Electricity

2. AC *versus* DC

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In the early years of power generation the alternating voltage from a single coil (with 2 or more parallel paths) was *commutated* to convert it to DC. Commutation essentially means reversing the negative polarity of the AC voltage so that the voltage produced does not alternately change its sign and the current delivered by the generator flows in one direction. The purpose of producing direct current was that it could be used to run motors available in those days and light electric bulbs. AC motors which constitute more than 80% of today's motors had not been invented at that time.

Tesla's Induction Motor

Around 1880, Nicola Tesla from Yugoslavia invented what is called an *induction motor.* Tesla had observed that 2-phase or 3-phase currents flowing through 2-phase or 3-phase coils placed in the stator of a motor produce what is called a *rotating magnetic field of constant amplitude.* If the rotor is fitted with short-circuited coils, the rotating magnetic field cuts the rotor coils and induces a voltage in them. Since the coils are short-circuited, currents flow through them and the rotor becomes an electromagnet which then 'chases' the rotating magnetic field produced by the stator. Such motors are called induction motors. More than 80% of AC motors are induction motors. (The electric fans that we use at home or small motors for refrigerators or pumps are all induction motors fed from a single phase which is split with the help of capacitors into equivalent 2-phase supply.)

Induction motors are robust and cheap unlike DC motors which are costly and need regular maintenance. The fact that AC voltage/current may be transformed and that alternating current may drive motors very efficiently, tilted the decision even more regarding the mode of power generation in favour of AC.

In the 'war of currents' between DC and AC, DC lost.

It is interesting to recount in this context that almost a war was waged in the United States during the end of the 19th century, to resolve whether DC or AC should be used for power supply. Thomas Alva Edison, a great inventor, advocated DC supply since he believed that DC was more suitable for lighting the bulbs that he had invented. Nicola Tesla and George Westinghouse advocated AC supply. The question became particularly crucial since the Niagara falls presented an immense storehouse of hydro electric energy. Edison wanted to generate DC and Tesla stood for AC.

Edison tried to convince the Americans that AC power was unsafe for use. To quote from Cheney's book [1], "At West Orange, New Jersey, families living in the neighbourhood of Edison's huge laboratory began to notice that their pets were vanishing. Soon they found out why. Edison was paying school boys twenty five cents a head for dogs and cats, which he then electrocuted in deliberately crude experiments with alternating current." He wanted to prove that AC was dangerous.

But fortunately for us all, Edison lost this 'war of currents' as it was called. Alternating current is generated and consumed all over the world today and the person we should be particularly grateful to is Nicola Tesla. It would have been impossible to generate DC power in bulk and transmit and distribute it economically. (See *Box 1*)

Since DC voltage/current cannot be stepped up or down using transformers, a meagre 10 MW of power generated at say Niagara at 400 volts to be transmitted to New York would involve the transmission of 10 בְּ 10^6/400 = 25000 amperes of current. This huge amount of current would need two copper conductors of approximately 15 cm diameter each, spanning hundreds of

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[1] *TESLA: Man out of time.* Margaret Cheney. A Laurel Book, Dell Publishing Company. New York 1983.

Box 1. HVDC

Having lost the 'war of currents', DC transmission has staged a come back in the form of high voltage DC (HVDC) transmission. Transmission of bulk power across long distances demands high voltage. Although in India we have 220kv and 400kv for power transmission, Ultra High Voltage AC (UHVAC) transmissions at 500 or 735kv is not uncommon in the west. If instead of AC, we could transmit power at HVDC over long distances it becomes cheaper beyond a certain length, since DC transmission needs two conductors whereas AC transmission needs three (or six), transmission towers and insulation costs are also less. For obtaining HVDC, AC power is stepped up to high voltage, (400 – 600kv). It is then rectified (i.e. alternating current changing direction 50 or 60 times a second is made to flow in one direction) and transmitted. At the receiving end DC is inverted (i.e. turned into 3-phase AC at the system frequency) and stepped down.

HVDC links also enable us to interconnect areas at different frequencies. In India although we use 50Hz, the system frequency often drops below this frequency. Our generation cannot meet the demand and the losses, particularly in the northern and the eastern sector. A national grid helps us to transmit power from surplus to deficit areas. If areas depending mainly on hydropower (Kerala, Karnataka) suffer deficit due to monsoon failure, power from thermal stations in other areas can be transmitted to meet the demand.

