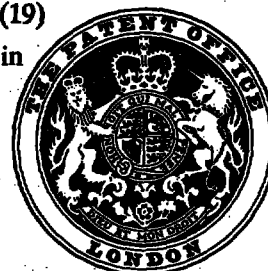


PATENT SPECIFICATION

(11) 1 588 053

- (21) Application No. 41431/77 (22) Filed 5 Oct. 1977 (19)
(31) Convention Application No. 51/136056 (32) Filed 12 Nov. 1976 in
(33) Japan (JP)
(44) Complete Specification Published 15 Apr. 1981
(51) INT. CL.³ G01R 21/00
(52) Index at Acceptance
GIU BE



(54) ELECTRIC POWER TO DC SIGNAL CONVERTER

(71) We, YOKOGAWA ELECTRIC WORKS, LTD., a Japanese Company of 9-32 Nakacho 2-Chome, Musashino-shi, Tokyo 180, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to an electric power to d-c signal converter which receives a voltage and a current of an a-c circuit and, after multiplying the voltage by the current, produces an output d-c signal proportional to the input electric power of the a-c circuit. Among the conventional apparatus for measuring electric power in a power circuit, there is known heretofore an electrodynamic type wattmeter using a stationary coil and a movable coil as multiplying elements.

In such a wattmeter, the current of an a-c circuit is applied to the stationary coil while the voltage thereof is applied to the movable coil through a high resistance, and the force resulting from the electromagnetic interaction between the two coils is utilised to obtain the electric power of the power circuit. However, the electrodynamic type wattmeter becomes complicated in the structure due to the necessity of a stationary coil and a movable coil, hence, requiring intricate assembly and adjustment as well.

Moreover, there exists a disadvantage of difficulty in attaining high accuracy in addition to its constructional bulkiness. Furthermore, in a three-phase wattmeter equipped with a movable mechanism where two movable coils are attached to a movable shaft, there is another disadvantage that it is impossible to adapt the component parts of a single-phase wattmeter directly to the three-phase one.

The present invention has been accomplished in an attempt to eliminate the above-described disadvantages of the conventional apparatus, and to provide a converter which can be composed entirely of electronic circuits without employing any of such movable or stationary coil as a multiplying element.

According to the invention there is provided an electric power to d-c signal converter comprising a pulse width-modulator having a first protective circuit on the input side including an integrator to which a voltage signal from a power circuit is applied and an analog switch having a second protective circuit on the input side thereof and driven by the output signal of said pulse width modulator for turning on and off a current signal from said power circuit, whereby a signal indicative of the power in said power circuit is provided.

The invention enables the assembly and adjustment of the converter to be facilitated because the pulse-width modulator, which functions as a multiplier, can be formed fully into an electronic circuit configuration.

The invention also enables a compact, lightweight and low cost electric power to d-c signal converter to be provided, which offers a high accuracy and is adapted for construction as an integrated circuit.

Another advantage of the invention is that it provides an improved converter which is easily capable of converting three-phase electric power, three-phase reactive power or three-phase four-wire power to a d-c signal by employing two pulse-width modulators of the same composition as that of a device used for conversion of single-phase power to a d-c signal.

The invention provides an improved converter suited for stock at various ratings.

Further objects, features and advantages of the present invention will become more apparent from the following detailed description of examples when read in conjunction with

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the accompanying drawings in which:-

Figure 1 is a connection diagram illustrating the operating principle of an electric power to d-c signal converter;

Figure 2 is a circuit diagram showing an exemplary embodiment of the converter of Figure 1;

Figure 3 is a waveform chart for explaining the operation of the converter shown in Figure 2; and

Figures 4 to 6 are circuit diagrams of other embodiments of the converter of Figure 1.

