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Why is the neutral conductor not dangerous?

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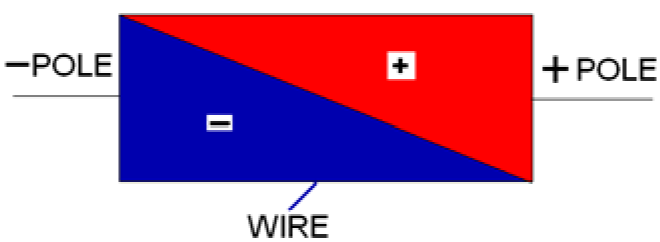
I will begin this article with a brief extract from my article to the question what a battery is, because I need it for what follows (for more details please see ***What is a battery?***).

A battery can be regarded as a container of a dissolved agent (acid, base or salt) wherein two metal plates (say copper and zinc) are partly immersed. The part of the copper plate outside the liquid is polarized in one sense (plus +), the immersed part in the opposite sense (minus -). For the zinc plate applies the opposite. Plus means blowing, Minus means suctioning (in relation to this, please see **Is positive and negative electricity nomenclature arbitrary?** and **What is an electric wind?).** The two metal plates of the battery can be imagined as two fans. The one that is blowing outside the liquid (positive electrode = copper), it is suctioning inside the liquid; the one that is suctioning outside the liquid (negative electrode = zinc), it is blowing inside it. When the electrodes are connected with a metal wire, a closed flux is created. The Plus is the strongest near the Plus-pole and, as we move away from it through the wire, its strength continuously decreases. The same applies to the Minus, but starting from the Minus-pole. Figuratively, we can represent it this way:

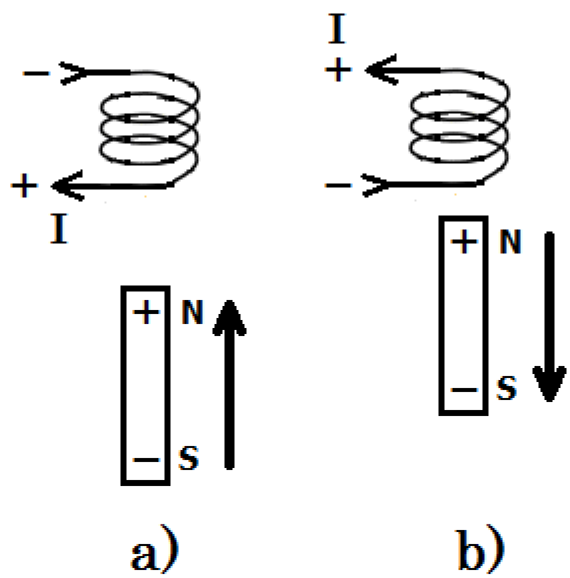


Let's say the DC source is of a pretty high voltage. If we touch with one hand one of its terminals and with the other hand a large electrically conductive object (which is not otherwise connected with the circuit), then we can sense an electric shock. However, if we do the same again, but this time touching ***the middle of the connecting wire***, then nothing will happen, that is, we won't sense anything. Why?

In the first case we have touched either the Plus or the Minus terminal of the DC source where the intensity of the blowing or of the suctioning is very strong. In the second case we have touched a point on the wire where the blowing and the suctioning have equal intensities. ***Thus in that point they completely cancel each other out regarding their intensities toward outside the circuit***.

In other words, if ***two equal resistors*** are connected in series to a high voltage source, then the point between the resistors is not dangerous toward outside the circuit. What does it mean **"***toward outside the circuit***"**? It means that if we touch that point with one hand and at the same time a large electrically conductive object (which is not otherwise connected with the circuit) with the other hand, then no electric shock will be sensed. In relation to this, please see ***these two very important*** articles ***What is "Ground" in electricity?*** and ***Electricity flows in an open circuit, too!***

Let me now jump to the alternating current. As many of you already know, when we move a magnet in and out of a coil, we induce an alternating current in it. When **we move the magnet toward and into the coil**, we induce an electric current in one direction. When **we move the magnet out and away from the the coil,** we induce an electric current in the contrary direction. We can also move the magnet only toward and away from the coil, **without inserting it inside (figure below).** In this case the induced current is somewhat weaker.

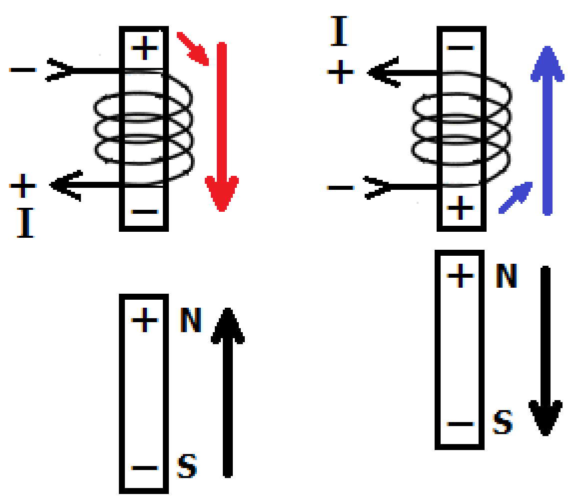


When we move the magnet toward the coil, then the induced current in it has such a magnetic field that it resists the movement of the magnet, that is, it repels the magnet. When we move the magnet away from the coil, then the induced current in it has such a magnetic field that it resists the movement of the magnet again, that is, it attracts the magnet (this is the so-called Lenz's law).

