Sept. 7, 1937. T. INAGI 2,092,213

DEVICE FOR GENERATING CONSTANT VOLTAGE AT VARIABLE SPEED

Filed June 10, 1935 3 Sheets-Sheet 1

Fig. 1.

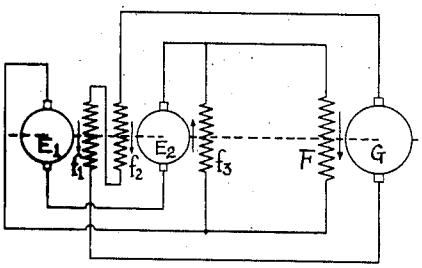


Fig. 2.

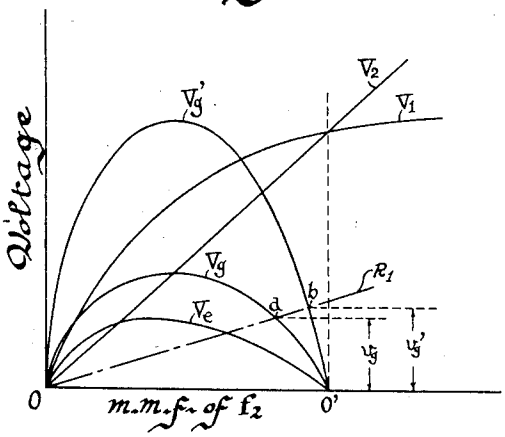


Fig. 3.

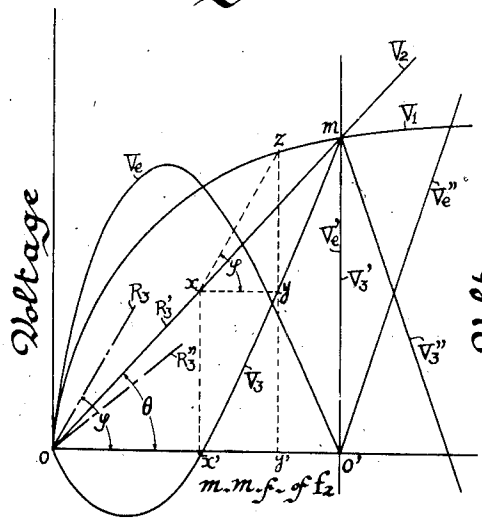
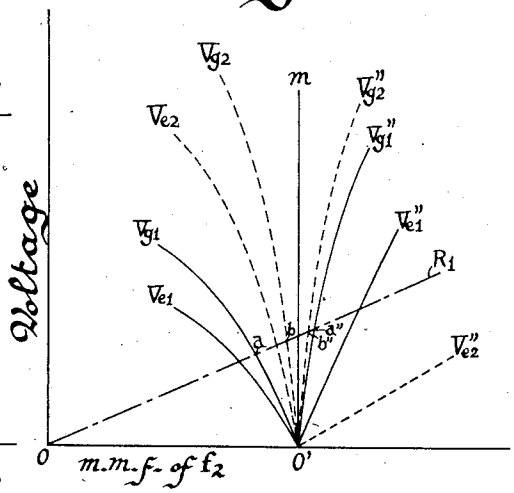


Fig. 4.



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Filed June 10, 1935 3 Sheets-Sheet 2

Fig. 5.

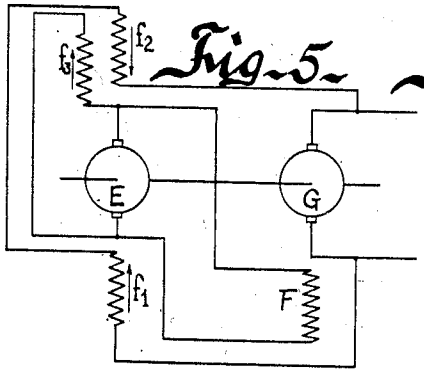


Fig. 6.