In the block diagram of Figure 1 illustrating the operating principle of an electric power to d-c signal converter, the converter PL consists of an input circuit IP which receives a voltage V of a power circuit to which a load LO is connected. The converter also receives a current A from the power circuit through a current transformer CT and includes a pulse-width modulator PWM serving as a multiplier, and a scaling amplifier SA. The output of converter PL is indicated by means of a meter M. A rectifier circuit RE receives and converts the input voltage V to a d-c voltage $\pm VC$. Figure 2 is a circuit diagram of an embodiment of the present invention for converting a single-phase electric power to a proportional d-c signal. In this diagram: P1, P2 are terminals to receive the voltage V of the power circuit shown in Figure 1; IS, IL are terminals to receive the current A of the power circuit; and RE is a rectifier circuit to produce a voltage $\pm VC$. This rectifier circuit may be equipped with a power transformer separately, and the voltage may be obtained therefrom. PWM is a pulse-width modulator consisting of an integrator IG and a comparator COM. The integrator IG comprises an amplifier Ai, an input resistor Ri and a feedback capacitor Ci; and the comparator COM comprises an input resistor RC1, a feedback resistor RC2, and NAND gates NG1, NG2 of C-MOS (complementary MOS). The d-c voltage $\pm VC$ obtained from the rectifier circuit RE is applied as a power source to the NAND gate NG1. The comparator has hysteresis characteristic according to the action of feedback resistor RC2. The terminal P1 to receive the voltage V of power circuit is connected to the input resistor Ri of integrator IG, whose output terminal is connected to the input resistor RC1 of comparator COM. RE is a feedback resistor connected between the addition input terminal of integrator IG and the output terminal of comparator COM; CT is a current transformer; IP is an output circuit; SA is a scaling amplifier; M is a moving-coil type meter; and AS is an analog switch. The primary of current transformer CT is connected to the terminals IS, IL to which the current A of power circuit is applied, while the secondary of CT is connected to the input terminal of input circuit IP, whose output terminal is connected to the meter M through the analog switch AS and the scaling amplifier SA. Each of G1, G2, G3 and G4 is a circuit consisting of a pair of diodes connected in parallel with each other in the opposite direction: wherein G1 and G2 protect the input of each amplifier in the integrator IG and the input circuit IP from an impulse input; G3 protects the analog switch AS from an impulse input; and G4 protects the meter M. The analog switch AS is controlled by an output signal e2 of NAND gate NG2 in such a manner as to be turned on when e2 is "1" or to be turned off when e2 is "0".

In the converter of the above-described structure, the operation is performed in the following manner. Supposing now that, as shown in Figure 2, potentials e0, e1, e2 are present at the output terminals of integrator IG constituting the pulse-width modulator PWM and at the input terminal of NAND gate NG1 and the output terminal of NG2 constituting the comparator COM, then the waveforms of e0, e1, e2 are such as illustrated in Figure 3(a), (b) and (c) respectively. The potential e2 becomes a rectangular-wave voltage represented by $\pm Es$ as shown in (c), and this voltage is fed back to the input terminal of integrator IG through a resistor RF. The integrator IG executes addition and integration of a current i_v caused to flow in the resistor Ri by the voltage V to be measured and a current $\pm i_f$ caused to flow in the feedback resistor RF by the feedback voltage $\pm Es$. Since the values of the two currents are so selected as to satisfy the condition $|i_v| < |i_f|$ to avoid overmodulation in the normal operating state, the output voltage e0 of integrator IG increases, during integration of i_v and $-i_f$ by the integrator IG, at a fixed angle of inclination as illustrated in the period T1 of Figure 3(a). And during the period T1, the voltage e1 rises as shown in Figure 3(b) at the angle of inclination determined by the ratio between the resistors RC1 and RC2, and when the voltage reaches the threshold voltage Vs of NAND gate NG1, the output voltage e2 of NAND gate NG2 becomes a "1" level and then is fed back to the input terminal of NAND gate NG1 through the resistor RC2, thereby causing a sudden rise of e1. The "1" level voltage e2 or $+Es$ is fed back through the resistor RF to the integrator IG, which executes addition and integration of the current i_v and the current $+i_f$ caused by the positive feedback voltage $+Es$. Accordingly, as illustrated in the period T2 of Figure 3(a), the output e0 of integrator IG falls at a certain angle of inclination sharper than that in the period T1. As the output voltage e0 of integrator IG begins to advance in the negative direction, the voltage e1 also decreases, and indicates a sudden drop immediately