If we now place a soft iron core in the coil and **move the magnet again toward and away from the coil** (holding the core with the other hand to prevent it from attaching to the magnet), then the induced current has the same direction as before, only it is considerably stronger. But look, something very interesting is happening here: when we were moving the magnet toward the empty coil, the magnet was repelled by the magnetic field of the induced current in the coil; when we were moving the magnet away from the empty coil, the magnet was attracted by the magnetic field of the induced current in the coil. But now, when we are moving the magnet toward the non-empty coil (that is, with the iron core in it), the magnet is attracted to the iron core; and when we are moving the magnet away from the non-empty coil, the magnet is repelled by the iron core **(footnote 1)**. In other words, we have actually opposite situations in the cases with and without the iron core. **But in spite of that, nothing changes regarding the direction of the induced current.**

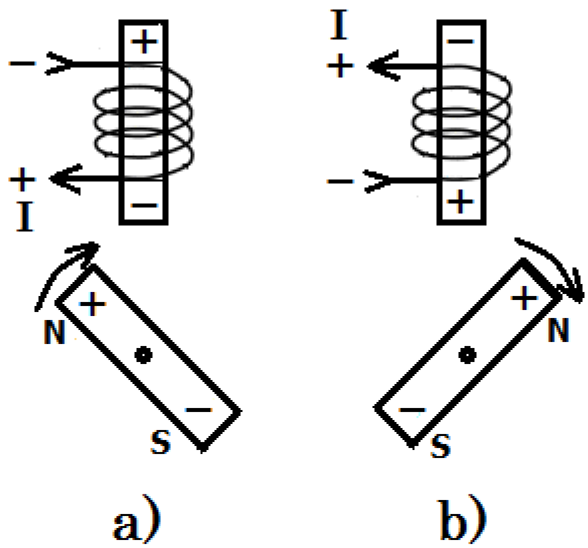
(footnote 1) If we hold with one hand the iron core and with the other hand move the magnet, we can feel how the core is moving toward the magnet during the movement of the magnet toward the core and we can also feel how the core is moving away from the magnet during the movement of the magnet away from the core. See also ***Is the force between a magnet and a magnetic material always attractive?*** **[end of footnote]**

How can we explain the fact that the direction of the induced current is the same in both cases? Look, when we insert a magnet into an empty coil with its Plus-pole ahead (I call **Plus** the pole of the compass-needle which points North. In relation to this please see*:* ***Is positive and negative electricity nomenclature arbitrary?*****),** then the direction of the induced current is the same as when we insert the magnet **with its Minus-pole ahead into the opposite side of the coil**. Therefore, the case when we move the magnet with its Plus-pole ahead toward a non-empty coil is equivalent to the case when we insert a magnet with its Minus-pole ahead into the opposite side of the empty coil [marked with the red arrow in the figure (a) below]. However, the case when we move the magnet with its Plus-pole ahead away from a non-empty coil is equivalent to the case when we insert a magnet with its Minus-pole ahead into the same side of the empty coil [marked with the blue arrow in the figure **(b)** below].



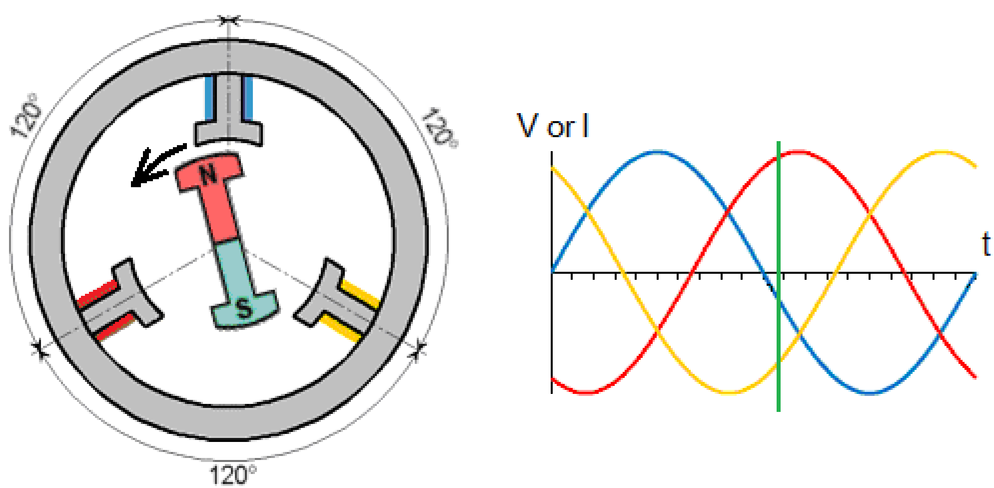
a) b)

But inducing a current in a coil by oscillatory motion of a magnet is not feasible in practice. Therefore, the current in the generators is induced by rotational motion of a magnet. Look at figure below:



The magnet, which sits on the same axle as the turbine, is rotating clockwise. When the Plus-pole is approaching the coil with the iron core (figure **a**), then it is comparable to the situation **(a)** of the second to last figure. When the Plus-pole is moving away from the coil with the iron core (figure **b**), then it is comparable to the situation **(b)** of the same figure. When the magnet is, so to say, face to face with the coil, then the induced current drops to zero.

