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# ЭФФЕКТИВНОСТЬ ПЕРЕДАЧИ ЭЛЕКТРОЭНЕРГИИ ПРИ УВЕЛИЧЕНИИ ЧИСЛА ФАЗ
# EFFICIENCY OF ELECTRIC POWER TRANSMISSION WITH INCREASING NUMBER OF PHASES

**Аннотация.** В данной статье рассматриваются передовые конфигурации систем передачи электроэнергии, разработанные для повышения эффективности и минимизации воздействия на окружающую среду. Исследование сосредоточено на трех основных технологиях: многофазных линиях электропередачи (МЛЭ), многоцепных линиях электропередачи (МЦЛЭ) и компактных линиях высокой пропускной способности. Основные результаты показывают, что преобразование традиционных трехфазных систем в многофазные (например, шестифазные) значительно увеличивает пропускную способность за счет снижения потерь энергии, интенсивности электромагнитного поля (ЭМП) и акустического шума. Кроме того, внедрение многоцепных и компактных конструкций с использованием специализированных опорных конструкций и оптимизированного расстояния между проводниками позволяет значительно сократить требования к приобретению земельных участков и ширину коридоров. В статье освещается международный опыт развертывания МЦЛЭ и обсуждаются технические преимущества компактных линий, такие как снижение индуктивности и увеличение собственной мощности [1-13].

**Abstract.** This article examines advanced configurations for power transmission systems designed to enhance efficiency and minimize environmental impact. The study focuses on three primary technologies: multiphase transmission lines (MTL), multi-circuit transmission lines (MCTL), and compact high-capacity lines. Key findings indicate that converting traditional three-phase systems to multiphase operation (e.g., six-phase) significantly increases transmission capacity while reducing energy losses, electromagnetic field (EMF) intensity, and acoustic noise. Furthermore, the implementation of multi-circuit and compact designs utilizing specialized support structures and optimized conductor spacing allows for a substantial reduction in land acquisition requirements and corridor widths. The article highlights international experience in MCTL deployment and discusses the technical advantages of compact lines, such as reduced inductance and increased natural power [1-13].

**Ключевые слова:** Многофазная передача электроэнергии, многоцепные линии, компактные воздушные линии, пропускная способность, снижение электромагнитного поля, эффективность энергосистемы.

**Keywords:** Multiphase power transmission, multi-circuit lines, compact overhead lines, transmission capacity, electromagnetic field reduction, power system efficiency.

**Introduction**. Multiphase systems with transformer converters are widely used in the creation of multi-pulse rectifiers [1]. Based on such converters, multiphase power transmission lines can be implemented (Figure 1).

Compared to three-phase transmission lines (TPL), multiphase transmission lines (MTL) offer the following advantages [6]:

• increased transmission capacity;
• smaller differences in conductor currents;
• reduced energy losses and electromagnetic field strengths.

Their use makes it possible to minimize the negative effects of corona discharge by reducing radio emissions and acoustic noise. In some cases, it becomes possible to avoid the use of expensive transposition supports [1, 10].

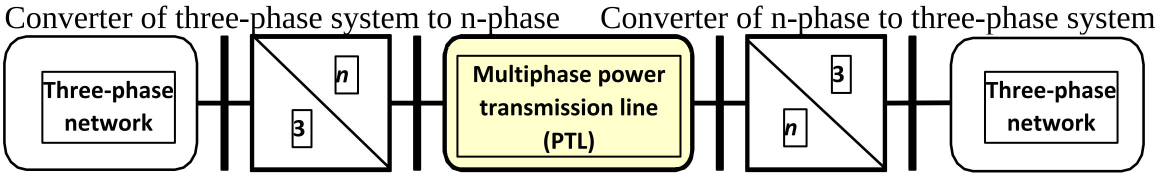



Figure 1. Multiphase EPS

By increasing the number of phases, a lower impact of the transmission line's electromagnetic fields on the surrounding environment can be achieved. As a result, the size of land exclusion zones along the routes of such transmission lines can be reduced. The presence of line voltages equal to or less than the phase voltage in multiphase transmission lines allows for the compaction of these lines by placing wires circumferentially and performing appropriate phasing.

