

April 15, 1930.

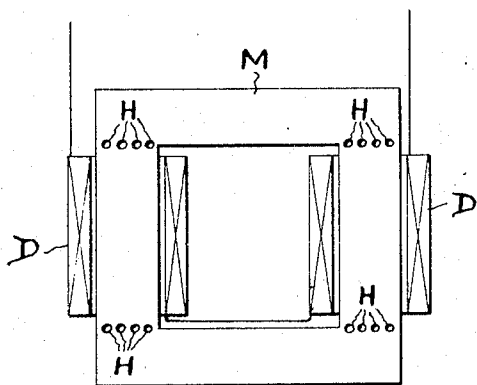
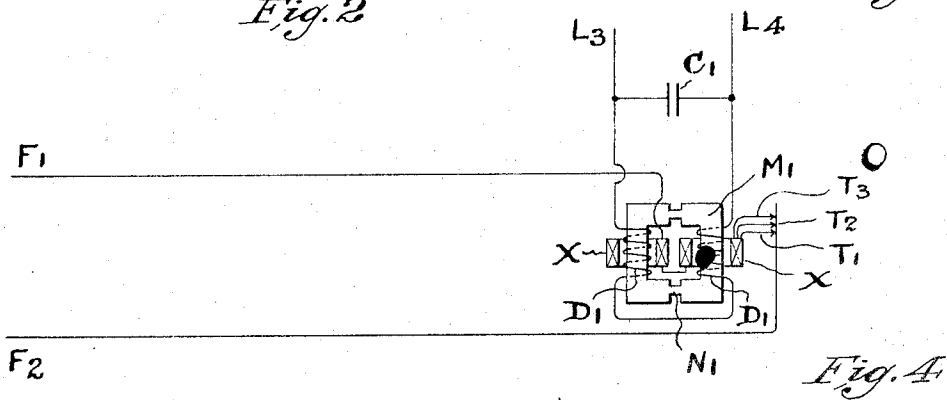
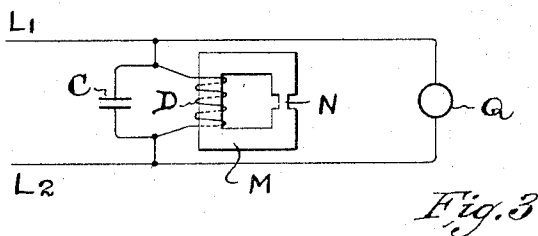
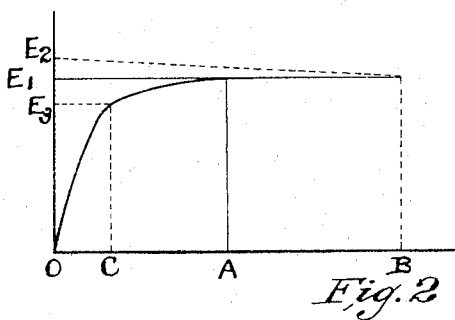
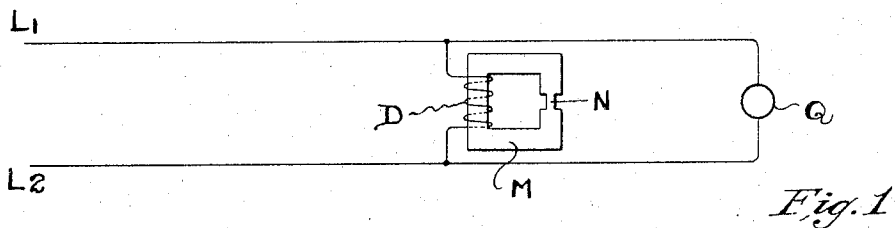
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1,755,060