If the magnet is rotating between three coils placed at angles of 120°, we get three independent sources of alternating current, a three-phase generator (diagram below).

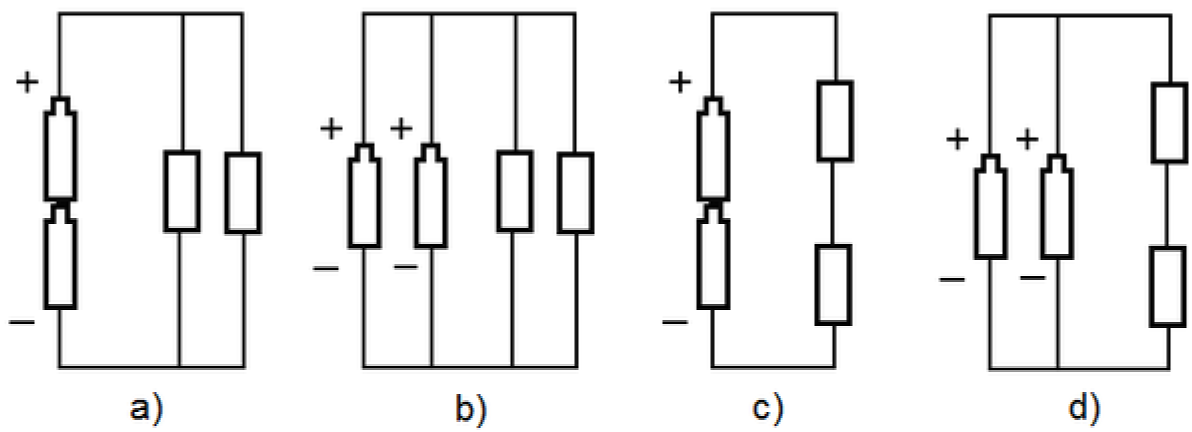


The magnet in the diagram is turning counter-clockwise. With the vertical green line in the graph on the right is marked the moment, that is, the position of the magnet in the left diagram. The faster the magnet is turning, the greater will be the frequency as well as the induced voltage/current.

That the magnet is turning counter-clockwise, we can conclude it from the graph most easily in the following way: when the magnet is exactly opposite the blue coil, then its current is zero. The next encounter exactly opposite a coil will occur between the opposite pole of the magnet and one of the other two coils. Since after a zero point of the blue sine curve follows a zero point of the yellow curve, it means that the S-pole will move toward the yellow coil.

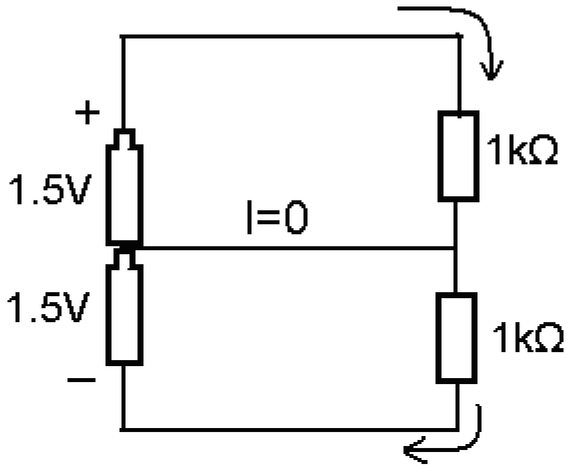
Although the three coils are independent sources of alternating current, still in practice they are connected. The connection can be star- or delta-connection. I use to call the star-connection a series-connection, while the delta-connection a parallel connection. Let me explain something and later on we will see that the series connection corresponds to the star-connection.

Imagine we have two equal batteries and two equal resistors. They can be connected in four ways presented below:

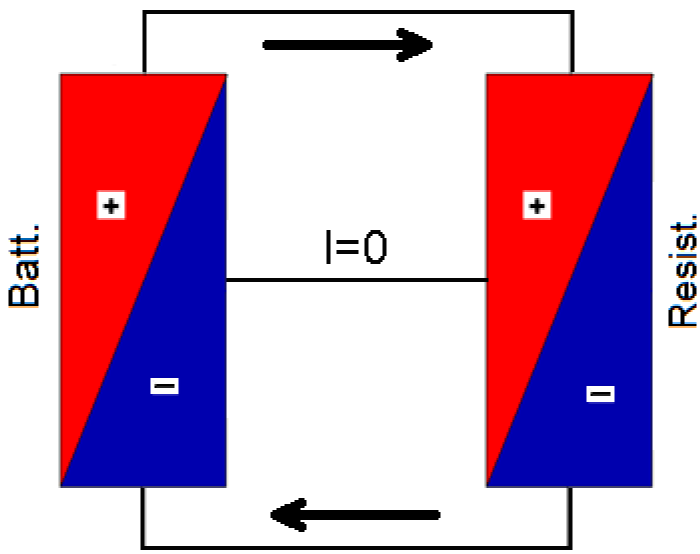


The batteries as well as the resistors can be connected either in series or in parallel connection. In the circuit marked with **(a)** is flowing the maximum current. The four circuits are actually ordered from the maximum to the minimum current. **The series connection is a Plus-connection on the generator's side (intensifying, increasing), while it is a Minus-connection on the load's side (attenuation, decreasing).** The opposite is valid for the parallel connection. So, we get a maximum current when the batteries are connected in series and the resistors in parallel. The minimum current we get when the batteries are connected in parallel and the resistors in series.