Interconnecting the northern and the southern grid by AC lines presents major problems since these areas often operate at different frequencies. Interconnecting large AC areas by AC links present problem in many countries and HVDC has proven to be cheaper and effective in this respect.

Large, far-flung power systems may be prone to instability. Voltage, current frequencies may oscillate leading to a system collapse. HVDC links often help to alleviate such problems.

kilometres for its transmission. It is virtually impossible to do so.

On the other hand, 3-phase AC power, which needs no commutation, can be produced at a relatively high voltage (11-15 kV). A typical thermal generator produces 220 MW or 500 MW of power. If the generated voltage is stepped up to 400 kV, the current required to transmit 500 MW of power down 3 lines would be only 1400 amperes *requiring 1/18th conductor size for transmitting 50 times the power.* The case is clearly in favour of AC.

The Power System

It is necessary to realize in this context that AC generators are seldom operated in isolation for power production. If the power requirement of a small town is 10 MW and we have a single AC generator of 10 MW supplying the load requirement of this town, we would need at least two generators, one in operation and the other as a stand by to allow for breakdown and routine maintenance. It is uneconomical to generate small amounts of power except for small hydroelectric units for remote areas. Duplication is necessary for maintaining continuity of power supply.

A large number of generators are made to feed into a common grid rather than operate in isolation.

It is, therefore, a standard practice to form a large pool and wherever power is generated it is fed into this common pool. Power required for a town can be simply drawn out of this pool. Such an arrangement not only avoids unnecessary duplication but ensures good performance, economy and continuity of supply. Needless to point out in this context that electrical energy can hardly be stored and power generated by all the generators connected to the pool has to be immediately consumed, allowing for the losses in transmission and distribution. *Figure 1* represents a small system comprising generators, transformers and loads. Huge steel towers supporting three or six lines suspended from insulators are commonly seen in the countryside. A thinner wire at the top of the towers is called the ground wire (providing protection against lightning) and the three (or six) thicker wires carry three phase current. These constitute transmission lines represented by single lines in *Figure 1*.

If the total power generated is given by $\sum_{i=1}^{n} P_{Gi}$ and the total load is $\sum_{j=1}^{m} P_{Lj}$ then

$$\sum_{i=1}^{n} P_{Gi} = \sum_{j=1}^{m} P_{Lj} + \sum P_{Loss}.$$

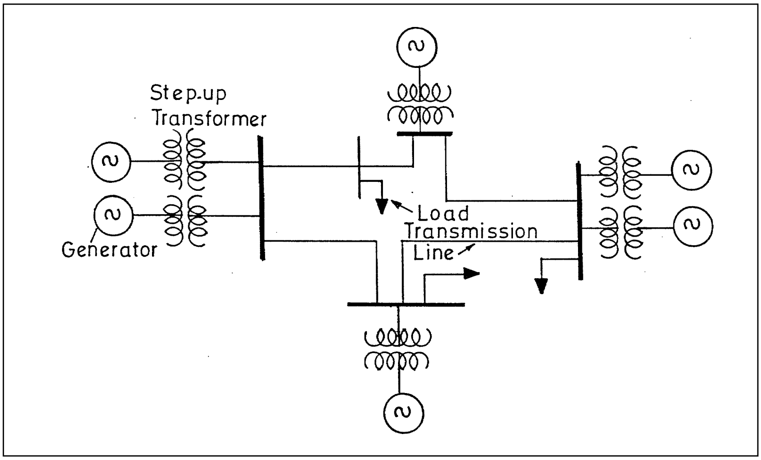


Figure 1. A single line representation of a small power system. The generators are connected to a 'power pool' from which the loads are supplied. Power supply can continue if one or two generators are taken out or a line is disconnected. Hydro generators and thermal generators are all 'synchronized' into the system. All of the generators must generate AC at a specified frequency (50 Hz in India).