As an example, Figure 2 shows the arrangement of wires in a six-phase transmission line cross-section.

The main disadvantage of multiphase power transmission lines is the increased cost of the converter equipment [2, 5].

**Multi-Circuit Power Lines**

The task of reducing land allocation for the construction of power generation facilities is particularly relevant in modern conditions. One possible solution is the use of multi-circuit transmission lines [4, 7]. This method allows the construction of new transmission lines by increasing the number of circuits on existing transmission lines without extending beyond designated corridors.

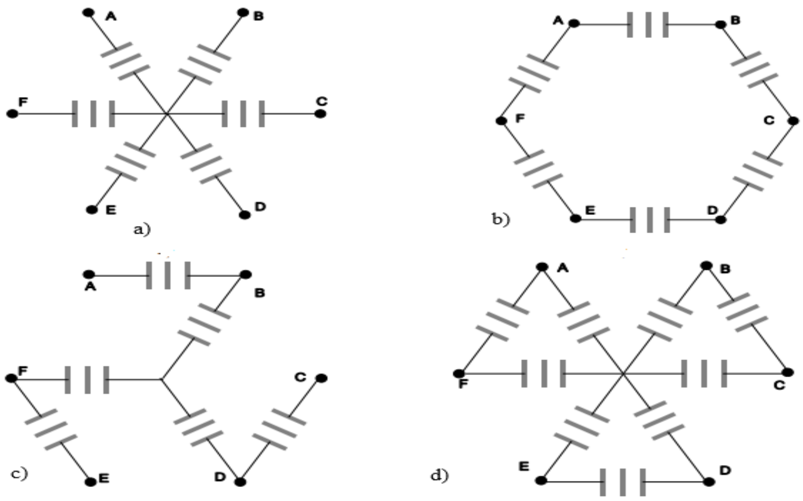
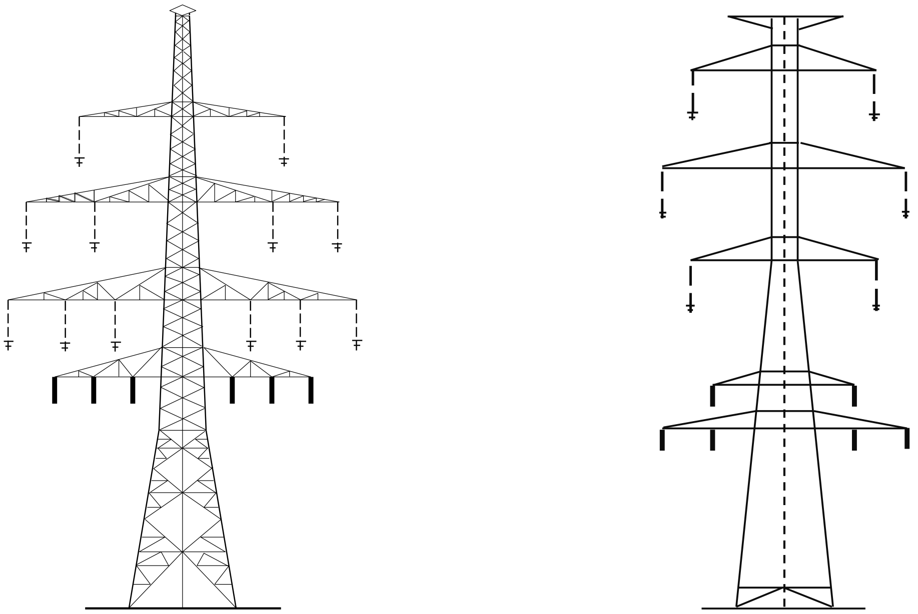



Figure 2. Arrangement of six-phase power transmission line wires:
a – star; b – hexagon; c – zigzag; d – triple triangle

There is experience in constructing combined multi-circuit transmission lines in both domestic and foreign practice. Such lines have been used abroad since the 1970s. Specifically, a six-circuit transmission line was installed in Germany. Two 380 kV lines are suspended from the two upper crossarms of its supports, while the lower and middle crossarms each carry two 220 kV and 110 kV lines (Figure 3.a). A four-circuit 230–66 kV Taba–Sharm el-Sheikh line operates in Egypt. The Donau multi-circuit transmission line (Figure 3.b) operates in the Republic of Slovakia. It includes two upper 400 kV circuits and two lower 110 kV circuits (Figure 3.).