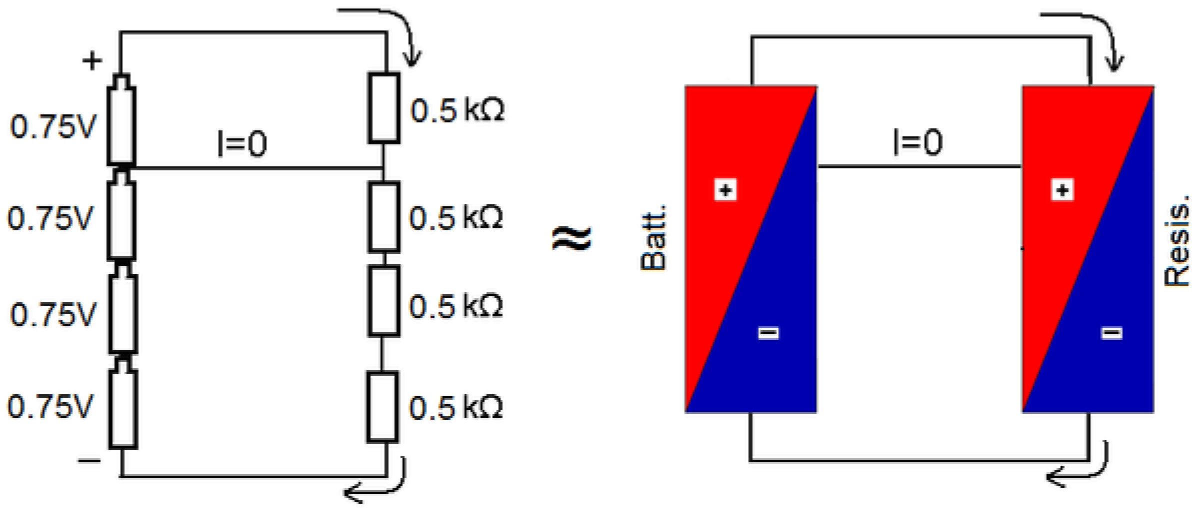
Let's say we connect now those two identical batteries and resistors as presented below:



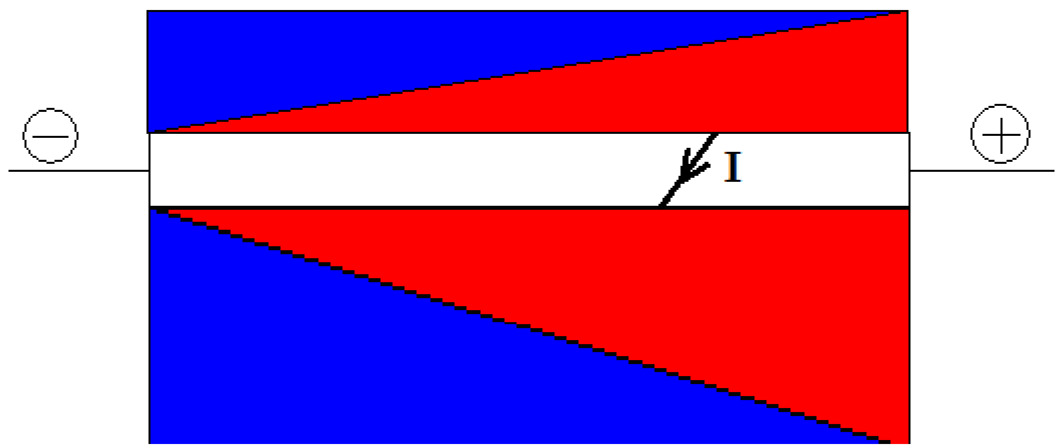
No current is flowing through the middle horizontal branch. Why? Look at the next figure:



The distribution of the Plus- and the Minus-intensity in the batteries can be figuratively represented just as it was represented in the resistor from the beginning of this answer. Since the horizontal middle wire connects two points where the ratio Plus/Minus is the same, no current can flow through it. Let's imagine that instead of two 1.5V batteries and two 1K resistors, we have four 0.75V batteries and four 0.5K resistors connected as in the figure below. If we connect, so to say, the 1/4 points on both sides, we will again get no current in the middle horizontal branch.

