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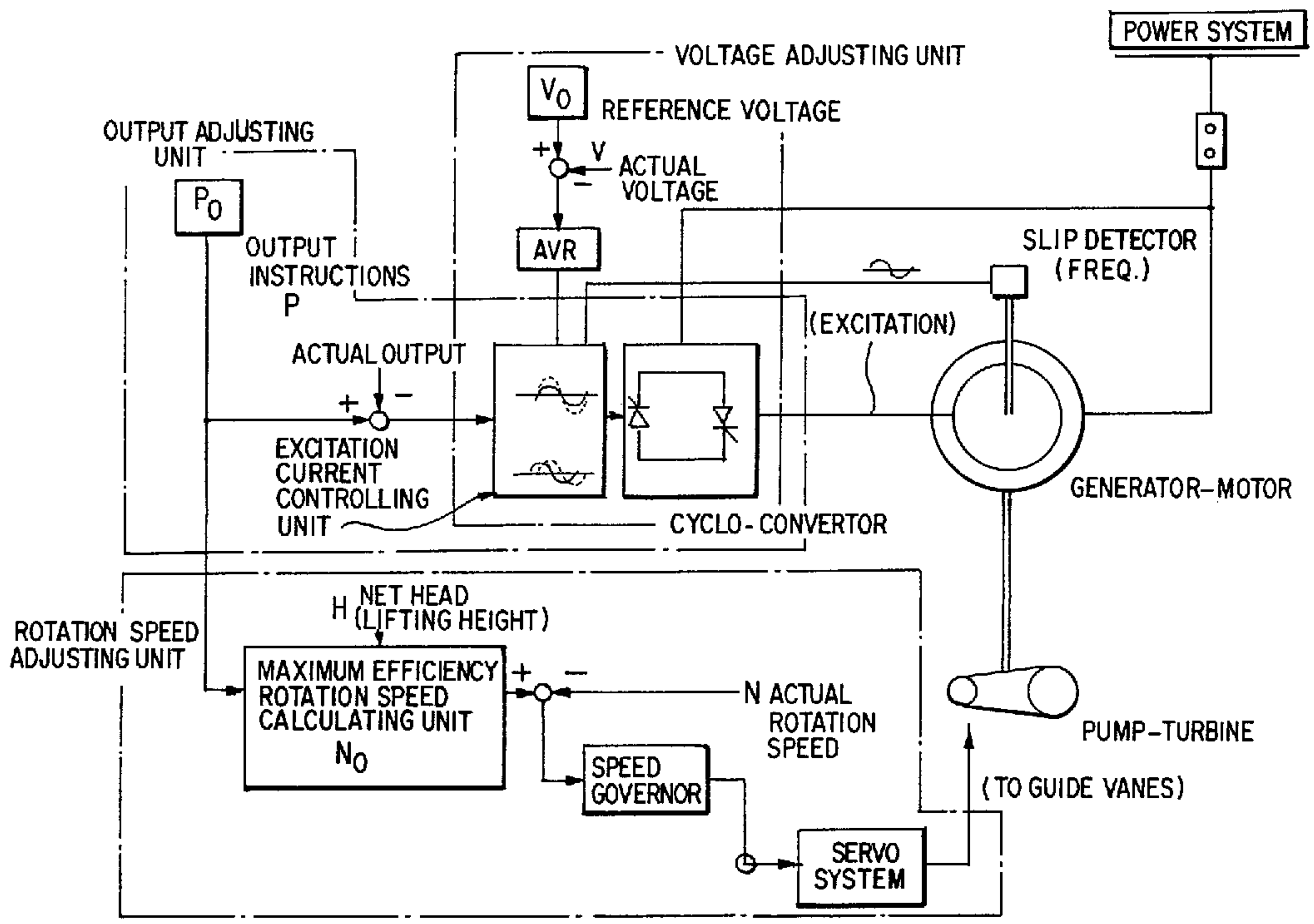
(54) **GROUPE ELECTROGENE; MODE D'EMPLOI**

(54) **ELECTRICAL POWER GENERATING INSTALLATION AND METHOD OF OPERATING SAME**



(57) An electric power generating installation has a plurality of generation units, each of which has a motor for converting kinetic energy into torque. A generator is connected mechanically to the motor and electrically to an electric power system for converting torque into electric energy. Equipment controls the motor and the generator in such a way that they can be operated stably and continuously. The control equipment controls the different generator/motor units in different control modes to minimize side-flow and resonance or beat.

Abstract

An electric power generating installation has a plurality of generation units, each of which has a motor for converting kinetic energy into torque. A generator is connected mechanically to the motor and electrically to an electric power system for converting torque into electric energy. Equipment controls the motor and the generator in such a way that they can be operated stably and continuously. The control equipment controls the different generator/motor units in different control modes to minimize side-flow and resonance or beat.

ELECTRICAL POWER GENERATING INSTALLATION AND METHOD OF OPERATING SAME

The present invention relates to control equipment for an electric power generating installation and to methods of controlling such an installation.

It is well known that a circulating current flows between generators when the reactive power is varied by external disturbances in a system with a plurality of synchronous generators having the same specifications and characteristics, and operated in parallel. Hereinafter, this circulating current will be referred to as a side-flow.

An example of a side-flow suppressing system is disclosed in Japanese Patent Application Laid-open No. 58-54837 (1983).

While it is possible to recover the variation of the reactive power by using the method disclosed in the above document, the recovery method may take several seconds, because it adopts a two-step loop control.

It is desired to instantaneously correct the electric power system when a disturbance occurs in the system, since otherwise social activities dependent on electric power are interrupted. A variable speed pumping-up power generation system was developed in order to comply with such a high speed requirement. This variable speed system adopted a secondary excitation induction motor. It becomes possible to recover the effective power of the troubled power system within some milli-seconds by using such a variable speed pumping-up power generation system. When the side-flow flowed between the variable speed generation motors in the variable speed pumping-up power generation system under parallel operation, it is very difficult to eliminate the side-flow in a short time utilizing the prior art techniques mentioned above. Accordingly, the advantages of the high speed response of the variable speed pumping-up power generation system are not attainable in practice in systems having a plurality of such variable speed units.

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Further, when a plurality of variable speed generator/motor units are operated utilizing the same operation control method, a resonance or "beat" may occur between the variable speed generation motors. Accordingly, it is undesirable to operate the plurality of variable speed generator/motor units in the same operational condition.

An object of the present invention is to provide an improved control system for electric power generating installations having variable speed generator/motor units, in which the resonance or beat does not occur.

In order to achieve this object, a variable speed pumping-up power generation system including at least two variable speed generator/motor units operated in parallel, is divided into at least two groups. Each of the groups is controlled by using physical quantities different from each other, in which feedback control is performed, or control quantities different from each other are used in the control equipment of each group, or both of them are combined.

According to the present invention, each group of the variable speed pumping-up power generation system is controlled in a different way or control mode. Therefore, the resonance or beat does not occur between the groups. The side-flow produced by the external disturbance can be quickly eliminated. As a result, instantaneous recovery of the variable speed pumping-up power generation system becomes possible.

Specifically, the invention provides an electric power generating installation comprising: a first generator/motor unit supplied with kinetic energy from a kinetic energy source and serving to supply electric power to a power grid, a second generator/motor unit supplied with kinetic energy from the kinetic energy source and serving to supply electric power to the power grid in parallel with the supply from the first generator/motor unit, and a control installation for controlling the respective first and second generator/motor units in respectively different control modes to thereby minimize side-flow between the first and second generator/motor units while providing stable and continuous control of said units in response to variations in electric power load in the power grid.

The invention also provides a method of controlling generator/motor units in an electric power generating installation of the type having: a first generator/motor unit supplied with kinetic energy from a kinetic energy source and serving to supply electric power to a power grid, a second generator/motor unit supplied with kinetic energy from the kinetic energy source and serving to supply electric power to the power grid in parallel with the supply from the first generator/motor unit, said method comprising: controlling the respective first and second generator/motor units in respective different control modes to thereby minimize side-flow between the first and second generator/motor units while providing stable and continuous control of same in response to variations in electric power load in the power grid.

As described above, according to the present invention, the stable operational condition of the variable speed pumping-up power generation system can be maintained, and thus the stability of the power system can be improved.

In the drawings:

Figure 1 is a schematic depiction of an electrical power grid of the type contemplated by the present invention;

Figure 2 is a schematic depiction of a power generation unit that includes a plurality of variable speed generator/motor units of the type controlled in accordance with the present invention;

Figure 3 is a schematic diagram depicting a prior art control installation;

Figure 4 is a schematic side-by-side comparison of a conventional generator/motor unit system and a variable speed generator/motor unit system of the type contemplated in preferred embodiments of the present invention;

Figure 5 is a schematic comparison of the stator/rotor/magnetic patterns for a conventional generator/motor unit and a variable speed generator/motor unit

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of the type contemplated for use in preferred embodiments of the present invention;

Figure 6 is a schematic diagram showing the operation and control of a variable speed generator/motor unit of the type contemplated for use with preferred embodiments of the present invention;

Figure 7 is a schematic diagram depicting a control installation constructed according to a first preferred embodiment of the present invention;

Figure 8 shows another embodiment of the present invention in which the same physical quantities are detected and the control quantities of the control equipments are different from each other;

Figure 9 shows still another embodiment of the present invention in which four groups of variable speed generation systems are operated in parallel;

Figure 10 shows a further embodiment of the present invention in which predetermined reference values are supplied from a feed command center.

Figure 11 is an illustration showing the concept of the present invention;

Figure 12 is another illustration showing the concept of the present invention.