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after arrival at V_s . Since the voltage e_1 of the waveform shown in Figure 3(b) is applied to the NAND gate NG1, the voltage e_2 at the output terminal of NAND gate NG2 is shaped into a rectangular wave represented by $\pm E_s$, as shown in Figure 3(c). Thus, the input terminal of integrator IG receives, during the period T_1 , the sum of the currents proportional respectively to the input voltage V and the feedback voltage $-E_s$, and also receives, during the period T_2 , the sum of the currents proportional respectively to the input voltage V and the feedback voltage $+E_s$. That is, a feedback loop is formed by the circuit consisting of the integrator IG, comparator COM and feedback resistor R_F , and when the feedback loop is formed, pulse-width modulation is performed for the feedback voltage, $+E_s$, $-E_s$ in response to the input voltage V . And when the periodic mean value of the feedback voltage $+E_s$, $-E_s$ and the input voltage V have cancelled each other the system is balanced. In other words, the comparator COM switches when $e_1 = V_s$, and when the system is in a balanced condition, the integrator IG is so acted that the mean value in the summing point of the integrator IG becomes zero. Therefore when the system is in a balanced condition the following Equation (1) is established.

$$(V - E_s) \frac{T_1}{T_1 + T_2} + (V + E_s) \frac{T_2}{T_1 + T_2} = 0 \quad \text{..... (1)}$$

From Equation (1),

$$V = E_s \left(\frac{T_1 - T_2}{T_1 + T_2} \right) \quad \text{..... (2)}$$

In the above, $\frac{T_1 - T_2}{T_1 + T_2}$ is expressed as follows:

$$\frac{T_1 - T_2}{T_1 + T_2} = \frac{T_1 + T_2 - 2T_2}{T_1 + T_2} = 1 - \frac{2T_2}{T_1 + T_2} \quad \text{..... (3)}$$

From equations (2) and (3),

$$\frac{V}{E_s} = 1 - \frac{2T_2}{T_1 + T_2} \quad \text{..... (4)}$$

$$\text{Thus, } \frac{T_2}{T_1 + T_2} = \frac{1}{2} \left(1 - \frac{V}{E_s} \right) \quad \text{..... (5)}$$

As is obvious from Equation (5), the width of the output pulse e_2 of comparator COM is modulated in accordance with the input voltage V applied from the power circuit.

In the meanwhile, the current A of the power circuit applied to the terminals 1S and 1L is converted to a proper value by means of current transformer CT and then is applied to the analog switch AS through the input circuit IP. The analog switch AS is controlled by the output e_2 of comparator COM constituting the pulse-width modulator PWM, in such a manner as to be turned on during the period T_2 or to be turned off during the period T_1 . Consequently, the current A applied to the input side of analog switch AS is connected or disconnected intermittently by the output signal e_2 of pulse-width modulator. The envelope curve of the current i flowing into the scaling amplifier SA is proportional to the input current A , and the relation between them is represented by the following equation:

$$i = \frac{T_2}{T_1 + T_2} \cdot A = \frac{1}{2} \left(1 - \frac{V}{E_s} \right) \cdot A = \frac{1}{2} A - \frac{V \cdot A}{E_s} \quad \text{..... (6)}$$

The mean value (d-c component) of Equation (6) is obtained from the output terminal of scaling amplifier SA. As the first term on the right side of Equation (6) denotes merely the a-c component, its mean value becomes zero. Accordingly, the output voltage E_0 of scaling amplifier SA is expressed as.