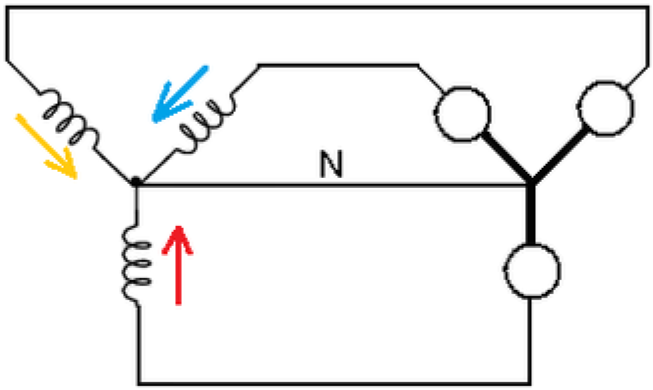


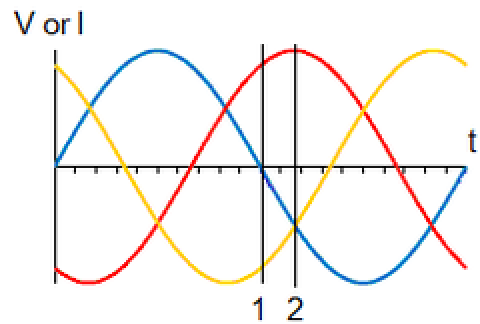
What has just been said does not apply only between generator's and load's side, but also between resistors connected in parallel. Look please at the figure below:



In this figure are represented two wires of different resistance connected to a battery. The lower wire has a lower resistance than the upper wire. Through the cross wire will flow an electric current downward because at the upper connection-point the ratio Plus/Minus is greater than at the lower connection-point. Please pay attention to this: although the Plus is stronger at the lower point, yet the Minus is also stronger there which considerably cancels the strength of the Plus. Note also this: since an electric current is flowing through the cross wire, the distribution of the Plus- and the Minus-strength in the two resistance wires will not look like in the figure anymore. However, the current through the cross wire is very weak when the cross wire connects two points with a small difference in their Plus/Minus ratios. In that case we can consider the presented distribution as approximately valid (in relation to this, see also **Wheatstone bridge - Wikipedia**).

Back to the three-phase current. Look please at the diagram below:

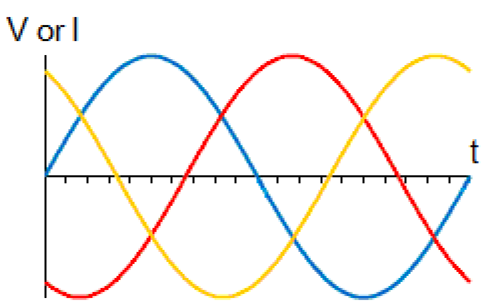




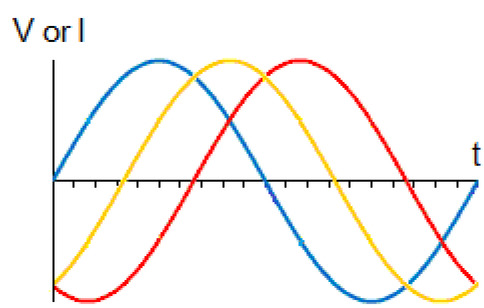
On the left side is shown a three phase generator with **three identical lamps** connected to it - one lamp to each phase **(so-called balanced load)**. The coils as well as the lamps are in star-connection. The central points of the stars are connected with a wire. It is the neutral wire.

As a reference direction for the induced currents in the coils we must choose between two possibilities: either all of them will point away from the star-point or all of them will point toward it. **(footnote 2)**

(footnote 2) Why must we choose so? Let me explain it. When we make a three-phase generator, we want the time dependence of the induced voltages/currents to be as shown in the figure (a) below. But if we don't pay attention to something, we may get an arrangement of the sine curves as shown in the figure (b). We don't want that to happen because in that case we won't have a proper Neutral, the electric motors will not turn and many, many other problems.