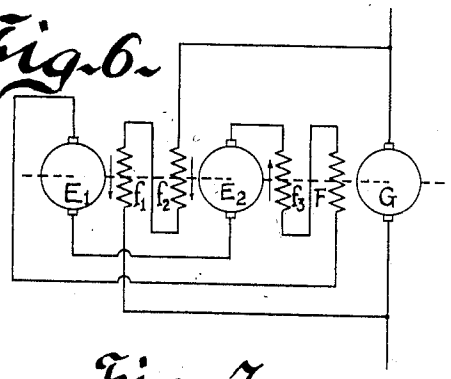


Fig. 8.

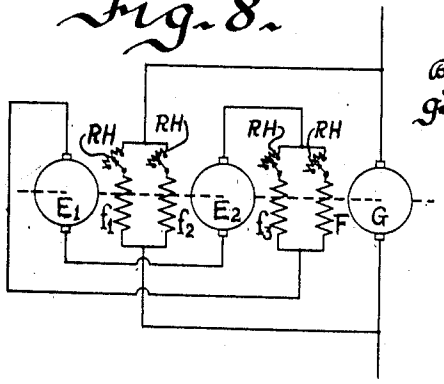


Fig. 7.

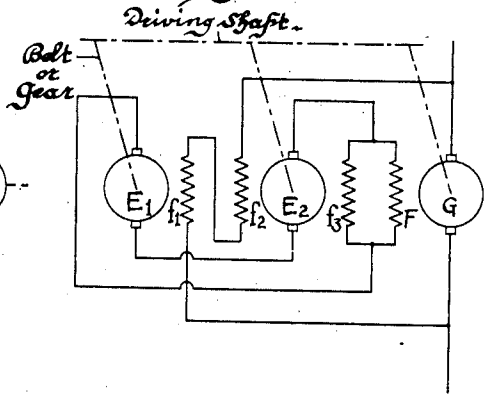
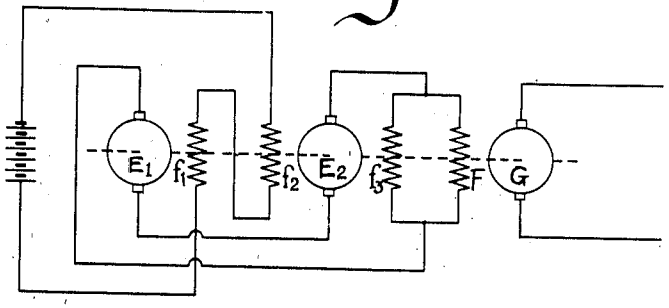


Fig. 9.



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Filed June 10, 1935 3 Sheets-Sheet 3

Fig. 10.

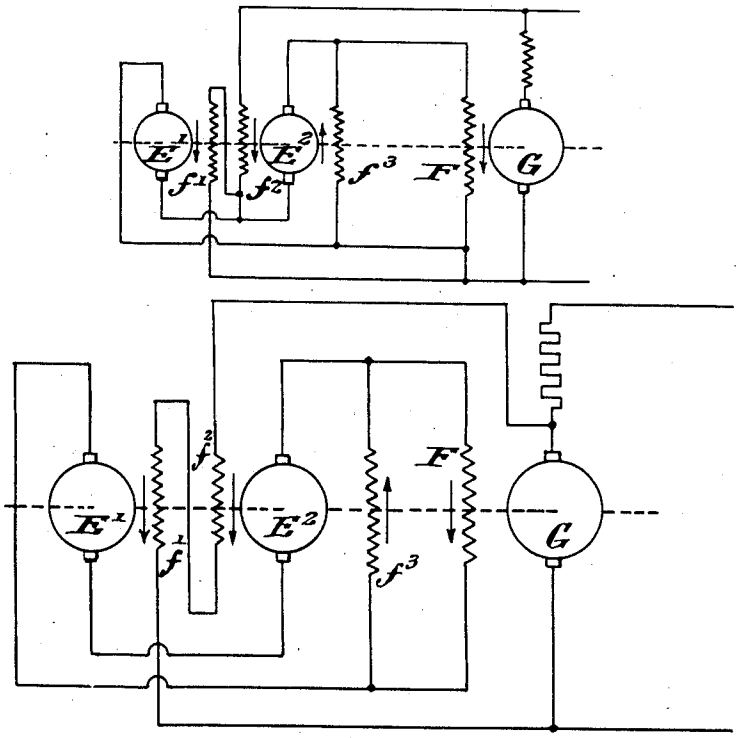
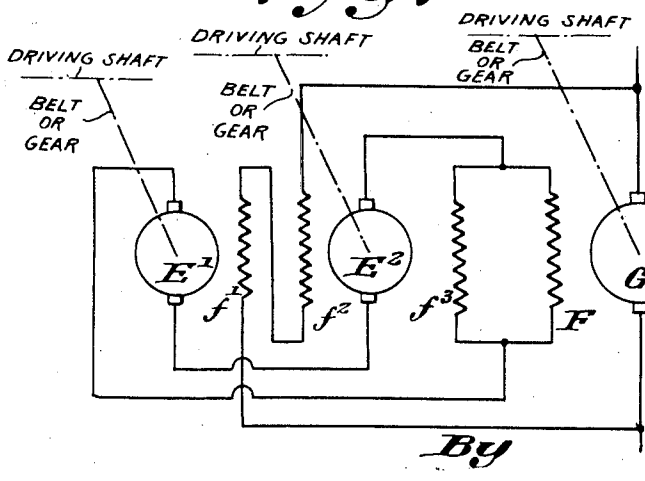