AUTOMATIC VOLTAGE REGULATING MEANS

Filed May 6, 1927

2 Sheets-Sheet 1



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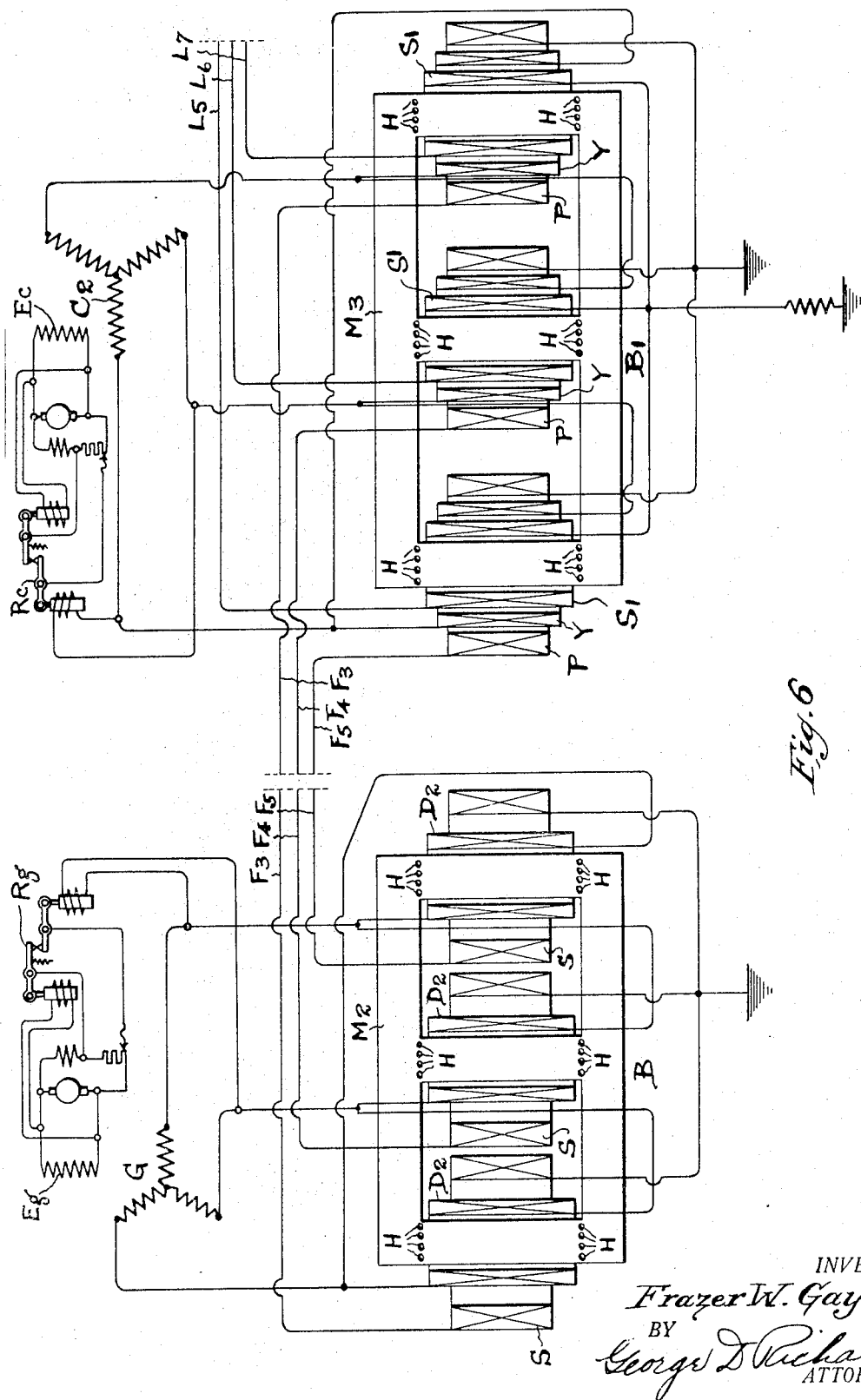
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AUTOMATIC VOLTAGE REGULATING MEANS

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2 Sheets-Sheet 2



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AUTOMATIC VOLTAGE-REGULATING MEANS

Application filed May 6, 1927. Serial No. 189,241.

This invention relates to improvements in voltage regulating means for power circuits; and the same has reference, more particularly, to a simple magnetic means adapted for substantially instantaneous automatic operation whereby the voltage transmitted through power lines is efficiently regulated under wide variations of load.