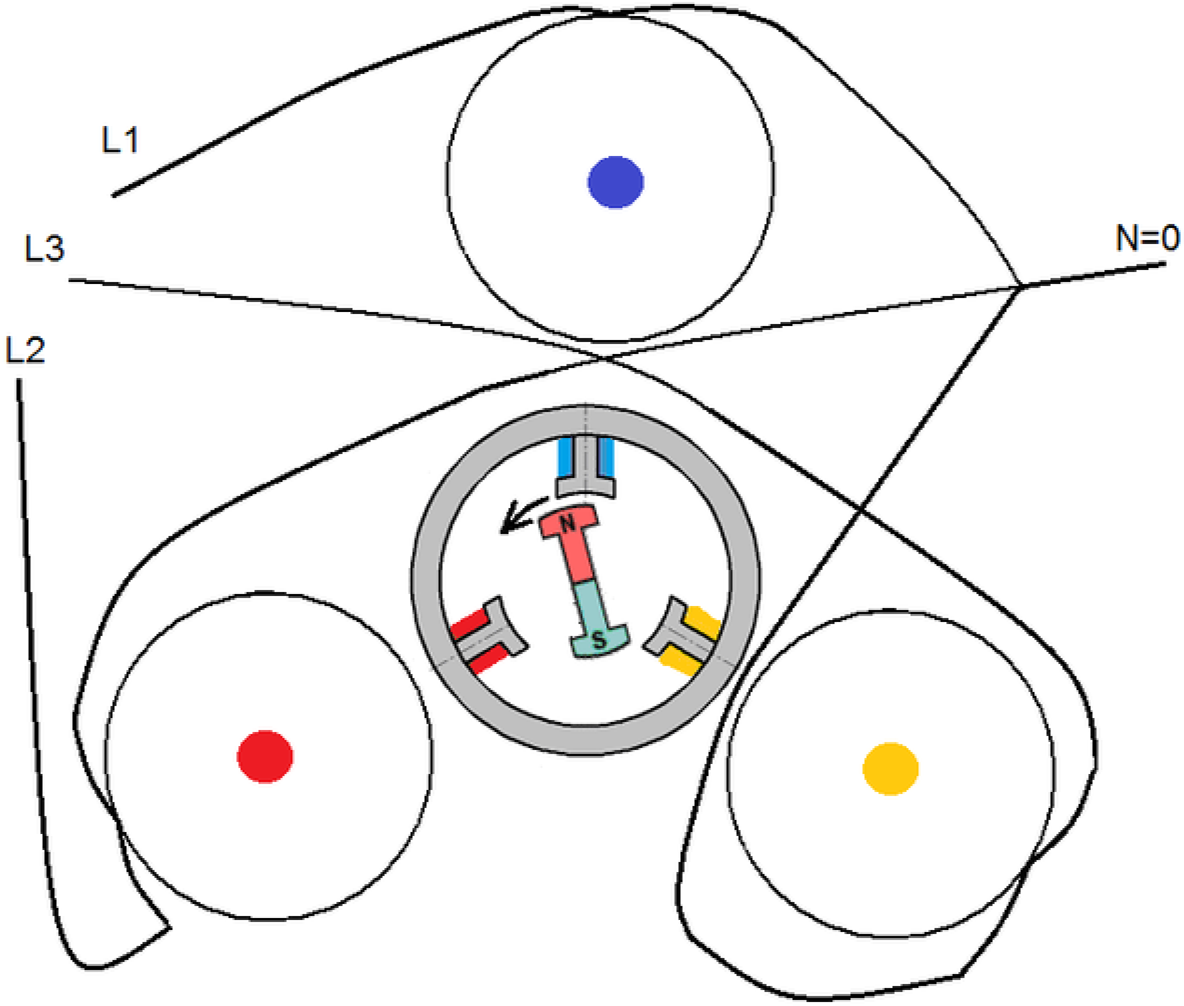


a)



b)

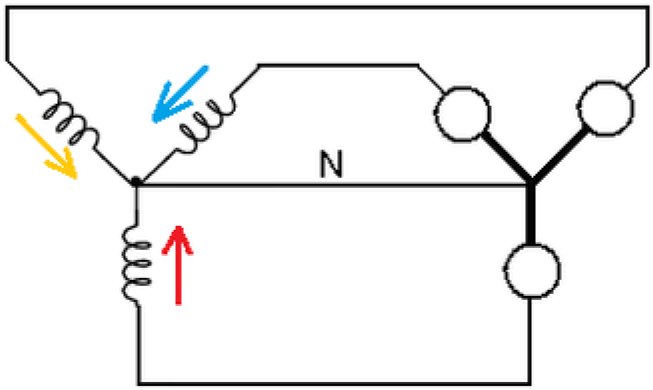
What should we pay attention to? Look please at the figure below. **The right ends** of all three coils are connected together to form the star-point and **the left ends** of all three coils are phases.

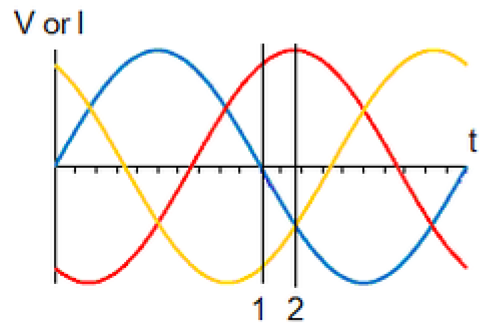


When the North-pole of the magnet is moving toward the red coil, then the left end of the coil will be Plus and the right end will be Minus. The same will happen when the North-pole is moving toward the other coils. Only in this way we will get a proper arrangement of the sine curves and consequently a proper Neutral.

With the arrows pointing either away from the star-point or toward it, we actually make something which is in agreement with the things I have just said. The arrows actually show that when a pole of the magnet is moving toward a coil, the induced current has always the same direction. **(end of footnote)**

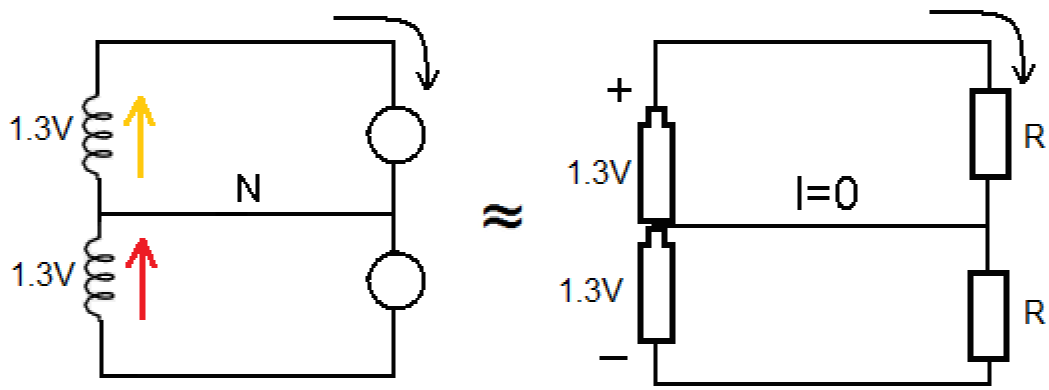
As you can see, with the arrows painted in the same colors as the sine curves (red, orange and blue) I have chosen the variant the arrows pointing **toward the star-point.**