$$E_0 \propto \frac{V \cdot A}{E_s}$$

..... (7)

Since E_s is constant in Equation (7), E_0 is the product of V and A , that is, the voltage corresponding to the electric power W in the power circuit. The voltage E_0 is fed in the form of current I_m to the meter M , which indicates the value of the electric power W . The scaling amplifier S performs scaling and amplification to set a rated electric power. The feedback resistor R_2 of scaling amplifier SA is of variable type, and scaling is effected by varying the value of resistor R_2 to change the gain. The scaling amplifier is theoretically unnecessary because the meter M has an integral characteristic, but actually is needed because without the scaling amplifier, the meter has to be highly sensitive and, moreover, scaling becomes inconvenient.

Thus, in the electric power to d-c signal converter of the present invention, integrated-circuit configuration is applicable to the pulse-width modulator serving as a multiplier, thereby rendering it possible to attain a compact, lightweight and low-cost converter. In addition to the above, various merits are achievable including that (1) no selector part is required to result in high accuracy, and (2) the numbers of wiring and adjusting processes can be minimised. Moreover, there exists another advantage in the present invention that, by providing a scaling amplifier SA in the manner mentioned above, converters of various ratings can be produced and stocked through adjustment of the scaling resistor R_2 . Furthermore, due to the provision of a protective circuit of diodes in each amplifier, the converter is permitted to remain stable against an input impulse.

Figure 4 is a circuit diagram showing an embodiment of a three-phase three-wire electric power to d-c signal converter, in which: P_1, P_2, P_3 are voltage terminals in a three-phase power circuit; $1S, 1L, 3S, 3L$ are current terminals; $PWM1, PWM2$ are pulse-width modulators each having the same composition as the modulator explained in Figure 1, wherein the input terminal of $PWM1$ is connected to the voltage terminal P_1 while the input terminal of $PWM2$ is connected to the voltage terminal P_3 ; $IP1, IP2$ are input circuits, in which the input terminal of $IP1$ is connected to the current terminals $1S, 1L$ through a current transformer $CT1$, and the input terminal of $IP2$ is connected to the current terminals $3S, 3L$ through a current transformer $CT2$; and $AS1, AS2$ are analog switches, in which a current $A1$ is applied to $AS1$ from the current terminals $1S, 1L$ while a current $A3$ is applied to $AS2$ from the current terminals $3S, 3L$. The analog switches $AS1, AS2$ are turned on or off intermittently by the outputs of pulse-width modulators $PWM1, PWM2$ individually. The voltage E_{ow} produced as the result of addition of the electric powers shown in Equation (7), that is,

$$\frac{V_1 \cdot A_1}{E_s} + \frac{V_3 \cdot A_3}{E_s},$$

is obtained from the output terminal of scaling amplifier SA , and this voltage E_{ow} corresponding to the three-phase three-wire electric power is indicated by means of a meter M .

Figure 5 shows an embodiment of the invention to convert a three-phase three-wire reactive power to a proportional d-c signal. When a false neutral point is formed in this circuit by connecting a terminal P_2 in common through a resistor RP , the result is $V_3 = V_{31} - V_{23}$, $V = V_{12} - V_{31}$ so that V_3 and V_1 come to have a $\pi/2$ phase advance to V_{12} and V_{23} respectively at completely balanced voltages. Consequently, through multiplying V_1 by the first-phase current A_1 in the power circuit and also multiplying V_3 by the third-phase current A_3 , a d-c signal E_{oa} corresponding to the three-phase three-wire reactive power (VAR) is obtained from the output terminal of scaling amplifier SA , and this d-c voltage is indicated by means of a meter M . Multiplication of the voltage by the current is performed by pulse-width modulators $PWM1$ and $PWM2$. As each of these modulators has the same composition as the foregoing pulse-width modulator PWM described already in Figure 2, repeating the explanation is omitted here.