Heretofore voltage regulation in connection with power circuits has been usually attained by means of motor operated induction regulators controlled by contact-making voltmeters, or by synchronous condensers either hand operated or controlled by automatic voltage regulators. Certain objections to the usual forms of induction regulators have been noticed; for example, the same are slow in operation; expensive to maintain, since they require more or less frequent repair, for which reason it is generally necessary to locate the same in substations where they may be subject to periodical inspection and overhauling; furthermore, such induction regulators are very noisy and for this reason can not be located in a residential district unless enclosed in sound-proof housing. Synchronous condensers are fairly well adapted to serve long transmission lines for carrying heavy power, but such electrical devices are generally very large and are usually slow acting, requiring an appreciable time (running into several seconds) to effect large increases or decreases of the machine magnetism. Furthermore, under sudden and large variations in load there are corresponding sudden and great variations in voltage. In the event the load is suddenly decreased, as, for example, by the opening of a circuit breaker following a short circuit, the voltage at the end of a long transmission line may rise to a very high value due to the slow operation of the automatic electro-mechanical means connected with transformers and regulating devices ordinarily included in the line, and which operate to balance line drops in voltage caused by variations in load. When the above effects are coupled with the effects of a heavy charging current normally existing in a long transmission line, and which is also immediately operative on decrease in load

to raise voltage both at the generator station as well as at the distant end of such long transmission line, the very high resultant voltage, especially at the end of the long line, may reach a dangerous value. In the event the transmission line is operating at a very heavy load and an additional heavy load of low power factor comes on, such, for example, as is caused by a feeder short circuit through reactors, then the voltage will suddenly fall, and the resulting disturbance coupled with low voltage may be sufficient to upset the stability of the entire system, and cause the falling out of step of synchronous apparatus with consequent interruption to normal power service.

The instant invention has for its principal object to provide a novel and simple means for voltage regulation which will overcome the above noted and other difficulties, the same comprising a quick and automatically operative regulator device in the form of a reactor or transformer having a core constructed to provide a magnetic circuit adapted to saturate at a predetermined induced voltage value, preferably in combination with a condenser of sufficient capacity to more or less neutralize the magnetizing current of the reactor or transformer at approximately normal voltage; all whereby the core of the reactor possesses a saturated section to absorb large watt-less magnetizing kilovolt-amperes at normal voltage, which magnetizing kilovolt-amperes will greatly increase upon a slight increase in voltage and almost disappear upon a slight decrease in voltage. The resultant wide variation in magnetizing current largely offsets load variations, so that there is very little change in voltage under such load variations. Thus the novel regulating means of this invention may be employed alone, or as an auxiliary to the ordinary electro-mechanical regulating devices commonly included in long transmission lines so that the former instantaneously operate in maintaining the normal line voltage pending the operation of said slower acting electro-mechanical devices.

Various embodiments of my present inven-

tion are illustrated in the accompanying drawings, in which:—

Figure 1 shows a simple form of my novel magnetic voltage regulator device connected across a power circuit, the core of the device having a portion of reduced cross section to provide a magnetic circuit having the desired saturated section;

Figure 2 is a diagram showing a saturation curve taken on the magnetic voltage regulator device;

Figure 3 shows the novel magnetic voltage regulator device having a static condenser connected in multiple therewith;

Figure 4 shows the novel magnetic regulator device as in incorporated part of a transformer;

Figure 5 shows the magnetic regulator device with a modified form of reduced core section to provide the magnetic circuit with the desired saturated section; and

Figure 6 is a diagrammatic view showing the novel voltage regulator means incorporated in a generator fed three phase transformer at the station end of a transmission line, and in a three phase transmission transformer feeding a local three phase distribution circuit at the distant end of the same transmission line.

Similar characters of reference are employed in the above described views, to indicate corresponding parts.

Referring to Figure 1, I have shown therein my novel magnetic voltage regulator in a simple form, comprising a coil D connected across the power circuit L_1 and L_2 , said coil being wound on a magnetic core M. The core M is provided with a portion of reduced cross section N to provide a saturated section in the magnetic circuit of said core. A load Q is indicated at the end of the single phase power circuit L_1 and L_2 . In Figure 2 I have shown a saturation curve taken on the magnetic voltage regulator of Figure 1, in which OE_1 indicates normal voltage, and OA indicates the value of the magnetizing current at normal voltage. If in the operation of the power circuit, the voltage increases, for example, to five per cent above normal, indicated by OE_2 , it will follow that the magnetizing current will greatly increase, being substantially doubled, attaining a value indicated by OB. If in the operation of the power circuit, the voltage decreases, for example, to five per cent below normal, indicated by OE_3 , the magnetizing current will greatly diminish, attaining a value indicated by OC. From this it will be evident that a wide variation of magnetizing current accompanies tendencies to voltage fluctuation, so that variations of load on the power circuit are automatically off set and consequently the voltage of the power circuit is automatically regulated or stabilized.