Figure 1 schematically depicts a power grid system PG of the type contemplated by the present invention. A plurality of electric power generating units G_1, G_2, G_3, G_4 are connected in the power grid PG. By way of example, unit G_2 could be a nuclear power plant that supplies 30% of peak power loads, unit G_3 could be a thermal power plant that supplies 55% of peak power loads, and unit G_4 could be a water turbine power plant that supplies 10% of peak power loads. The unit G_1 could be a generator/motor power plant which supplies 5% of peak power loads and functions to precisely control the power supply (generating mode) and the power loading (pumping mode) of the grid.

Electric power loads PL are imposed on the power grid PG in the form of electrically driven equipment of factories, household appliances, and the like. The power loads fluctuate throughout the day, with usually very low loads at night. In practice, generating units G_3 and G_4 may be shut down during low loads, while unit G_2 will run continuously. Unit G_1 will continue to operate and serve to precisely and rapidly control power grid supply fluctuations.

Referring to Figure 2, unit G_1 is configured as a system with a water reservoir WR, and water tunnel WT connected to the reservoir WR, and two generator/motor units GM_1 and GM_2 driven by the water in the water tunnel WT. The units GM_1 and GM_2 include selectively operable pumps for pumping water back to the reservoir WR when excess power is available in the grid PG. In this way, these generator/motor units GM_1 and GM_2 serve to balance the fluctuating power needs. The present invention is concerned with an improved system of units like GM_1 and GM_2 and their control.

The example of the above-mentioned Japanese Patent Application No. 58-54837 (1983) will be explained with reference to Figure 3. In an electric power system 7 in which a power source 2 is connected to a demand 3, two generator/motor units 18a and 18b are connected to a parallel point 6 and operated in parallel with each other. The parallel point 6 is connected to a parallel point 5 in the electric power system 7, and two pumping hydraulic turbines 12a and 12b are connected directly to the generator/motor units 18a and 18b, respectively.

The reactive power of the system in which each generator is connected is detected by a reactive power detector 13. The output signal of the reactive power detected in each system is inputted to a reactive power reference value regulator 14, in which the average value of the reactive power is calculated by using its output signal. The output signal of the reference value regulator 14 is inputted to a reactive power regulator (AQR) 15 as a reference signal. In the reactive power regulator 15, the reference signal is compared with the reactive power output signal of each system. The output signal of the reactive power regulator 15 is outputted to a voltage regulator (AVR) which controls the voltage of the electric generator. When the reactive power of each system was varied by the external disturbances, etc., the side flow may flow between the system including the first generator/motor unit 18a and the system including the second generator/motor unit 18b. However, the reactive power reference value regulator 14 regulates so as to match the reactive power to the reference value. The output voltages of the electric generator/motor units 18a and 18b are regulated by the voltage regulators 17a and 17b, respectively, in accordance with the output of the reference value regulator 14, thereby the difference between the reactive powers of the systems can be eliminated, and thus the side flow can be also reduced.

Figures 4 - 6 schematically depict and explain features and advantages of variable speed generator/motor units of the type contemplated for use with the present invention. By utilizing alternating current (AC) excitation with a cycloconverter, the speed of the unit can be continuously adjusted with rapid, precise control response characteristics. The following description of preferred embodiments of control installations according to the present invention are based on utilizing variable speed generator/motor units of this type.

Generator/motor units 18a and 18b shown in Figure 3 correspond to variable speed generator/motor units 1a and 1b, respectively, in Figure 7. An effective power regulator 11a compares the effective power reference value Po with the output signal from an effective power detector 10a, and controls an effective power output of the variable speed generator/motor unit 1a. An automatic rotational speed regulator (ASR) 9b compares the predetermined rotational speed reference value No with the output signal from a rotational speed detector 8b for the generator/motor unit, and controls the rotational speed of the pump type hydraulic turbine 12b. Thereby, each of the variable speed pumping-up power generation systems can be controlled in a different way, and

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thus the side-flow that flows between the variable speed generator/motor units can be instantaneously eliminated.

Figure 8 shows another embodiment of the present invention. In the groups including variable speed generator/motor units 1a and 1b, the effective powers detected by the effective power detectors 10a and 10b are transferred through multipliers 19a and 19b to automatic effective power regulators (APR) 11a and 11b having a predetermined reference value Po, respectively. The automatic effective power regulators 11a and 11b compare the reference value Po with the output value of the multipliers 19a and 19b, respectively, and control the effective power output of the variable speed generator/motor units 1a and 1b, respectively.

By presetting different numerical values to the multipliers 19a and 19b, it is possible to change the control method in each of the groups including the variable speed generation motors 1a and 1b. Therefore, a similar effect as with the embodiment of Figure 3 can be obtained insofar as avoiding resonance and side flow.

Figure 9 shows still another embodiment of the present invention, in which four variable speed generator/motor units 1a to 1d are connected with one another at a parallel point 6, and are operated in parallel. The parallel point 6 is connected to a parallel point 5 in a power system 7. The pump type hydraulic turbines 12a to 12d are connected directly to the variable speed generator/motor units 1a to 1d.

In the groups including variable speed generator motor units 1a and 1b, the effective powers detected by the effective power detectors 10a and 10b are transferred through multipliers 19a and 19b to automatic effective power regulators 11a and 11b, respectively. The automatic effective power regulators 11a and 11b compare the predetermined reference value Po of the effective power with the output value of the multipliers 19a and 19b, respectively, and control the effective power output of the variable speed generation motors 1a and 1b, respectively. Different

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numerical values are preset to the multipliers 19a and 19b in the manner described above for Figure 8.

In the groups including variable speed generator/motor units 1c and 1d, the rotational speeds detected by the rotational speed detectors 8c and 8d of the generator/motor units are transferred through multipliers 19c and 19d to automatic rotational speed regulators 9c and 9d, respectively. The automatic rotational speed regulators 9c and 9d compare the predetermined reference value No of rotational speed with the output value of the multipliers 19c and 19d, respectively, and controls the rotational speed of the pump type hydraulic turbines 12c and 12d, respectively. Different numerical values are preset to the multipliers 19c and 19d so that it is possible to change the control method in each of the four groups of the variable speed pumping-up power generation system.

Referring now to Figure 10 which shows a further embodiment of the present invention, in which there is provided a feed command center 21 in addition to the circuit of Figure 7. The feed command center 21 is provided in the power plant. The feed command center 21 compares the detected values derived from the effective power detector 10a and the rotational speed detector 8b of the generator/motor unit, and supplies the effective power reference value Po and the rotational speed reference value No to the automatic effective power regulator 11a and the automatic rotational speed regulator 9b. Thereby side-flow between the two groups can be instantaneously eliminated.

The physical quantities controlled by the rotational speed regulators 9b, 9c and 9d, the effective power regulators 11a and 11b, the reactive power reference value regulator 14, and the voltage regulator 17a and 17b, etc., are correlated. For example, the correlation between the output of the generator, the output of the motor, and the rotational speed is closer due to the kinetic energy. If two conditions are determined, the remaining condition is unconditionally determined. On the other hand, the correlation between the reactive power and the voltage is relatively weak.

An object of the present invention is to provide control equipment in which physical quantities having the correlation mentioned above are controlled in cooperation without contradiction.

Figures 11 and 12 are illustrations of the concept of the present invention. As seen from these figures, even if the input and the output of two control equipments are the same, it is possible to obtain the desired effect when different control modes are performed in the two control equipments. For example, with regard to the control of effective power, the magnetic exciting control is used in one example, but the motor governor control is used in the other example. The same method can be used with regard to the rotational speed. Further, even if the control method of the two control equipments is the same, it is possible to obtain the desired effect when a different time constant and a different correlation gain due to the feedback control are used.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example, and is not to be taken by way of limitation. The spirit and scope of the present invention are to be limited only by the terms of the appended claims.

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Claims:

1. An electric power generating installation comprising:

a first generator/motor unit supplied with kinetic energy from a kinetic energy source and serving to supply electric power to a power grid,

a second generator/motor unit supplied with kinetic energy from the kinetic energy source and serving to supply electric power to the power grid in parallel with the supply from the first generator/motor unit,

and a control installation for controlling the respective first and second generator/motor units in respectively different control modes to thereby minimize side-flow between the first and second generator/motor units while providing stable and continuous control of said units in response to variations in electric power load in the power grid.

2. An electric power generating installation according to claim 1, wherein said first and second generator/motor units are variable rotational speed units that are similar to one another.

3. An electric power generating installation according to claim 2, wherein a said kinetic energy source is a water tunnel, and wherein said first and second generator/motor units include turbine wheels powered by water flow in the water tunnel.

4. An electric power generating installation according to claim 3, wherein said generator/motor units are controllable to operate respective water pumps for pumping water in the water tunnel to an upstream reservoir when excess power is available in the power grid.

5. An electrical power generating installation according to claim 1, wherein said control installation

includes means for controlling the first generator/motor unit in a power control mode as a function of effective power output detected at the first generator/motor unit and means for controlling the second generator/motor unit in a rotational speed control mode as a function of the rotational speed of the second generator/motor unit.

6. An electric power generating installation according to claim 3, wherein said control installation includes means for controlling the first generator/motor unit in a power control mode as a function of effective power output detected at the first generator/motor unit and means for controlling the second generator/motor unit in a rotational speed control mode as a function of the rotational speed of the second generator/motor unit.

7. An electric power generating installation according to claim 6, wherein said generator/motor units are controllable to operate respective water pumps for pumping water in the water tunnel to an upstream reservoir when excess power is available in the power grid.

