has advantages:

- return losses and environmental effect are reduced
- in case of fault in one line, current can flow by return path in monopolar mode
- in very uncomfortable surrounding, second conductor can be track in transmission towers, it gives possible flow power even at the completely breaking second line.

Bipolar systems may carry as much as 3000 MW at voltages of +/-533 kV. Submarine cable installations initially commissioned as a monopole may be upgraded with additional cables and operated as a bipole.[1]

Back to back is configuration with both inverters and rectifiers are in the same area. This system is used as follows areas:

- in Japan, where occur necessity of changing current frequency
- in lines with different phase relationship
- in lines with different frequency and phase number

System with transmission line is the most common configuration. In this structure two inverter or rectifier stations are connected by powerline. This system is applied in long lines, unsynchronized grids and underwater connections.

Tripole: current modulating control. It's new idea of transmission DC (since 2004). This structure based on two circuit which work as bipole and third wire which operate as parallel monopole. Parallel monopole relive current in periods from other pole. Bipole wires are loaded for few minutes. In tripole system can be carry higher current. Tripole system let pick up about 80% transferred power than AC lines.

V. ADVANTAGES AND DISADVANTAGES

The advantage of HVDC than AC is ability to transmission big amount of power on long distances with lower wastes. DC technology is better in such situations:
- undersea connections
- power transmission and stabilization between unsynchronized AC distribution system
- connection generating plants remote from power grid
- stabilizing AC grid
- connection between countries with different current frequency/voltage
- synchronize AC produced by renewable energy sources

Long underwater lines have a high capacitance. In AC transmission is required process of charging and discharging, what is causes of power losses. HVDC has minimize this effect. In AC lines occurs also dielectric losses.

To disadvantages of HVDC we can include conversion, switching and control. Static converters are expensive. In short distances losses in static inverter may be even bigger than in AC transmission. In the future static converters will be replaced by thirystors.

In DC system controlling of multiterminal configuration is quite hard, because required good communication between terminals. Also circuit-breakers are difficult than AC.

VI. ECONOMICAL ASPECTS

Is not simple estimate a cost of buildings HVDC transmission line and operations unit. Cost are very different and depends on power of line, length connection, environment of track wires (air or water) and so on. Usually the biggest producers of high-voltage direct current transmission as Areva, Siemens or ABB don't reveal financial information about investments. Despite narrow basement of information, we can estimate some costs of built DC line, which is show on Fig.3

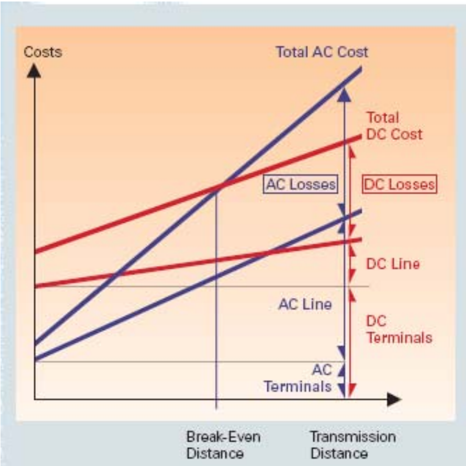

Fig.3 Relation between length of line and costs in AC and DC line

About 50% cost of DC structure are converter transformers, valves and infrastructure as buildings.

VII. APPLICATIONS

HVDC system can connected unsynchronized grids, therefore such lines very often are natural boundaries between countries. DC line is also meeting in places where is require undersea transmission (e.g. wind farm) and between two long distant points. From such reasons was built grids e.g. in Siberia, Canada, Australia or Scandinavia. Problem of synchronized AC because of different frequency system occur e.g. in Japan, North America, South American (enormous hydroelectric power plant) – between Brazil and Paraguay In Europe the most lines are between UK, Scandinavia and continental Europe.

Fig 4. Nicolet convert station in transmission line Québec - New England

VIII. CONCLUSIONS

Today HVDC is very important issue in transmission energy. In near future this technology probably will be develop very intensive. Influence on future may have intensive spread of renewable energy source, also wind farm which need undersea connections. Also problem of cascade blackout, can be reduced by application of HVDC. Intensive, very large investments in e.g in China and India shows that high-voltage direct current will very important in the future, especially in big, new-industries countries.

VIII. REFERENCES

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