Fig. 11.

Fig. 12.



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DEVICE FOR GENERATING CONSTANT VOLTAGE AT VARIABLE SPEED

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Application June 10, 1935, Serial No. 25,955
In Japan July 10, 1934

9 Claims. (Cl. 171—223)

This invention relates to improvements in a device for generating constant voltage at variable speed, such as a generator for use on car axles, comprising a main generator whose field winding is fed by two exciters in series with opposing electromotive forces, of which one is the main exciter of saturated characteristic and the other is the auxiliary exciter of unsaturated characteristic.

The invention embodies the provision on the said auxiliary exciter of another field winding fed by the combined electromotive force of the two exciters in series and in opposed relation to original field winding thereof.

The main object of the invention is to obtain a generator which is able to generate a more constant voltage than has been possible heretofore at a reduced size of the machine.

Other objects and features of the invention will be understood from the following descriptions and the accompanying drawings, in which,

Fig. 1 shows an electrical connection of the device according to the invention.

Figs. 2 to 4 are diagrams for explaining the performances of the device.

Figs. 5 to 9 show modifications of the invention.

Fig. 10 is a schematic view showing a modified arrangement.

Fig. 11 is a schematic view of a circuit embodying a modification of the invention.

Fig. 12 is a similar view illustrating a further modification of the present invention.

Referring to Fig. 1, G is a main generator having a separately excited field winding F. E_1 is a main exciter having a field winding f_1, and E_2 is an auxiliary exciter having field windings f_2 and f_3. The field windings f_1 and f_2 being connected in series are connected to the terminals of the main generator G, and the field windings F and f_3 being connected in parallel are connected to the terminals of the two exciters connected in series. The field windings f_2 and f_3 of the auxiliary exciter E_2 act differentially. On the other hand, the electromotive force of the main exciter E_1 is additive with the electromotive force of the auxiliary exciter E_2 as induced by the field winding f_3, but is differential with the electromotive force induced by the field winding f_2. These relations are shown by arrow heads in Fig. 1. The main exciter E_1 has a saturated characteristic, while the auxiliary exciter E_2 has an unsaturated characteristic. The generator G and the two exciters E_1 and E_2 are mechanically connected directly with one another and with a driving shaft.

To simplify the explanation, first the performance of the device in which the field winding f_3 is not provided will be explained with reference to Fig. 2. In this figure, V_1 shows the saturation curve of the exciter E_1 at a certain speed of the aggregate, and V_2 that of the exciter E_2, the magneto-motive force of the exciting winding f_2 being taken as abscissa. The curve V_e, which is the difference of the two saturation curves V_1 and V_2, shows the resultant exciting voltage acting upon the field winding F. Being excited by such voltage V_e, the generator G induces the voltage V_g. Let OR_1 be the curve of ohmic drop across the field windings f_1 and f_2. Then the point of intersection a of the line OR_1 and the generator voltage curve V_g represents the terminal voltage of the main generator at this particular speed. When the speed increases, all the voltages including the exciter voltage V_e and the generator voltage V_g increase correspondingly. Thus at a certain increased speed, the curve of the main generator voltage assumes the position represented by V'_g, and the generator voltage will displace from the point a to the point b.