Power loss takes place in transformers and in transmission lines. If the load demand [$\sum P_{Lj}$] increases and the generated power is inadequate, the frequency drops below the stipulated 50Hz. This drop in frequency activates governors and more steam (or water) is forced into the turbine to generate more power. If the load drops, the frequency increases and steam input is reduced. Generated power is fed to transmission lines through STEP UP transformers. (See *Figure 2* in Part 1 of the article.) Closer to the load centre, the transmitted power (at 400 kV or 220 kV) is received at a substation where it is stepped down to 110 or 66 kV, stepped down further to 11 kV until it almost reaches our doorstep.

Domestic Connection

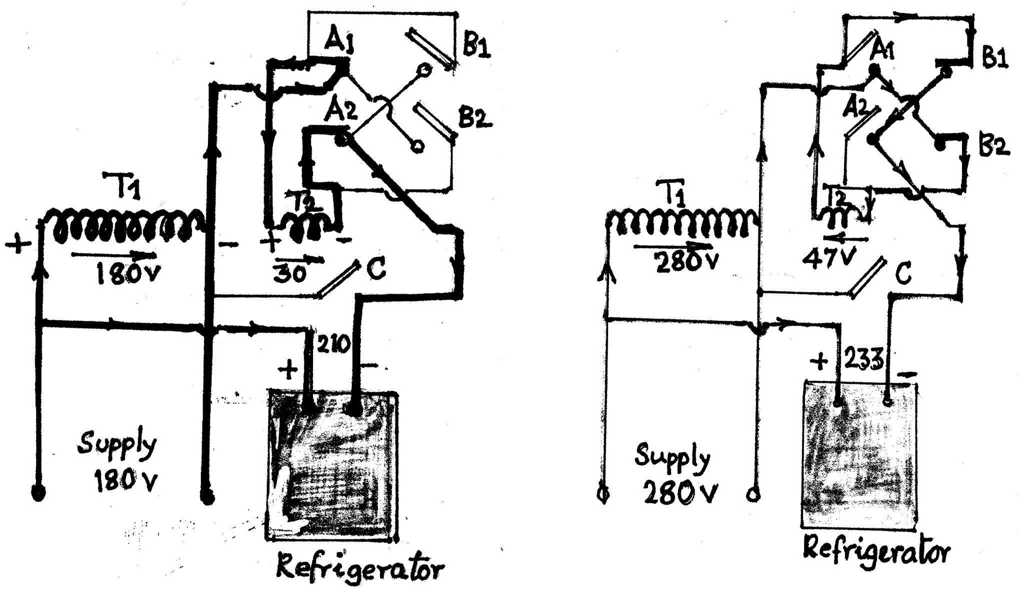
Close to our residence, we may notice small transformers called distribution transformers mounted on poles. Three phase power is fed to the primary windings of this transformer at 11 kV. At the secondary we have three phase output at 415 volts. There are three conductors for the three phases and a fourth wire called the *neutral*. The voltage measured between any two phases (or lines) is 415 volts and the voltage measured between one of the phases and the neutral is about 240 volts. Power is supplied to our households by providing one of the three phases and the neutral. This essentially is a single phase supply.

Box 2. Voltage Stabilizer

The voltage stabilizers that are commonly used to protect refrigerators or other domestic appliances are essentially simple devices. *Figure 2* represents a simplified version. T_1 and T_2 represent the primary and secondary windings of a transformer. The secondary has about 1/6 th the number of turns of the primary.

If the supply voltage is within the range of say 200 - 240v, the switch C is closed and the supply (from the socket) is directly connected to the appliance to be protected.

If the supply voltage drops to say 180v, the stabilizer comes into action. The switch C is opened and A_1, A_2 closed (*Figure 2a*). Trace the path (shown in red) and you will see that the 180 volts across the primary adds to the 30 volts ($N_2 / N_1 = V_2 / V_1 = 1/6$) and a total of 210 volts is applied across the refrigerator. If the supply voltage goes too high, to say 280 volts, the switch C is opened and B_1, B_2 are closed instead of A_1, A_2. The secondary voltage is 1/6 th of 280v, i.e. 47 volts approximately. Trace the path again (shown in blue in *Figure 2b*) and you will see that the secondary voltage is subtracted from 280 volts and a net voltage of 233 volts is applied across the refrigerator. So the refrigerator receives safe voltage although the supply voltage may vary from 180v to 280v. There are electronic sensors which sense the voltages and relays to actuate the switches as required.