Figure 6 is a concrete circuit diagram of an embodiment of the invention relating to a three-phase four-wire wattmeter, in which P_o is a neutral point. A pulse-width modulator $PWM1$ receives voltages V_1, V_2 applied from terminals P_1, P_2 ; and $PWM2$ receives voltages V_2, V_3 from terminals P_2, P_3 . The pulse-width modulator $PWM1$ multiplies the voltages V_1, V_2 by the currents A_1, A_2 fed to current terminals $1S, 1L, 2S, 2L$; and the pulse-width modulator $PWM2$ multiplies the voltages V_2, V_3 by the currents A_2, A_3 fed to current terminals $2S, 2L, 3S, 3L$. The results of such multiplications are averaged by a scaling amplifier SA , and its output voltage E_{ot} is indicated by means of a meter M . The

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principle of multiplication performed by each of the pulse-width modulators PWM1 and PWM2 is exactly the same as that described in Figure 2.

The converters shown in Figures 4 to 6 have the same effect of action as that mentioned in relation to the single-phase electric power to d-c signal converter of Figure 2, and are capable of converting three-phase three-wire power, three-phase three-wire reactive power and three-phase four-wire power to a proportional d-c signal respectively.

WHAT WE CLAIM IS:

1. An electric power to d-c signal converter comprising a pulse width-modulator having a first protective circuit on the input side including an integrator to which a voltage signal from a power circuit is applied and an analog switch having a second protective circuit on the input side thereof and driven by the output signal of said pulse width modulator for turning on and off a current signal from said power circuit, whereby a signal indicative of the power in said power circuit is provided.

2. An electric power to d.c. signal converter according to Claim 1, in which said integrator includes a d.c. amplifier and an input resistor through which said voltage signal from the power circuit is applied, a feed-back capacitor connected across the d.c. amplifier; and the pulse width modulator includes a comparator comprising a first NAND gate connected through a resistance element to the output terminal of said integrator, a second NAND gate connected in series to the first NAND gate, and a feedback resistor connected between the input terminal of the first NAND gate and the output terminal of the second NAND gate; the pulse width modulator also including a feedback resistor connected between the input terminal of the d.c. amplifier of said integrator and the output terminal of the second NAND gate of said comparator.

3. An electric power to d.c. signal converter according to Claim 1 or 2, including a smoothing amplifier for smoothing the output of the analog switch and a rectifier circuit for smoothing the voltage signal from said power circuit.

4. The electric power to d.c. signal converter as defined in any of Claims 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltage of a first line in a three-phase power circuit, of which a second line is connected in common, is applied to the first pulse-width modulator, while the voltage of a third line is applied to the second pulse-width modulator; and the current flowing in the first line is applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the current flowing in the third line is applied to the second analog switch controlled to be on or off by the output signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

5. The electric power to d-c signal converter as defined in any of Claim 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltage of a first line in a three-phase power circuit, of which a second line is connected in common through a resistor, is applied to the first pulse-width modulator, while the voltage of a third line is applied to the second pulse-width modulator; and the current flowing in the third line is applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the current flowing in the first line is applied to the second analog switch controlled to be on or off by the output signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

6. The electric power to d-c signal converter as defined in any of Claim 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltages of first and second lines in a three-phase four-wire power circuit with a neutral point are applied to the first pulse-width modulator, while the voltage of second and third lines are applied to the second pulse-width modulator; and the currents flowing in the first and second lines are applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the currents flowing in the second and third lines are applied to the second analog switch controlled to be on or off by the outlet signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

7. The electric power to d-c signal converter as defined in any one of Claims 3 to 6, in which the smoothing amplifier is a scaling amplifier with a variable resistor connected between the input and output thereof.

8. An electric power to d-c signal converter as defined in any one of Claims 1 to 6, wherein a moving coil type indicator is connected to said output terminal of said smoothing circuit.