In order to make the increase of the generator voltage, which takes place when the speed is increased, sufficiently small, the resultant exciting voltage curve V_e and, consequently, the generator voltage curve V_g at the lowest working speed must have as steep fronts as possible at the neighborhood of the point O', where the vertical line passing through the point of intersection of V_1 and V_2 curves meets the abscissa. This requires that the exciter voltages V_1 and V_2 must both be very high in comparison to the resultant exciting voltage V_e, and this fact inevitably leads to the disadvantage that the size and weight of the exciters are increased. These disadvantages are effectively obviated according to the invention by providing on the auxiliary exciter E_2 another exciting winding f_3 acting differentially to the first winding f_2 and choosing the intensity of excitation of the said field winding f_3 within certain predetermined limits. The effect of such field winding f_3 will be described below.

The saturation curve of the auxiliary exciter E_2, as provided with the exciting winding f_3, may be obtained on the following consideration.

Referring to Fig. 3, V_1 is the saturation curve at a certain speed of the main exciter E_1, the magnetic circuit of which is sufficiently saturated, and V_2 is the saturation curve of the auxiliary exciter E_2 when it is excited only by the field

winding f_2. If we assume, for the sake of simplicity, that the magnetic path of this exciter as of ideally unsaturated, the curve V_2 will be a straight line. Let m represent the point of intersection of two curves V_1 and V_2.

Let I_2 be the current flowing in the field winding f_2, and n_2 be the number of turns thereof, and let I_3 and n_3 be the corresponding figures of the winding f_3. Then at a certain magnetomotive force $I_2n_2=oy'$ of the winding f_2, the counteracting magnetomotive force $I_3n_3=y'x'$ of the winding f_3 will be prevailing at the same time, so that the resultant effective magnetomotive force will be represented by Ox'. The voltage induced in the exciter E_2 by such resultant magnetomotive force will be represented by $x'x$. Let the horizontal line through the point x meet the vertical line $y'z$ at the point y. Then yz, being the difference between $y'z$ and $x'x$, evidently is the resultant exciting voltage acting across the winding f_3. Let R_3 be the ohmic resistance of the winding f_3. Then yz will be equal to the I_3R_3. So that we have

$$\tan \angle yxz=\tan \varphi=\frac{I_3R_3}{I_3n_3}=\frac{R_3}{n_3}$$

It will thus be seen that the tangent of the angle φ is constant, but varies directly with the resistance of the exciting circuit f_3 and inversely with the number of turns. In other words, this angle decreases when the intensity of excitation of the field winding f_3 increases. Let us now draw through the origin O a line OR_3 parallel to the line xz, and call it a line of ohmic drop across the field winding f_3. Then we can conclude that the saturation curve V_3 of the auxiliary exciter E_2 may be obtained as the locus of the point y of right angled triangles drawn across two saturation curves V_1 and V_2 with its hypothenuse xz parallel to the said line of ohmic drop OR_3.

It will easily be seen from Fig. 3 that when the angle φ is equal to the angle θ, which is the angle of inclination of the saturation curve V_2 to the horizontal line, the ohmic drop line assumes the position OR'_3, and the curve V_3 is reduced to a vertical line V_3' passing through the point m. At such an intensity of excitation of the field winding f_3, which may be called the critical field intensity, theoretically only one magnetomotive force OO' is possible. At any other current I_2, the performance of the device is unstable. In actual cases, however, the saturation curve V_2 is never a true straight line, especially at high magnetomotive forces, so that the device operates quite stably even at other excitations than OO'.

At an increased excitation of the field winding f_3, or at a smaller angle φ, such as corresponds to the line OR''_3, the saturation curve assumes the position indicated by V''_3. In this case, the performance of the machine is unstable theoretically at a magnetomotive force which is smaller than OO'. The respective resultant exciting voltages are represented by V_e, V_e' and V_e'' in Fig. 3.

Thus it will be seen that the characteristics of the resultant exciting voltage can be regulated at will by varying the intensity of excitation of the field winding f_3.