Multi-chain transmission lines (MCTLs) have not yet been widely used in Azerbaijan's power grids. Several similarly designed transmission lines are currently in use: a three-phase 500 kV section of the Azerbaijan and 8 November TES power distribution network [8, 13].

The classification of overhead power lines by number of circuits is illustrated in the diagram in Figure 4.



a) b)

Figure 3. Designs of intermediate supports of the six-circuit (a) Multi-Overhead Lines 2×380 kV +2×220 kV + 2×110 kV and the four-circuit (b) Donau line 2×400 kV + 2×110 kV

The types and designs of multi-circuit transmission line (MCTL) towers differ in their material, construction, and wire suspension method. Figure 5a shows a 63.4-meter-tall tower for a German multi-circuit line [9, 12].

Single- and double-circuit high-voltage lines utilize standardized metal and reinforced concrete support structures. In contrast, multi-circuit transmission line supports are unique. In recent years, multi-faceted metal pole-type supports have come into use for multi-circuit transmission lines (Figures 5a and 5b).

The asymmetrical arrangement of conductors on multi-circuit transmission line supports results in uneven inductances and capacitances of different phases. Furthermore, significant mutual electromagnetic interference occurs between the line circuits. Therefore, it is advisable to use phase coordinates to model power system conditions that include multi-circuit transmission lines

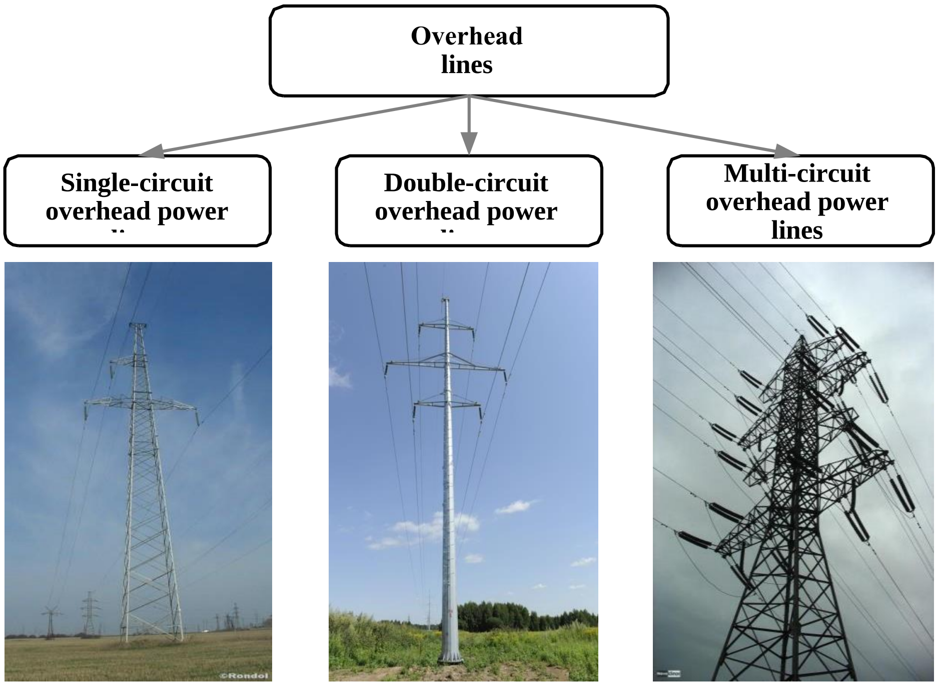



Figure 4. Classification of overhead power lines by the number of circuits

Multi-circuit lines are also implemented at low voltage using self-supporting insulated conductors (Figure 6).

Figure 5. Supports of the MC transmission line

**Compact High-Capacity Power Lines**

Compact power lines are characterized by an unconventional arrangement of wires and phase spacing to the minimum permissible distances, taking into account technical limitations determined by the following factors [3-5].

• wire movement within the span due to wind;
• asynchronous sway;
• vibrations during ice shedding;
• overvoltage and corona discharge limiting conditions.