8. An electric power generating installation according to claim 3, wherein said control installation includes means for controlling both the first and second generator/motor units in a power control mode as a function of effective power output detected at the respective first and second generator/motor units,

and wherein said control installation includes respective different mathematical conversion factors for converting detected physical operating conditions used in control of the respective first and second generator/motor units.

9. An electric power generating installation according to claim 3, wherein said control installation includes a feed command center for collecting operating data from both the first and second generator/motor units and for separately

controlling said first and second generator/motor units as a function of the respective operating data.

10. An electric power generating installation according to claim 5, wherein said control installation includes a feed command center for collecting operating data from both the first and second generator/motor units and for separately controlling said first and second generator/motor units as a function of the respective operating data.

11. An electric power generating installation according to claim 6, wherein said control installation includes a feed command center for collecting operating data from both the first and second generator/motor units and for separately controlling said first and second generator/motor units as a function of the respective operating data.

12. An electric power generating installation according to claim 1, comprising a third motor/generator unit supplied with kinetic energy from the kinetic energy source and serving to supply electric power to the power grid in parallel with the supply from the first and second generator/motor units,

and wherein said control installation includes means for controlling the third generator/motor unit in a control mode which differs from at least one of the control modes for the first and second generator/motor units.

13. An electric power generating installation according to claim 2, comprising further similar generator/motor units, and wherein said control installation includes means for controlling the further generator/motor units in respective different operating modes than each other and the first and second generator/motor units.

14. A method of controlling generator/motor units in an electric power generating installation of the type having:

a first generator/motor unit supplied with kinetic energy from a kinetic energy source and serving to supply electric power to a power grid,

a second generator/motor unit supplied with kinetic energy from the kinetic energy source and serving to supply electric power to the power grid in parallel with the supply from the first generator/motor unit,

said method comprising:

controlling the respective first and second generator/motor units in respective different control modes to thereby minimize side-flow between the first and second generator/motor units while providing stable and continuous control of same in response to variations in electric power load in the power grid.

15. A method according to claim 14, wherein said first and second generator/motor units are variable rotational speed units that are similar to one another.

16. A method according to claim 15, wherein said generator/motor units are controllable to operate respective water pumps for pumping water in the water tunnel to an upstream reservoir when excess power is available at the power grid.

17. A method according to claim 14, comprising controlling the first generator/motor unit in a power control mode as a function of effective power output detected at the first generator/motor unit and controlling the second motor generator unit in a rotational speed control mode as a function of the rotational speed of the second generator/motor unit.

18. A method according to claim 14, comprising controlling both the first and second generator/motor units in a power control mode as a function of effective power output

detected at the respective first and second generator/motor units,

and wherein said controlling includes use of respective different mathematical conversion factors for converting detected physical operating conditions used in control of the respective first and second generator/motor units.

19. A method according to claim 17, wherein said first and second generator/motor units are variable rotational speed units that are similar to one another.