The foregoing discussion relates to the case when the intensity of excitation of the field winding f_3 is varied at a constant speed of rotation. Conversely, let us now consider the case when the intensity of excitation of the field winding f_3, that is, the inclination of the ohmic drop line OR_3, is kept constant, while the speed is varied.

When the speed is increased, the angle of inclination of the line V_2 increases ($\tan \theta$ varies proportionally with the speed), while the inclination of the ohmic drop line OR_3 certainly remains constant. Relatively speaking, when the speed increases, the line of ohmic drop would rotate clockwisely in relation to the line V_2, resulting to the increased effect of the field f_3.

Referring to Fig. 4, let V_{e1} and V_{e2} be the resultant exciting voltages corresponding respectively to speeds n_1 and n_2 (n_2 is greater than n_1) when the intensity of excitation of the field winding f_3 is OR_3 (Fig. 3), and similarly let V_{e1}'' and V_{e2}'' be the resultant exciting voltages at like respective speeds, when the intensity of the field winding f_3 is oR_3''. Let V_{g1}, V_{g2}, and V''_{g1}, V''_{g2} be the voltages of the main generator G corresponding to the resultant exciting voltages V_{e1}, V_{e2}, and V''_{e1}, V''_{e2} respectively.

The voltage of the main generator G, for example V_{g1}, is substantially proportional to the product of the resultant exciting voltage (V_{e1}) and the corresponding speed (n_1). Let OR_1 be the ohmic drop line of the field windings f_1 and f_2. Then the points of intersection a, b, a'', b'' of the voltage curve V_{g1}, V_{g2}, V''_{g1}, V''_{g2} and the line oR_1 represent the respective voltages of the generator G.

As is clear from Fig. 4, when the intensity of excitation of the field winding f_3 is below the critical intensity, the exciting voltage curve V_{e2} corresponding to the higher speed n_2 is above the exciting voltage curve V_{e1} corresponding to the lower speed n_1 so that the generator voltage V_{g2} being proportional to n_2V_{e2} departs considerably from the voltage V_{g1}, which is proportional to n_1V_{e1}.

On the contrary, when the intensity of excitation of the field winding f_3 is above the critical intensity, the exciting voltage curve V''_{e2} corresponding to the higher speed n_2 is below the exciting voltage curve V''_{e1} corresponding to the lower speed n_1, so that the effect due to the increase of speed is effectively compensated by the decrease of the resultant exciting voltage and the generator voltage curve V''_{g1} and V''_{g2} are situated closely to each other.

It will be seen, therefore, that the voltage regulation is better when the strength of excitation of the field winding f_3 is higher than the critical intensity. When the speed is sufficiently low, however, the regulation is fairly good even when the strength of excitation of field winding f_3 is below the critical value.

According to this invention, therefore, the intensity of excitation of the field winding f_3 is chosen in relation to the extent of variation of speed in such a manner that the effect of the latter is compensated in effect by the variation in the excitation of the main generator, so that the voltage of the generator is maintained practically constant.

In the above descriptions, the magnetic path of the auxiliary exciter E_2 has been assumed as absolutely unsaturated, but the same reasoning of course holds approximately even when this assumption is not strictly correct.

The device mentioned above is merely one embodiment of this invention and, of course, it may be modified in various ways without departing from the spirit of invention set forth in the appended claims. For example, two separate exciters above mentioned may be replaced by an exciter E of such construction in which the

armatures of two exciters are combined into one rotor rotating in two independent fields (Fig. 5). Also modifications may be made in the following manners:

The field windings f_3 and F may be connected in series (Fig. 6).

The generator G and the exciters E_1 and E_2 may be separately driven by a suitable prime mover (Fig. 7) or by suitable prime-movers maintaining a fixed speed relation with one another (Fig. 12).

The field windings f_1 and f_2 may be connected in parallel and connected to the terminals of the generator G (Fig. 8).

The field windings f_1 and f_2 may be excited by a suitable source of constant voltage, instead of by the generator G (Fig. 9).