(2a) **(2b)**

Figure 2. A simple domestic voltage stabilizer.

Earthing is important.

Most electrical gadgets that we use are fed from sockets with three holes. The large one at the top is called the *earth point*. The two lower ones are the phase and the neutral. The sockets usually come in 5 ampere and 15 ampere ratings. Gadgets up to 750 watts (electric iron for instance) can be safely used out of a 5 ampere socket.

If you insert an electric tester into one of the smaller holes of a socket and the tester glows, the hole corresponds to the phase. The hole in the socket corresponding to the neutral should strictly be at zero voltage and the tester should not glow if you insert the tester into it. But unfortunately sometimes the neutral is not properly grounded and the loads on the 3 phases feeding a locality are not uniformly distributed. This unbalance may cause the neutral to acquire a voltage which is undesirable and often unsafe. It is necessary that the earth wire of a gadget (usually the green one) is connected to the bigger pin of the plug and the larger hole in the socket is earthed. If the gadget has a metal body, earthing is particularly necessary. If for some reason the metal body gets connected to the phase wire, current flows into the earth rather than through our body. If the earthing is not proper it may be dangerous.

It is not uncommon in our country that line to line voltage (415v) appears across the phase and the neutral, damaging any equipment that happens to be connected.

Electric switches and sockets should not be located in the bathrooms. Collection of moisture in them and the drastically reduced body resistance when we are wet may prove dangerous. It is unfortunate that the voltage and the frequency of power supply in our country fluctuate well beyond permissible limits. If a refrigerator is not connected to a voltage stabilizer, switch it off as soon as the voltage drops. It is not necessary to worry about incandescent lamps. On the other hand if the voltage increases it is advisable that incandescent lamps are immediately switched off. Motors are not to be run when the voltage is low because high currents are drawn. Incandescent lamps can operate at low voltages but the power obtained will sharply drop since for an incandescent lamp, $P = V^2/R$. If the voltage goes a little too high (as may be evident from an incandescent lamp at night and impossible to know during the day) *everything* should be turned off. Since the damage to various equipment is done much faster than we realise, it is wise to protect expensive equipment by using voltage stabilizers. See *Box 2.* It is not uncommon in our country that line to line voltage (415v) appears across the phase and the neutral, damaging any equipment that happens to be connected.

Contingencies such as voltage and frequency fluctuations should not arise in a well designed and well maintained power system, leave alone the frequent load shedding that has become so common in India. Unfortunately, our power generation cannot meet our demand. Besides, our power systems are inadequate and poorly maintained. They have to be augmented and modernized significantly to meet the required standards if India has to step into the twenty first century.

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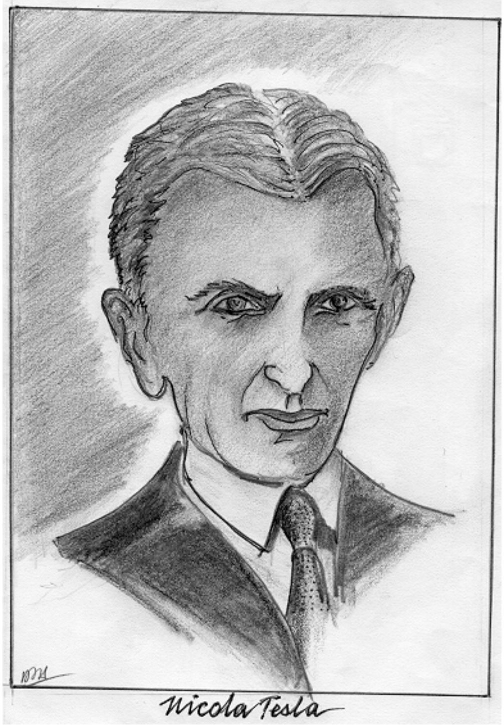

(1856-1943)

Nicola Tesla was born in Croatia in 1856. Described as a visionary genius, Tesla who harnessed the alternating current we use today is said to be the real inventor of radio. He invented fluorescent lighting and introduced the fundamentals of Robotics, computer and missile science. A loner, he died in 1943 in a New York hotel room where he lived most of his life. Tesla's discoveries changed and continue to change the world we live in. But we know so little about him!

(Illustration by the author)