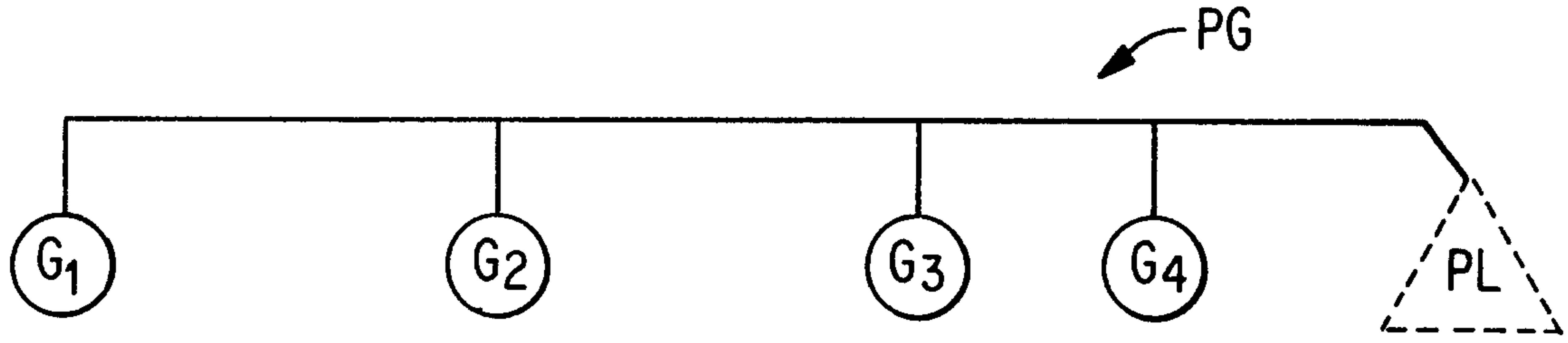


FIG. 1

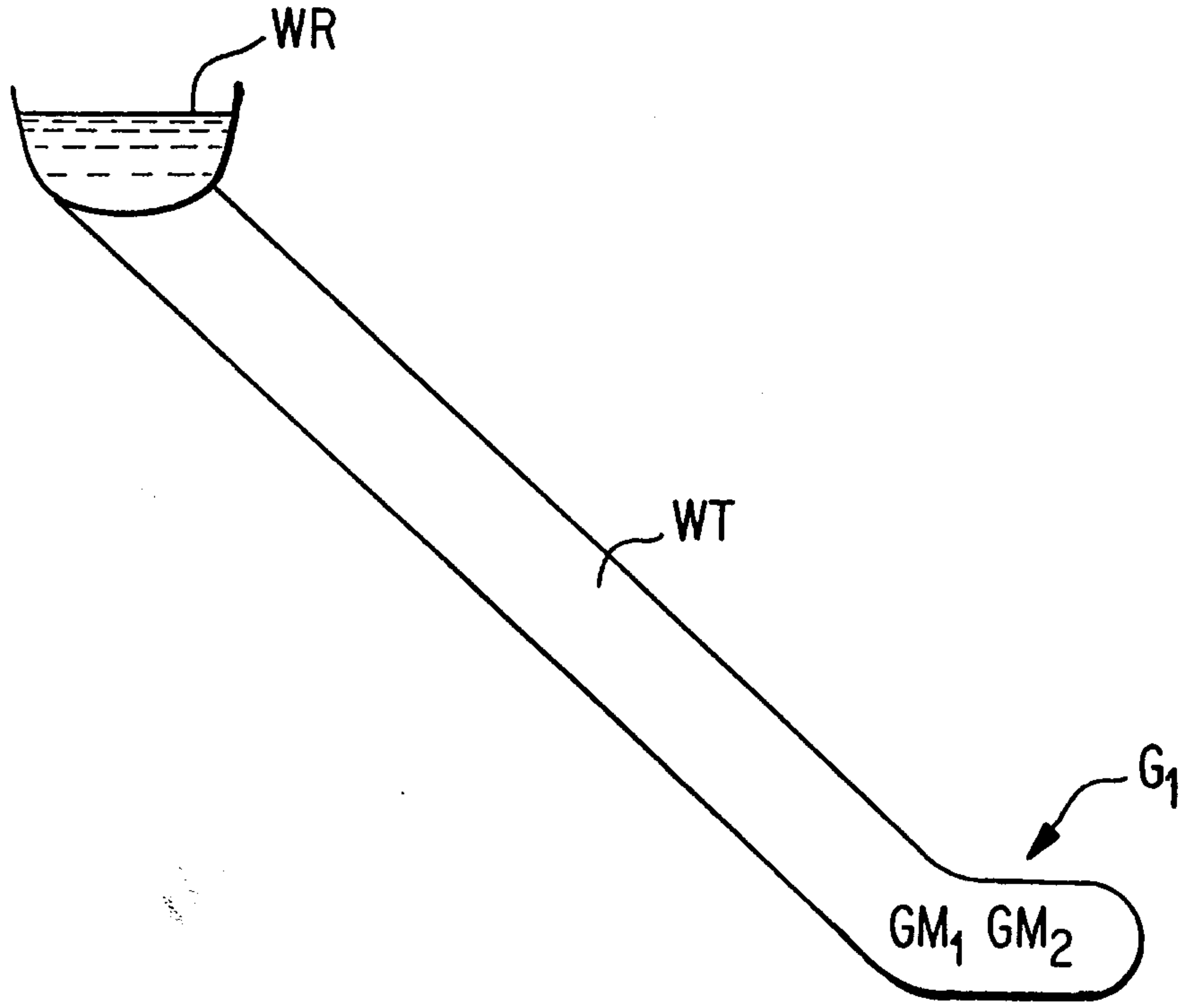


FIG. 2

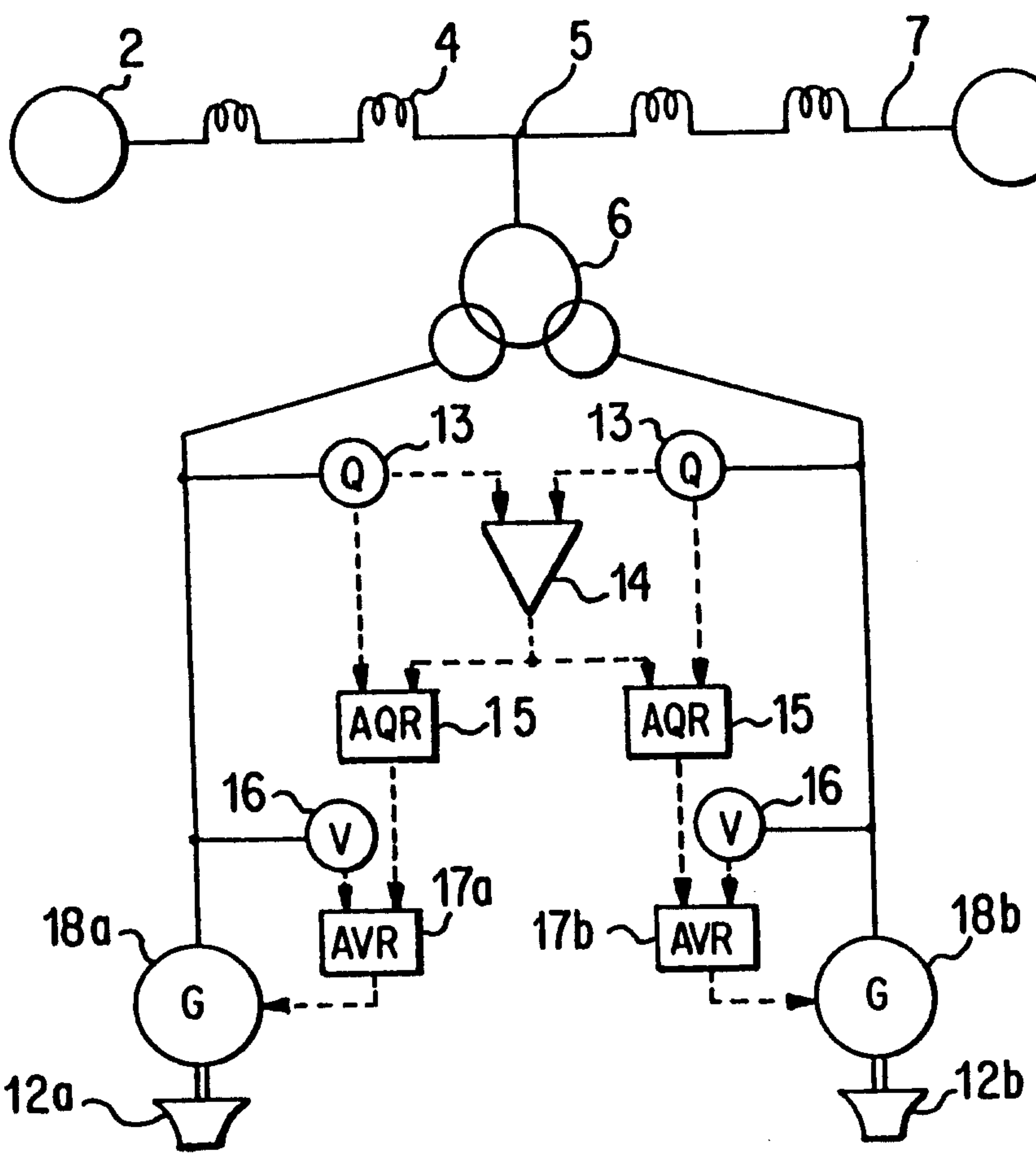


FIG.3
(PRIOR ART)

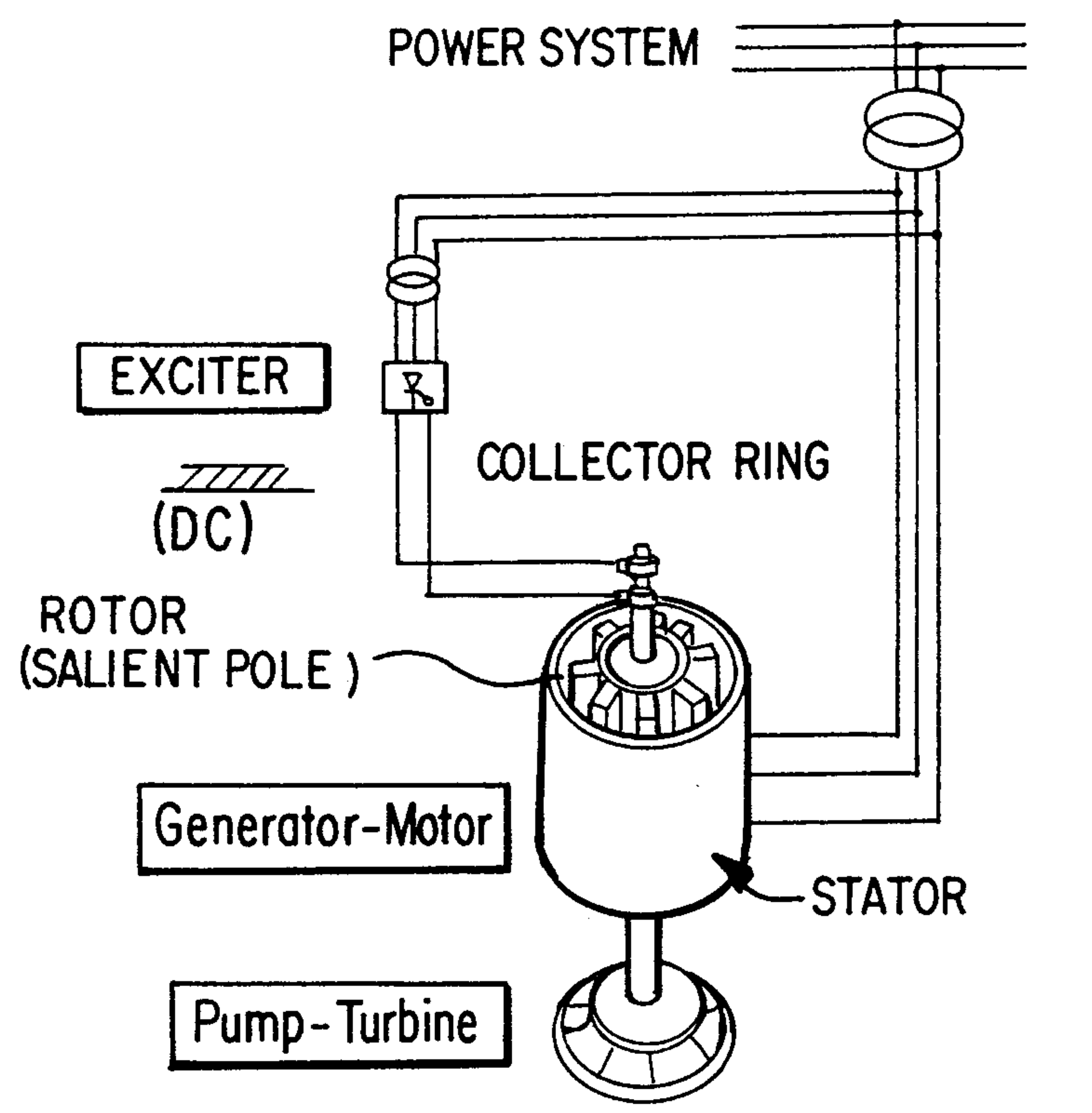
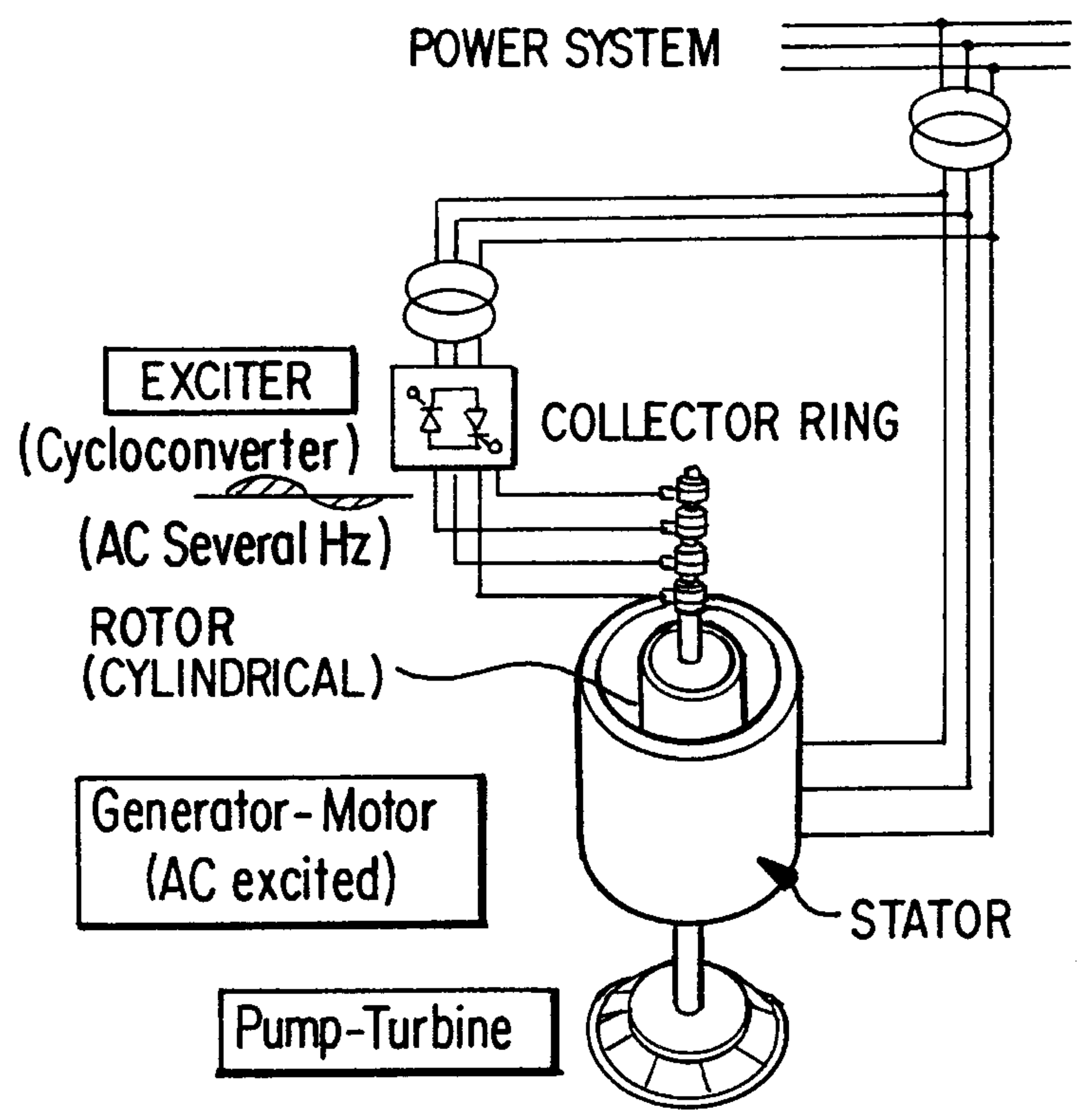
	CONVENTIONAL SYSTEM	ADJUSTABLE SPEED SYSTEM
SYSTEM		
POLE	SALIENT POLE	CYLINDRICAL
ROTOR COIL	LOW VOLTAGE (DC)	HIGH VOLTAGE (AC)
EXCITATION	DC EXCITATION	AC EXCITATION WITH CYCLOCONVERTER
SPEED	FIXED	ADJUSTABLE