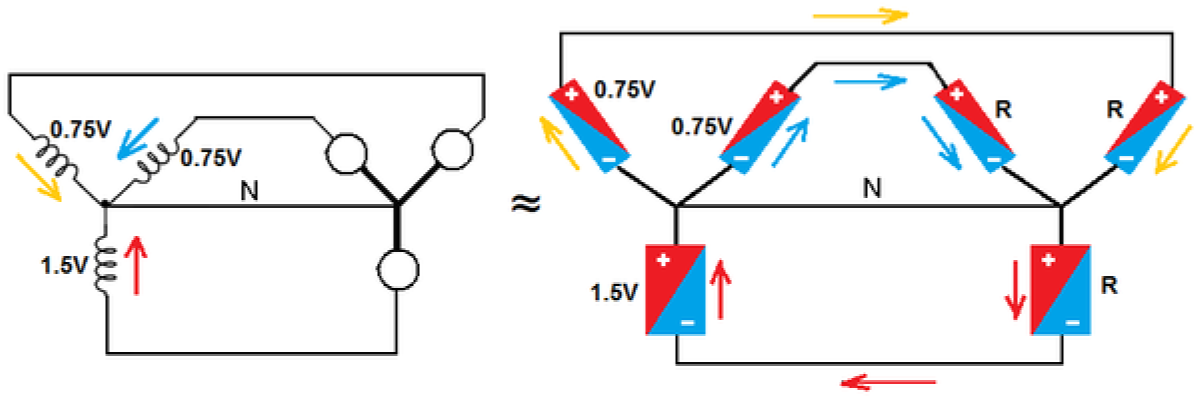


Let’s consider the two moments marked with No.1 and No.2 in the graph on the right. As we can see, in the moment No.1, the current in the blue phase is zero, while the currents in the red and orange coil have the same intensity, only the red current is positive, whereas the orange is negative. What does that mean? It means that the current in the red coil has the same direction as its arrow, while the current in the orange coil has the contrary direction of its arrow.

Let’s say the maximum voltage (i.e. the amplitude) which every phase reaches is 1.5V. In that case, the red and the orange coil in the described moment have a voltage of 1.3V (sin 60° x 1.5V=1.3V). Since the current in the blue coil is zero, in this moment the situation with the coils is **equivalent to the situation with the batteries** presented in the figure below:

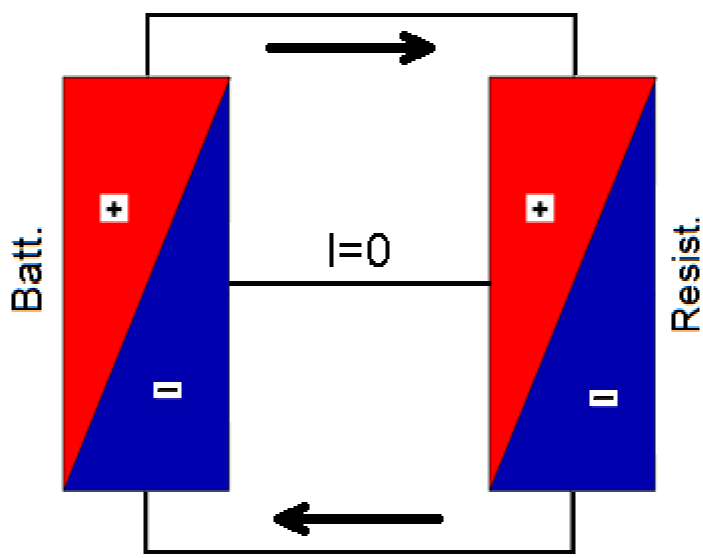


Let’s consider now the moment marked with No.2. The current in the red coil has risen to the positive maximum, whereas the current in both other coils is exactly half of the negative maximum. The situation in this moment can figuratively be represented in the following way:



Look please at the figure on the right. With the colored arrows are now shown **the factual directions** of the currents through the branches. As we can see, the blowing of the red coil toward the star-point is ideally met by two equal suctions of the other coils. The same applies also to the star-point on the resistor's side, only the directions are reversed.