In Figure 3 I have shown in combination

with the novel magnetic voltage regulator, a static condenser C connected in multiple therewith. The capacity of this condenser is so rated as to more or less neutralize the magnetizing current in the voltage regulator at approximately normal voltage of the power circuit, thus rendering the regulator more sensitive to voltage fluctuations in the power circuit. Now it will be readily understood that when the magnetizing current taken by the coil D is exactly equal to the charging current taken by the condenser C at normal voltage, the condenser and regulating device will be in resonance, and the charging current will lead the voltage 90° while the magnetizing current lags the voltage 90° , consequently the two currents will substantially neutralize each other so far as the transmission line is concerned, and at normal voltage the current taken from the line will be only that corresponding to losses in the regulating device plus harmonic currents due to the magnetization of the iron. The heavy currents in C and D will circulate around the local circuit C—D only. Referring to the diagram in Figure 2, if, however, the voltage of the line drops to a value corresponding to OE_3 , approximately 95% of normal, then the magnetizing current taken by the coil D will be

reduced in the ratio $\frac{OC}{OA}$, or to about 25% of the normal voltage value, while the charging

current in C will be reduced in the ratio $\frac{OE_3}{OE_1}$, or to about 95% of normal voltage value. It is therefore evident that a charging current of about 95% minus about 25% equals approximately 70% of the normal voltage of charging current which will be available for flow in the transmission line, thus greatly improving the line power factor and tending to increase voltage at the terminals of the device. On the other hand if the voltage rises to approximately 105%, or to OE_2 , then the charging current will rise to 105% of normal but the magnetizing current will rise to a value proportional to OB or approximately 200% of normal voltage value. The magnetizing current flowing in the line will therefore be approximately 200% minus 105% of the normal voltage current taken by the coil D. This magnetizing current will operate to cause a low lagging power factor in the transmission line, and will tend to hold down the voltage at the point of connection of the voltage regulating device.

In Figure 4 I have shown my novel magnetic voltage regulator incorporated in the magnetic core M_1 of a transformer feeding the low voltage power circuit L_3 and L_4 across which are connected the secondary coils D_1 ; this being a preferred form or embodiment of my invention. In this arrangement high voltage windings X are connected across a high voltage feeder circuit F_1 and F_2 , said

windings having taps T_1 , T_2 and T_3 so that saturation of the core M_1 may be made to take place at any desired terminal voltage within the range of available taps by making the desired selected tap connections. The magnetic core M_1 is provided with suitably disposed saturation sections N_1 of reduced cross section. The secondary coils D_1 feed the low voltage power circuit L_3 and L_4 , and a condenser C_1 is connected across the low voltage terminals of the transformer to more or less neutralize the magnetizing current in the core M_1 at the normal voltage delivered to the power circuit L_3 and L_4 .

In Figure 5 I have shown my novel magnetic voltage regulator provided with a modified form of core M wherein the saturation sections of reduced cross section are obtained by providing groups of perforations H arranged to provide such saturation sections at a plurality of points in the magnetic circuit of the core. The modified core structure thus provided possesses several important advantages. The small sections of iron between the perforations H in each group of the latter saturate normally at a high flux density at normal voltage and hence have a high loss per pound of material. But since it is desirable to reduce as much as possible the weight of iron in the core sections so saturated that losses caused by high densities will be reduced to a minimum, the provision of several groups of perforations tends to distribute the losses, and at the same time provides a maximum of accessibility to the centers of heat formed by the small iron sections between the perforations whereby the cooling oil, in which transformers are usually immersed, may be most efficiently applied to the hot spots.

In Figure 6 I have shown my novel magnetic voltage regulator means in combination with transformers in a connected three phase transmission circuit and three phase power distribution circuit. In this embodiment of my invention, G indicates a three phase generator having an excitation circuit E_g and a regulator R_g and feeding a long high voltage transmission line F_3 , F_4 and F_5 through a three phase transformer B , the primary coils D_2 of which receive the current from the generator G , and the secondary coils S of which feed through the line F_3 , F_4 and F_5 the primary coils P of three phase three winding transformer B_1 . The latter transformer B_1 is provided with tertiary coils or windings Y connected to a synchronous condenser C_2 having an excitation circuit E_c and a regulator R_c , and with secondary coils S_1 feeding a local three phase distribution circuit L_5 , L_6 and L_7 . The magnetic sections or cores M_2 and M_3 of the respective transformers B and B_1 are provided with the restricted saturation sections provided by the portions of reduced cross sec-