Moreover, with a view to controlling the voltage characteristics and to increase the stability of operation, a suitable rheostatic or other controlling means RH may be provided to any or all of said field windings (Fig. 8). Also a material having a suitable temperature coefficient may be used for resistance of said rheostats for compensating the variation in the characteristics due to the variations in temperatures. If desired, the main generator may be made so that it is either of overcompounding or undercompounding characteristic. For example, if a resistance is connected in the main generator circuit as shown in Fig. 10 and the terminals of the fields f_1 and f_2 are connected across the main generator and the resistance, the main generator will have an overcompounding characteristic (Fig. 10). On the other hand, if these fields are directly connected to the terminals of the generator, it will have an undercompounding characteristic (Fig. 11).

What I claim is:

1. Device for generating constant voltage at variable speed comprising a main generator and an exciter with two separate field systems, the said generator and exciter being arranged so as to be driven at predetermined relative speeds, in said device the said main generator is excited by the resultant voltage of said exciter, in which one of the field systems is excited by a substantially constant voltage and is magnetically sufficiently saturated and the other is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by a substantially constant voltage in opposite polar relation to the excitation of the first field system and the other is excited by the resultant voltage of the exciter in additive polar relation with the excitation of the said first field system, and the intensity of the last mentioned excitation is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

2. Device for generating constant voltage at variable speed comprising a main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined relative speeds, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by a substantially constant voltage and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by a substantially constant voltage in opposite polar relation to the excitation of the main exciter and the other is excited by the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary exciter is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

3. Device for generating constant voltage at variable speed comprising a main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined relative speeds, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by a substantially constant voltage and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by a substantially constant voltage in opposite polar relation to the excitation of the main exciter and the other is excited by the exciting current of the main generator in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary exciter is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

4. Device for generating constant voltage at variable speed comprising a main generator and a main and an auxiliary exciters directly coupled to the said main generator, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by a substantially constant voltage and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by a substantially constant voltage in opposite polar relation to the excitation of the main exciter and the other is excited by the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary exciter is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

5. Device for generating constant voltage at variable speed comprising a main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined relative speeds, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by a substantially constant voltage and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by said substantially constant voltage in series with the field winding of said main exciter and in opposite polar relation to the excitation of the main exciter and the other is excited by a current corresponding to the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary ex-

citer is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

6. Device for generating constant voltage at variable speed comprising a main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined relative speeds, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by a substantially constant voltage and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by said substantially constant voltage in parallel with the field winding of said main exciter and in opposite polar relation to the excitation of the main exciter and the other is excited by a current corresponding to the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary exciter is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

7. Device for generating constant voltage at variable speed comprising a main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined relative speeds, in which said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is excited by the substantially constant voltage of the main generator and is magnetically sufficiently saturated, and the auxiliary exciter is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by said substantially constant voltage of the main generator in opposite polar relation to the excitation of the main exciter and the other is excited by a current corresponding to the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, and the intensity of excitation of the last mentioned field winding of the auxiliary exciter is of such a value that the variation in said resultant voltage due to the variation of the driven speed is adapted to maintain the voltage of the main generator substantially constant.

8. Device for generating constant voltage at variable speed comprising a main generator, a resistance connected in series with said main generator, a main exciter and an auxiliary exciter arranged so as to be driven at predetermined speeds relatively to each other and to the main generator, in said device said main generator is excited by the resultant voltage of said two exciters, of which the main exciter is of high magnetic saturation and the auxiliary exciter is of low magnetic saturation and has two field windings acting differentially to each other, one of which is excited in series with the field winding of the main exciter by the terminal voltage of the said main generator and in opposite polar relation to the excitation of the main exciter and the other is excited by the resultant voltage of the two exciters in additive polar relation with the excitation of the main exciter, the main generator having an under-compounding characteristic.

9. Device for generating constant voltage at variable speed comprising a main generator and an exciting system with two separate field systems, the said generator and exciting system being arranged so as to be driven at predetermined relative speeds, in said device the said main generator is excited by the resultant voltage of said exciting system in which one of the field systems is excited by a substantially constant voltage and is magnetically sufficiently saturated and the other is of a low magnetic saturation and has two field windings acting differentially to each other, one of which is excited by a substantially constant voltage in opposite polar relation to the excitation of the first field system and the other is excited by the resultant voltage of the exciting system in additive polar relation with the excitation of the said first field system.

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