Figure 6. Four-circuit overhead line with insulated wires

Compact overhead power lines are created by bringing the phase conductors closer together in a span using ties made of electrical insulating materials, such as polymer rod insulators. In this case, the distances between phases on the supports remain unchanged.

Another method for creating compact overhead power lines is shown in (Figure 7) and is based on the use of special supports. In this case, overhead power lines can be constructed with horizontal phases, with an elevated (Figure 7a) or lowered middle phase (Figure 7b). When selecting the minimum permissible distances between phases for such transmission lines, switching overvoltages are the limiting factor. The minimum cross-sections are limited by radio interference and corona losses [2-4].

The technical specifications of compact overhead power lines are presented in Table 1. For comparison, it should be noted that for traditionally designed overhead power lines, the distances between phases are assumed to be:

- at 330 kV – 8.4 m;
- at 500 kV – 12 m;
- at 750 kV – 13.5...19.5 m.

The advantages of the triangular phase arrangement include virtually complete symmetry of the parameters, so there is no need for phase transposition [9].

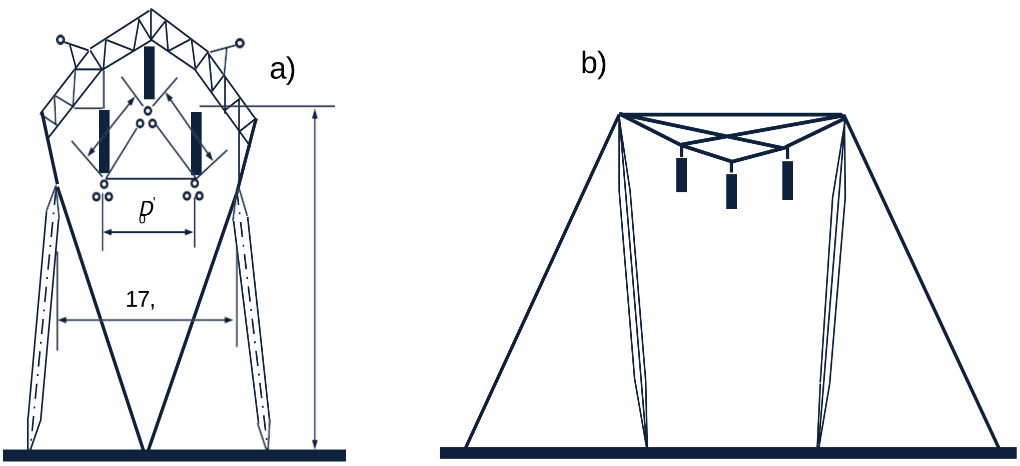



Figure 7. Support options for compact lines: a – with an arched crossarm for a 500 kV line; b – with a cable-stayed crossarm for a 750 kV line

Table 1.

Technical data of compact lines

| Voltage, kV | Minimum permissible distances for wire placement, m | | | | Minimum permissible cross-sections |
|---|---|---|---|---|---|
| | horizontal | | triangular | | |
| | $D_0$ | $D'_0$ | $D_0$ | $D'_0$ | |
| 330 | 5,5 | 11,0 | 6,0 | 6,0 | 2 x AC-400/22<br>3 x AC-185/56 |
| 500 | 7,5 | 15,0 | 7,8 | 10,0 | 3 x AC-500/27<br>4 x AC-240/56 |
| 750 | 9,0 | 18,0 | 10,0 | 12,0 | 6 x AC-330/45<br>7 x AC-240/32 |
| 1150 | 15…17 | 30…34 | – | – | – |

Here extreme phases:
$D_0$ – distances between the middle and extreme phases;
D' – distances between.

**Conclusion**

The study concludes that while converter equipment costs increase for multiphase systems, the ecological and throughput benefits offer a compelling solution for modern power grid development.

1. Converting three-phase transmission lines to multiphase operation allows for the following positive effects: increased transmission capacity; reduced conductor current asymmetry, power losses, and EMF intensity.

2. Multi-circuit and compact transmission lines can be used to reduce land acquisition distances for the construction of power facilities.

3. Compact transmission lines are characterized by reduced inductance, increased capacitance, reduced wave impedance, and higher natural power.

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