FIG. 4

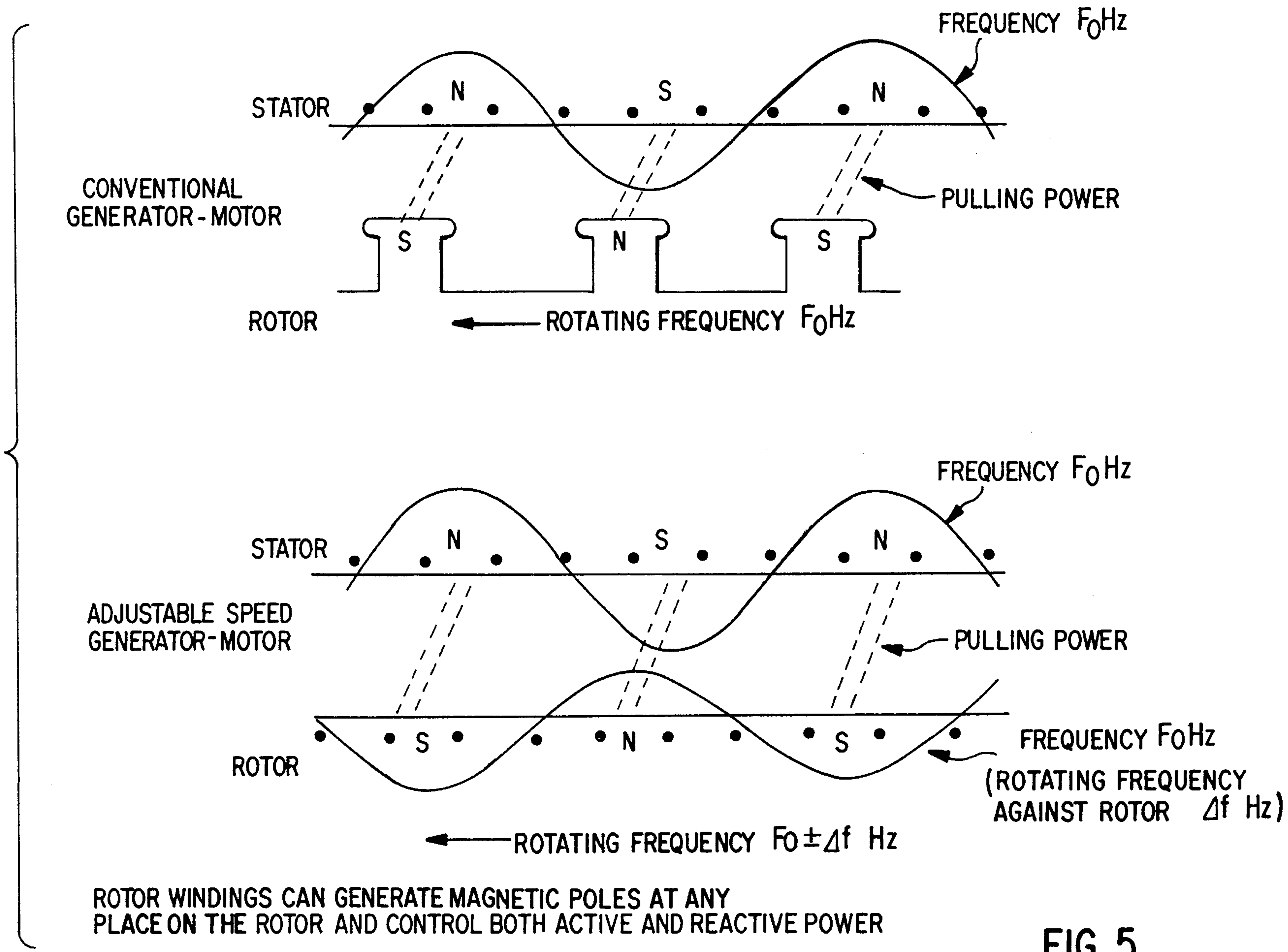


FIG. 5

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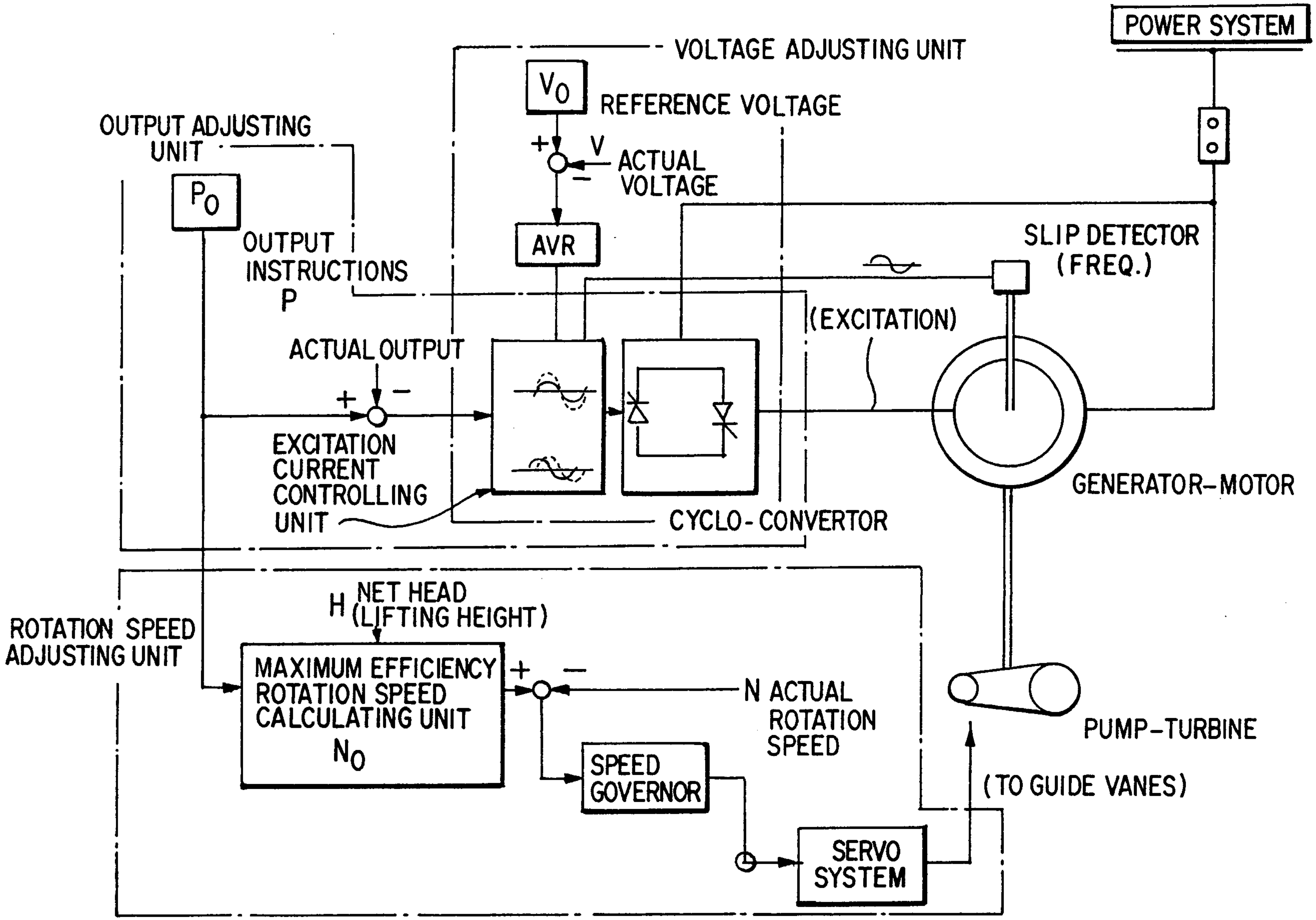