tion between the members of the groups of perforations H with which the cores are furnished, whereby, at normal voltage, the magnetic circuits require a considerable fraction of the output of the generator G and condenser C_2 for their magnetization. It will be obvious, in the event the load on the distribution circuit L_5 , L_6 and L_7 is suddenly dropped, that the voltage both at the transformer B_1 and the transformer B will rise, and that the excessive magnetic density thereby produced in the saturation sections of the cores of these transformers will absorb all the excess capacity of the generator G and condenser C_2 , until the voltage regulators R_g and R_c of these machines have brought the voltages at the transformers back to normal, and consequently an excessive voltage rise in the transmission circuits will be prevented. If, on the other hand, a heavy low power factor load comes on the distribution circuit L_5 , L_6 and L_7 , then the voltage at all points on the transmission system will fall slightly, and the magnetizing current of both transformers B_1 and B will be greatly reduced, so that the generator and condenser capacity released by the reduction of magnetizing current will be instantly available to compensate for the increased load and thus serve to prevent a further drop in voltage in the transmission system until the voltage regulators R_g and R_c on the generator and synchronous condenser have time to bring the line voltage back to normal.

It will be obvious that the saturation points desired in the magnetic circuit of my novel regulator device may be obtained by other means than the provision of the portions of restricted cross section; as, for example, by providing the core with a section of magnetic material adapted to saturate at a density relatively low with respect to the saturation density throughout the remainder of the core body.

As many other changes could also be made in the constructions above described and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a transformer having a magnetic core arranged to be saturated substantially above the knee of its saturation curve at its normal operating voltage, an inducing winding on said core, an induced winding on said core, a tertiary winding on said core, and a synchronous condenser connected to said tertiary winding for neutralizing the magnetizing current of said transformer at its normal operating voltage.

2. In combination, an electric circuit, a

- transformer connected thereto, a synchronous condenser connected to said transformer, and an automatic voltage regulator for said synchronous condenser to maintain normal voltage on said transformer, said transformer having a saturated section in its magnetic core adapted greatly to increase its magnetizing current with a rise in voltage above normal and greatly to decrease its magnetizing current upon a drop in voltage below normal to prevent a substantial change in the voltage of said transformer during the period required for said voltage regulator to become effective.
3. In combination, a power transmission line, a magnetic device including a winding in circuit with said transmission line, said magnetic device having a magnetic core with a portion thereof arranged to saturate at normal line voltage, and a condenser connected to said magnetic device for neutralizing the lagging component of current thereof at normal line voltage while permitting the lagging component of current of said magnetic device to predominate substantially when said line voltage increases slightly above normal and the leading component of said condenser to predominate substantially when said line voltage decreases slightly below normal.
4. In combination with a generator feeding its energy to a power circuit through a transformer, said transformer having a portion of its magnetic circuit adapted to be saturated substantially above the knee of its saturation curve at normal generator voltage whereby said transformer absorbs a large part of the capacity of said generator as magnetizing current upon a rise in generator voltage but reduces its magnetizing current to a very small value upon a drop in said generator voltage.
5. In an electrical power transmission system, the combination of a synchronous alternating current generator, a transmission line connected to said generator, a magnetic device including a winding connected to said transmission line and having a core portion arranged to be saturated substantially above the knee of its saturation curve at the normal operating voltage of said line, a capacitance connected to said magnetic device and arranged to neutralize the lagging reactive power thereof at the normal operating voltage of said line, and a regulator for automatically regulating the field excitation of said generator, said magnetic device being so saturated that upon variation in said line voltage from said normal value reactive power of sufficient magnitude is added in the interval required for said regulator to function to prevent said line voltage from changing to a value at which the line is unstable.
6. In an electrical power transmission system, the combination of a source of alternating current supply, a receiving circuit, a transmission line connecting said source of supply and said receiving circuit, a transformer in said transmission line arranged to be saturated substantially above the knee of its saturation curve at the normal operating voltage of said line, a synchronous condenser connected to said transformer and arranged to neutralize the lagging current of said transformer at said normal operating voltage, and a regulator for automatically regulating the field excitation of said generator and said condenser, said transformer being so saturated that upon change of load and consequent change in line voltage reactive power of sufficient magnitude is added to the system to prevent a material change in voltage during the interval required for the regulator to function to restore said line voltage to its normal value.
- In testimony that I claim the invention set forth above I have hereunto set my hand this 3rd day of May, 1927.
- FRAZER W. GAY.

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