9. An electric power to d-c signal converter substantially as described with reference to Figures 1 to 3 of the accompanying drawings.

10. An electric power to d-c signal converter substantially as described with reference to



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principle of multiplication performed by each of the pulse-width modulators PWM1 and PWM2 is exactly the same as that described in Figure 2.

The converters shown in Figures 4 to 6 have the same effect of action as that mentioned in relation to the single-phase electric power to d-c signal converter of Figure 2, and are capable of converting three-phase three-wire power, three-phase three-wire reactive power and three-phase four-wire power to a proportional d-c signal respectively.

WHAT WE CLAIM IS:

1. An electric power to d-c signal converter comprising a pulse width-modulator having a first protective circuit on the input side including an integrator to which a voltage signal from a power circuit is applied and an analog switch having a second protective circuit on the input side thereof and driven by the output signal of said pulse width modulator for turning on and off a current signal from said power circuit, whereby a signal indicative of the power in said power circuit is provided.

2. An electric power to d.c. signal converter according to Claim 1, in which said integrator includes a d.c. amplifier and an input resistor through which said voltage signal from the power circuit is applied, a feed-back capacitor connected across the d.c. amplifier; and the pulse width modulator includes a comparator comprising a first NAND gate connected through a resistance element to the output terminal of said integrator, a second NAND gate connected in series to the first NAND gate, and a feedback resistor connected between the input terminal of the first NAND gate and the output terminal of the second NAND gate; the pulse width modulator also including a feedback resistor connected between the input terminal of the d.c. amplifier of said integrator and the output terminal of the second NAND gate of said comparator.

3. An electric power to d.c. signal converter according to Claim 1 or 2, including a smoothing amplifier for smoothing the output of the analog switch and a rectifier circuit for smoothing the voltage signal from said power circuit.

4. The electric power to d.c. signal converter as defined in any of Claims 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltage of a first line in a three-phase power circuit, of which a second line is connected in common, is applied to the first pulse-width modulator, while the voltage of a third line is applied to the second pulse-width modulator; and the current flowing in the first line is applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the current flowing in the third line is applied to the second analog switch controlled to be on or off by the output signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

5. The electric power to d-c signal converter as defined in any of Claim 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltage of a first line in a three-phase power circuit, of which a second line is connected in common through a resistor, is applied to the first pulse-width modulator, while the voltage of a third line is applied to the second pulse-width modulator; and the current flowing in the third line is applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the current flowing in the first line is applied to the second analog switch controlled to be on or off by the output signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

6. The electric power to d-c signal converter as defined in any of Claim 1 to 3, comprising two sets of said pulse-width modulators and analog switches, wherein the voltages of first and second lines in a three-phase four-wire power circuit with a neutral point are applied to the first pulse-width modulator, while the voltage of second and third lines are applied to the second pulse-width modulator; and the currents flowing in the first and second lines are applied to the first analog switch controlled to be on or off by the output signal of the first pulse-width modulator, while the currents flowing in the second and third lines are applied to the second analog switch controlled to be on or off by the outlet signal of the second pulse-width modulator; and the outputs of the first and second analog switches are added to each other and are smoothed to produce an output d-c signal.

7. The electric power to d-c signal converter as defined in any one of Claims 3 to 6, in which the smoothing amplifier is a scaling amplifier with a variable resistor connected between the input and output thereof.

8. An electric power to d-c signal converter as defined in any one of Claims 1 to 6, wherein a moving coil type indicator is connected to said output terminal of said smoothing circuit.

9. An electric power to d-c signal converter substantially as described with reference to Figures 1 to 3 of the accompanying drawings.

10. An electric power to d-c signal converter substantially as described with reference to



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Figure 4 of the accompanying drawings.

11. An electric power to d-c signal converter substantially as described with reference to Figure 5 of the accompanying drawings.

12. An electric power to d-c signal converter substantially as described with reference to Figure 6 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1981.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from
which copies may be obtained.