FIG. 6

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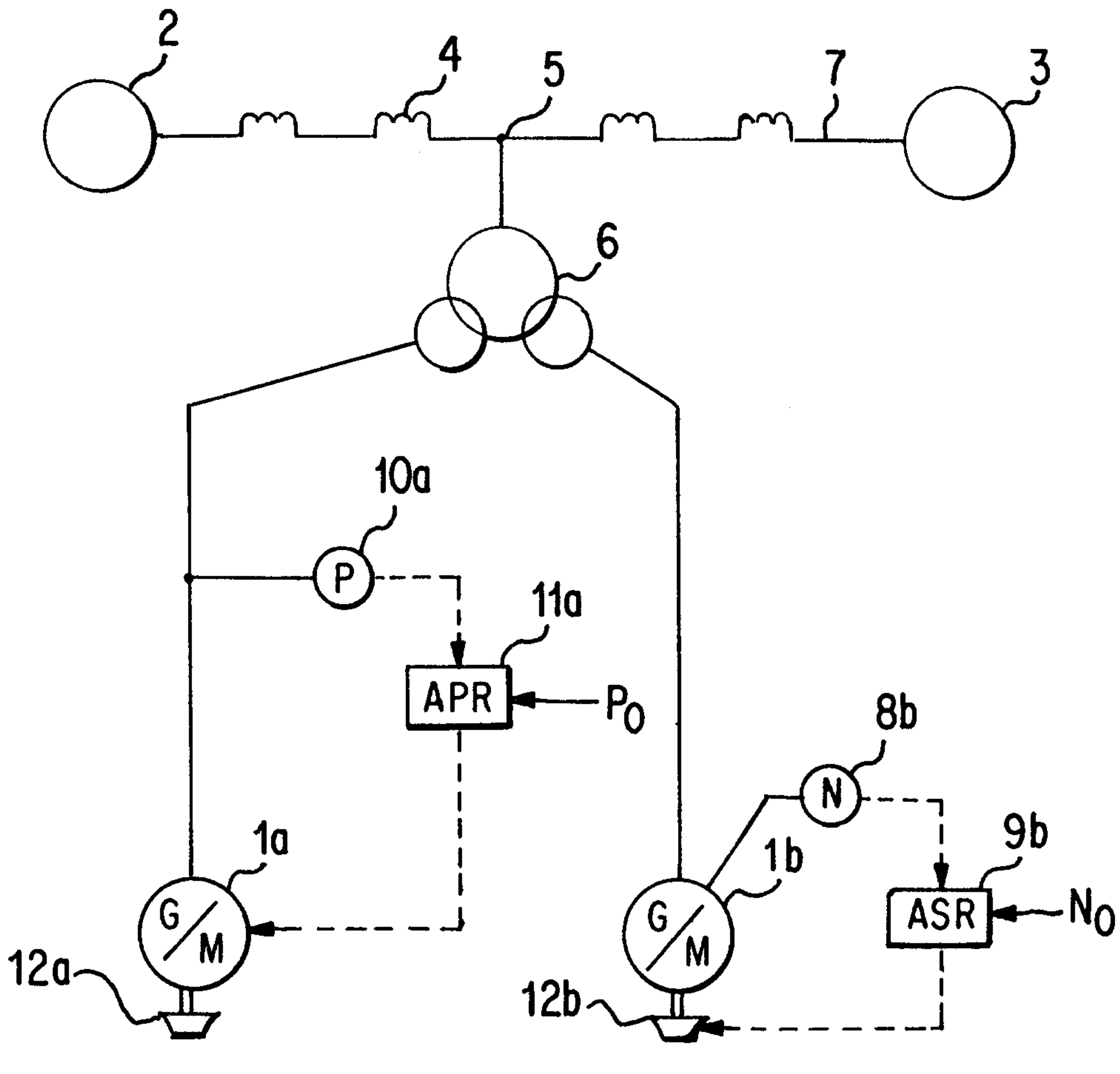

FIG. 7

Kirby, Eades, Gale, Baker

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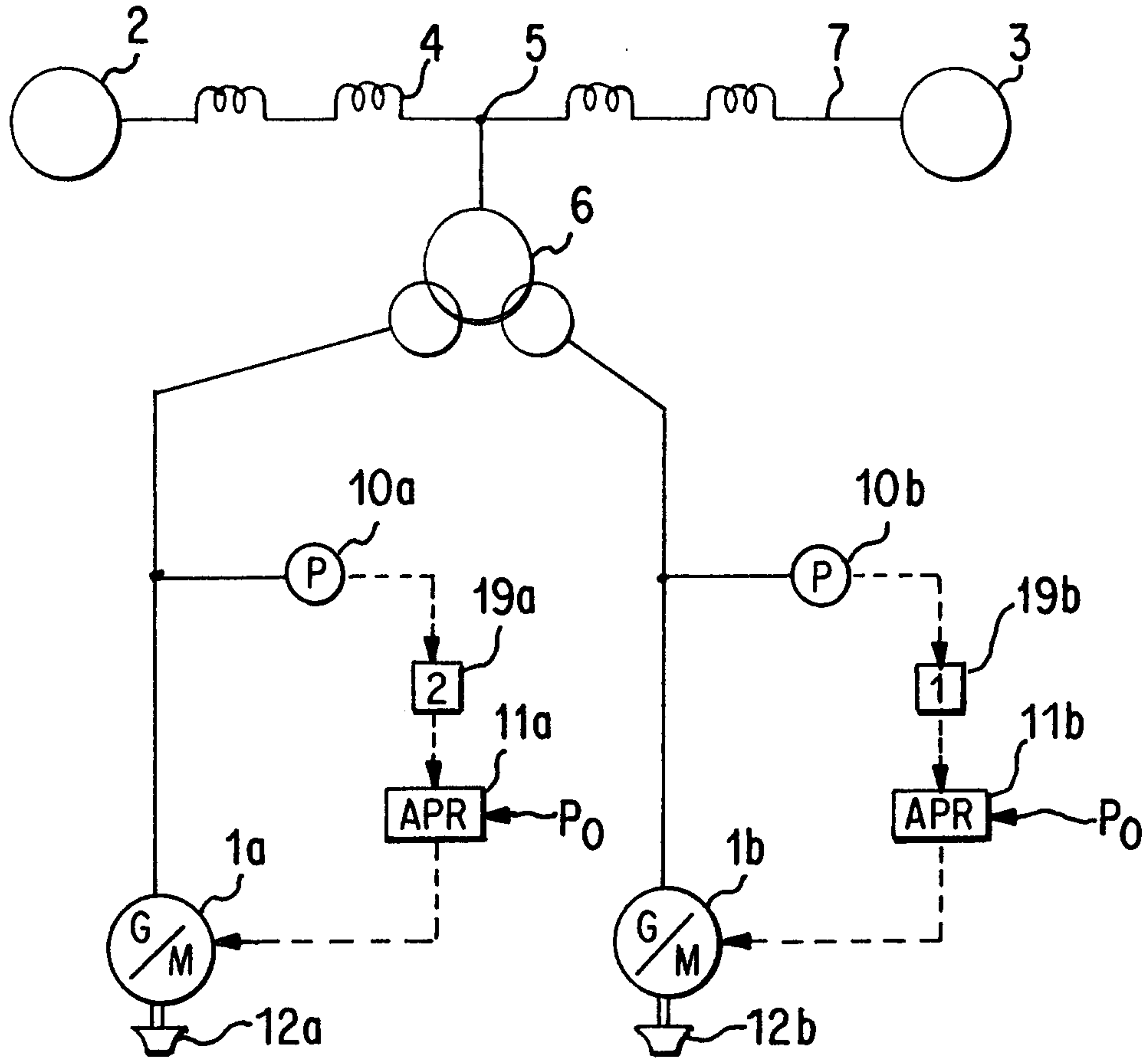