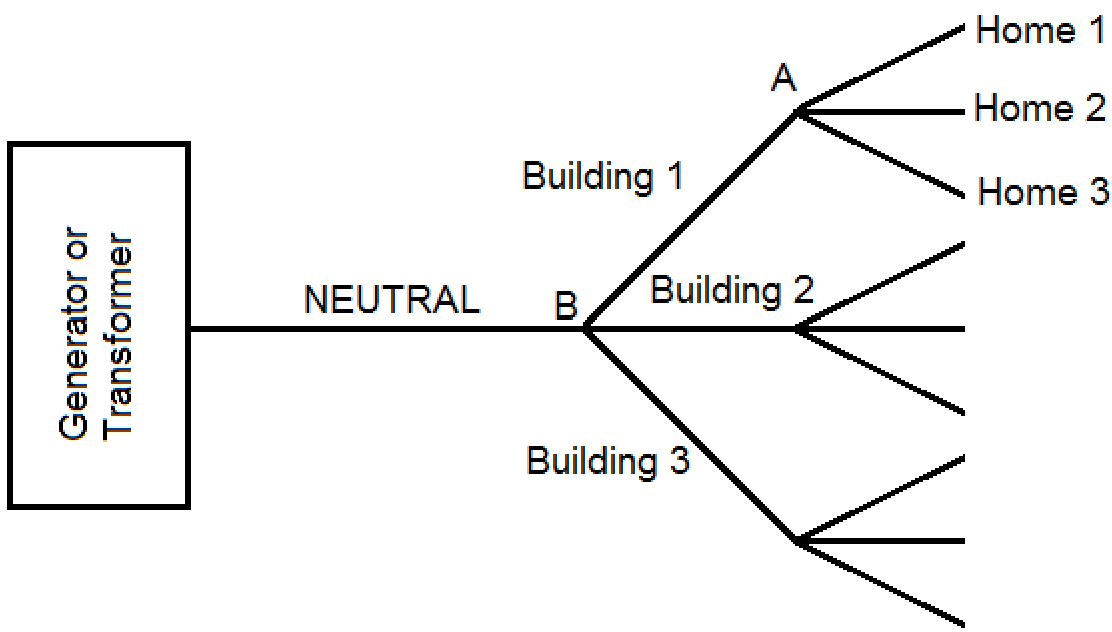
The sum of the orange and blue current is the red current. In this moment we have the same situation as we have already had above:



This situation takes place actually in every moment of time provided that the load side is balanced. In practice, the load side is always very close to balanced. How so? Because there is a large number of end-users. Let me make a comparison. If we throw a coin ten times, the result could be 7 to 3, or 70% to 30% in favor of heads or in favor of tails. But if we throw the coin thousands of times, the result will be very close to 50% to 50%. The same applies to the electricity. The higher the number of the end-users, the greater is the likelihood that the load on the three phases will be evenly distributed.

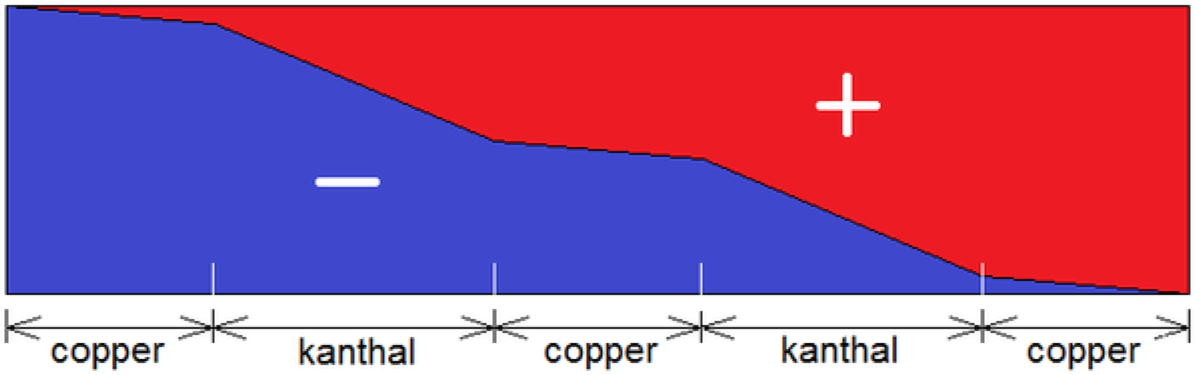
If the load is not evenly distributed, then a current will flow through the neutral conductor. It will bring disturbances in the rotation of the generator, that is, it will affect its smooth rotation. The coil where more current is flowing will offer a greater resistance to the rotation of the rotor's magnet than the coil where less current is flowing. If the load is evenly distributed and thereby increases, then the resistance to the rotation of the rotor's magnet also increases. Therefore the wicket gates at a hydropower plant need to be opened wider to allow greater flow of water to maintain the same frequency of turning and thus the same output voltage.

Let me briefly mention yet another thing. Once the neutral conductor comes out of the last transformer, we may call it a trunk. Then it branches off into many buildings and again each branch splits toward many apartments of the end-users (figure below). The same applies to the phases.



Let's consider an **"**ideal**"** case. Let's say that **the Phase 1 of the Home 1** is more loaded than the other two phases. It is also the case in the Home 2 but there with the Phase 2 and in the Home 3 but there with the Phase 3. Through the neutral wires in all three homes will flow a certain amount of current, but these three currents will close themselves in **the point marked with A** in the figure above**.** If they don't complement ideally, then a certain amount of current will flow between the points A and B. This current may complement with the currents from the other buildings. I have drawn in the figure only three buildings with three homes each, but the number is usually much bigger.

Wherever we touch the neutral wire, it doesn't make much difference, because it is usually made of copper. The copper is a very good conductor, thus the voltage drop along a copper wire is negligible. What is a voltage drop? Consider the following figure:



Two pieces of a highly resistive alloy (Kanthal) and three pieces of copper wire are connected in series. The two kanthal pieces are actually two resistors. We see that the ratio Plus/Minus along the kanthal sections changes much more rapidly than along the copper sections. The middle copper section corresponds to the neutral wire.

I am sure that the slope in the copper sections is much more gentle than it can be represented in a small drawing.

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See also: **What is an electrical current?**