FIG. 8

Kirby, Eades, Gale, Baker

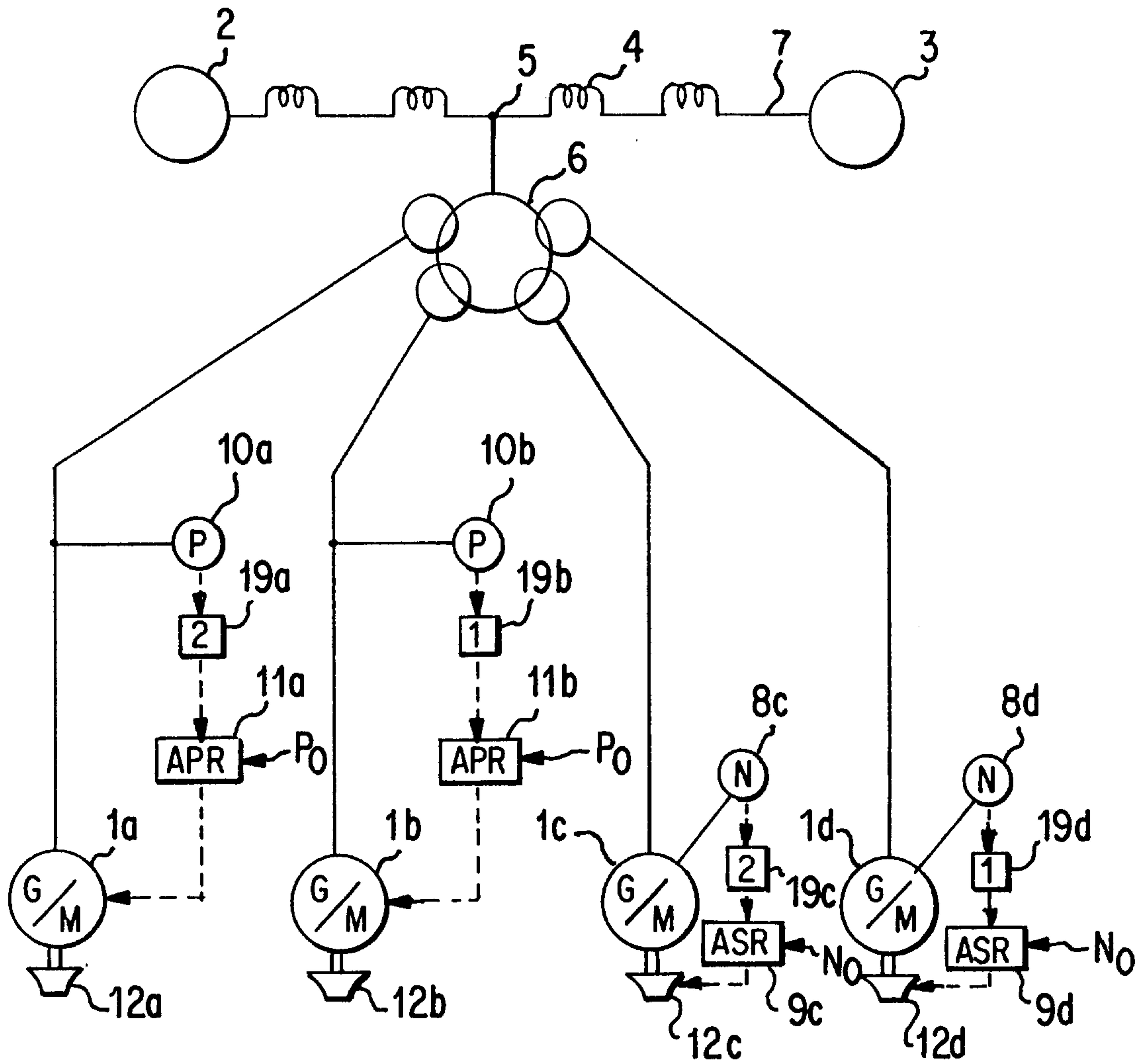

2
5
4
7
3
6
10a
10b
P
P
19a
2
19b
1
11a
11b
APR
APR
P0
P0
8c
8d
N
N
1a
1b
1c
1d
19d
G
M
2
19c
1
ASR
ASR
N0
N0
12a
12b
9c
9d
12c
12d

FIG.9

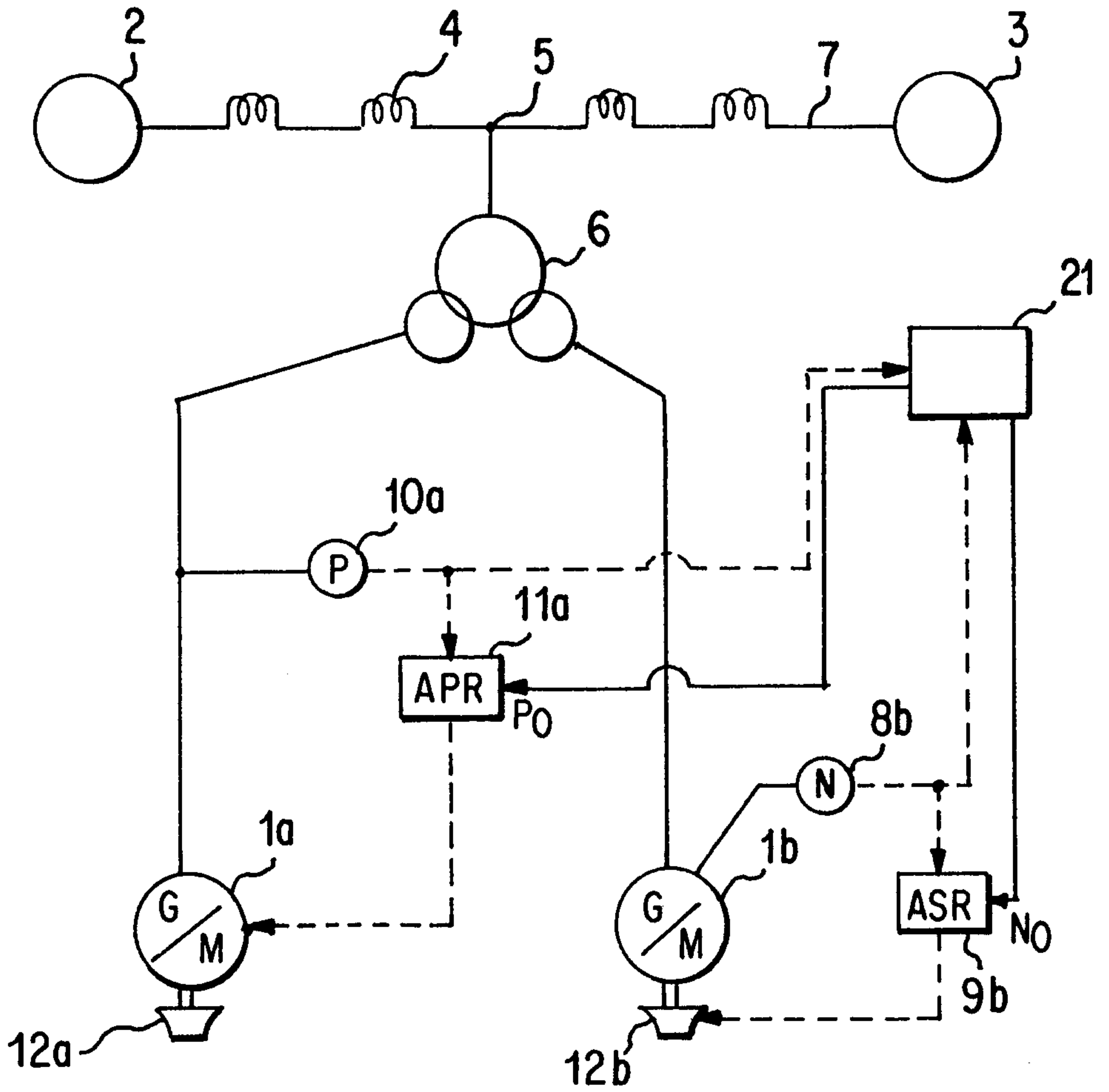


FIG. 10

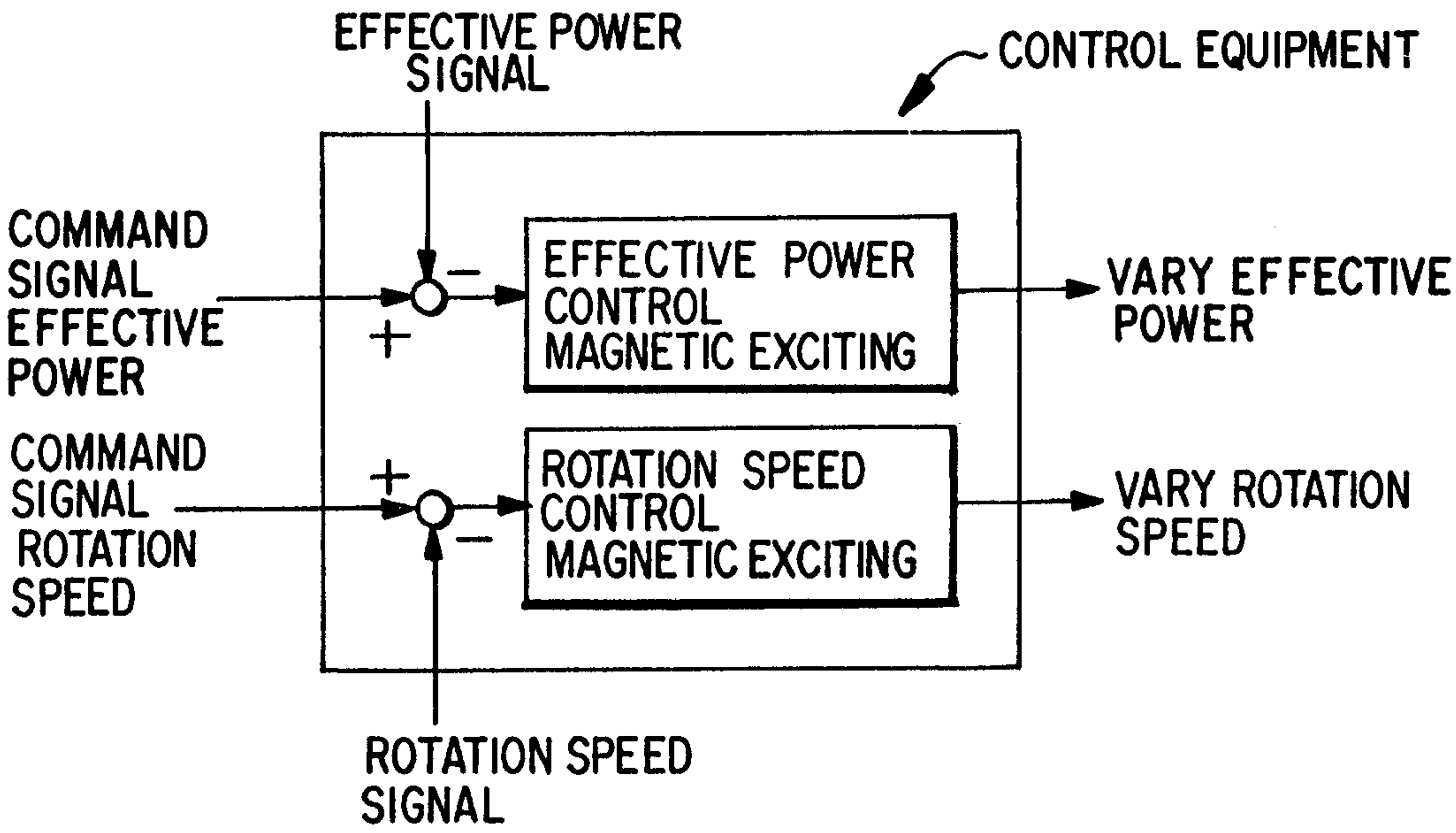

EFFECTIVE POWER SIGNAL
CONTROL EQUIPMENT
COMMAND SIGNAL EFFECTIVE POWER
EFFECTIVE POWER CONTROL MAGNETIC EXCITING
VARY EFFECTIVE POWER
COMMAND SIGNAL ROTATION SPEED
ROTATION SPEED CONTROL MAGNETIC EXCITING
VARY ROTATION SPEED
ROTATION SPEED SIGNAL

FIG. 11

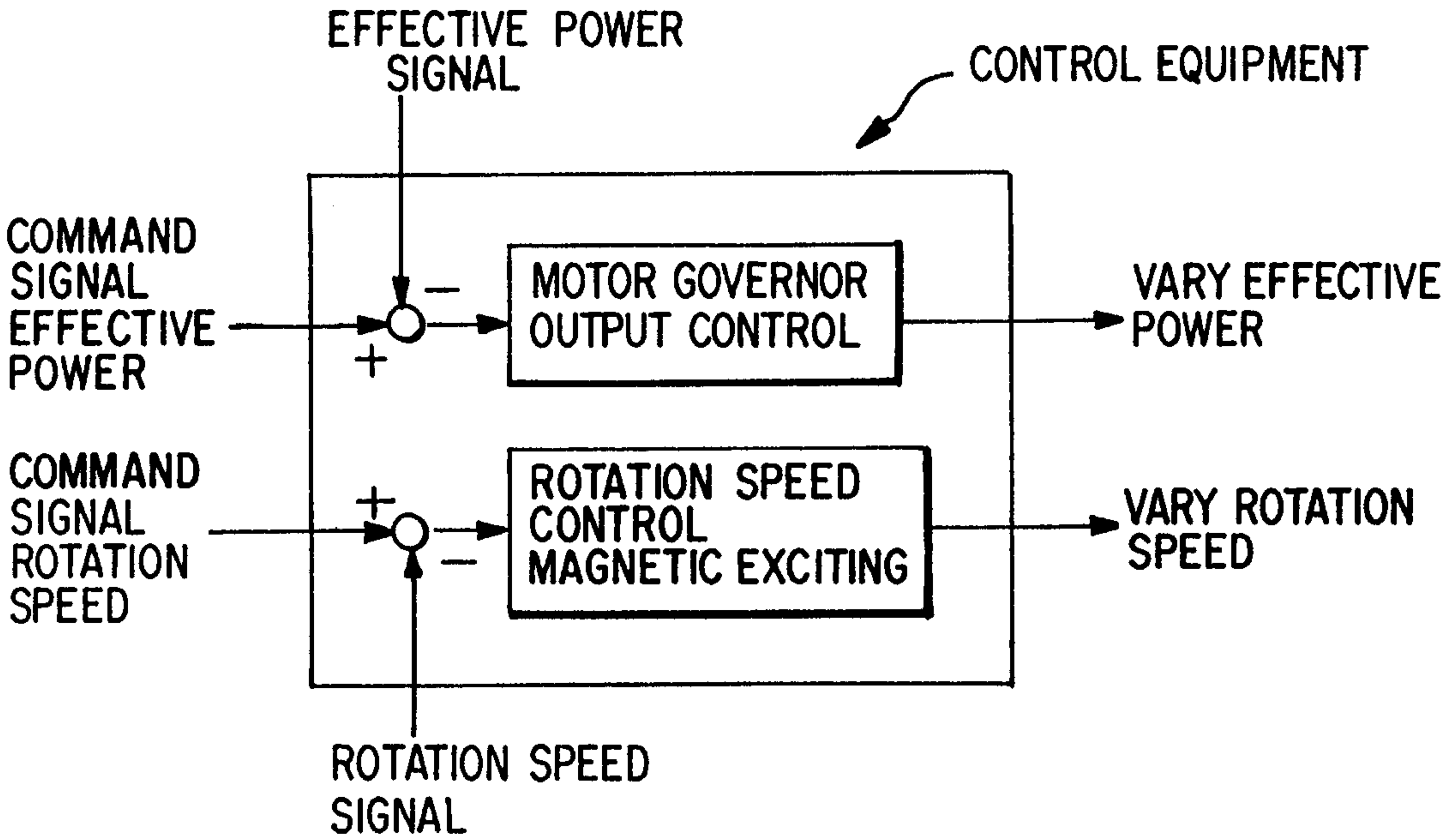
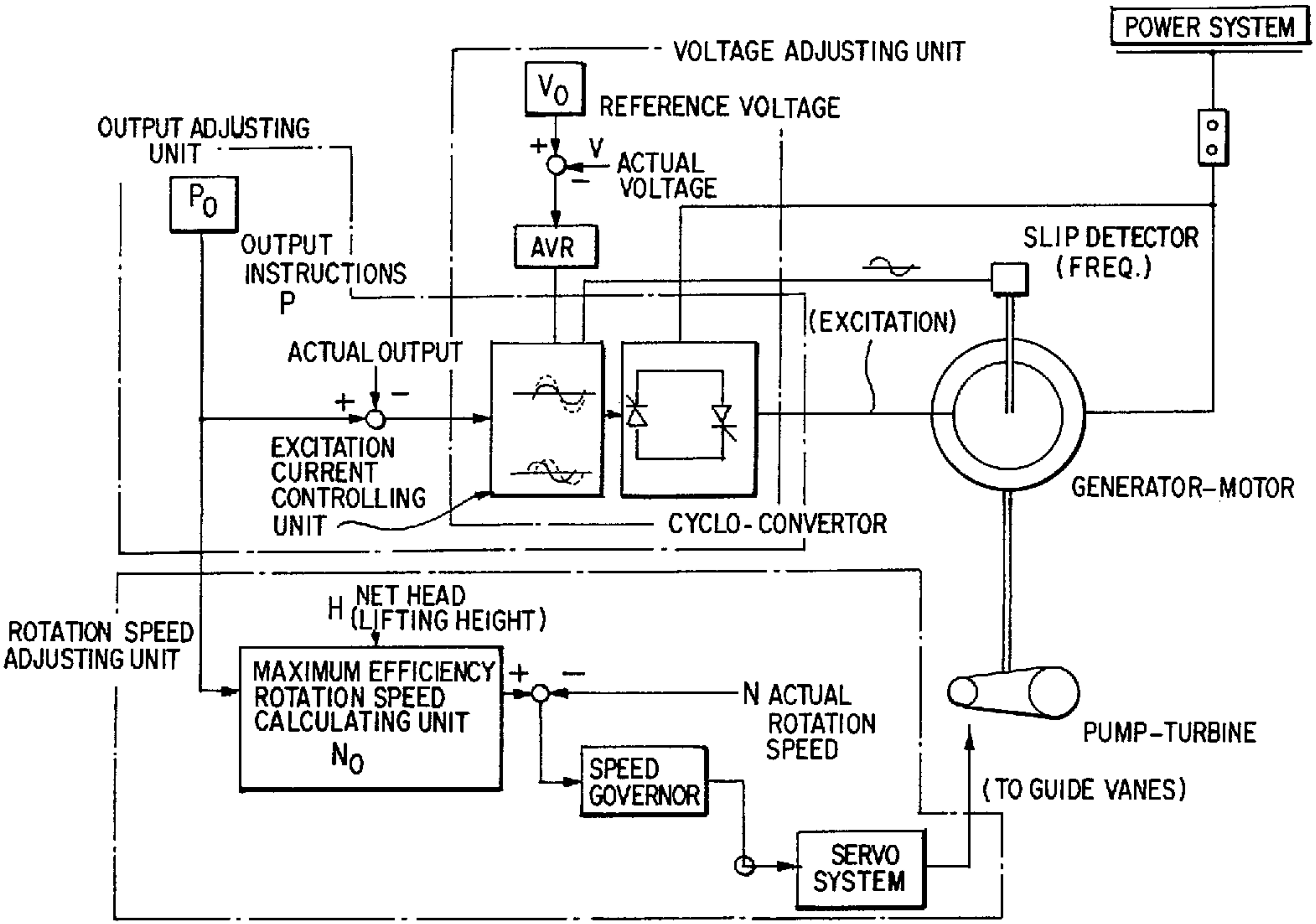

EFFECTIVE POWER SIGNAL
CONTROL EQUIPMENT
COMMAND SIGNAL EFFECTIVE POWER
MOTOR GOVERNOR OUTPUT CONTROL
VARY EFFECTIVE POWER
COMMAND SIGNAL ROTATION SPEED
ROTATION SPEED CONTROL MAGNETIC EXCITING
VARY ROTATION SPEED
ROTATION SPEED SIGNAL

FIG. 12



POWER SYSTEM
VOLTAGE ADJUSTING UNIT
V_0
REFERENCE VOLTAGE
OUTPUT ADJUSTING UNIT
V
ACTUAL VOLTAGE
P_0
AVR
SLIP DETECTOR (FREQ.)
OUTPUT INSTRUCTIONS
P
(EXCITATION)
ACTUAL OUTPUT
EXCITATION CURRENT CONTROLLING UNIT
GENERATOR-MOTOR
CYCLO-CONVERTOR
H
NET HEAD (LIFTING HEIGHT)
ROTATION SPEED ADJUSTING UNIT
MAXIMUM EFFICIENCY ROTATION SPEED CALCULATING UNIT
N_0
N
ACTUAL ROTATION SPEED
PUMP-TURBINE
SPEED GOVERNOR
(TO GUIDE VANES)
SERVO SYSTEM