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A		B		C	X
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File Number: T 592/91 - 3.5.2

Application No.: 84 112 921.6

Publication No.: 0 140 348

Title of invention: Method and apparatus for controlling PWM inverter

Classification: H02M 7/5387

D E C I S I O N
of 20 October 1992

Proprietor of the patent: HITACHI, LTD.

Opponent: 01) Robert Bosch GmbH
02) Siemens AG

Headword:

EPC Article 56

Keyword: "Inventive step - yes"



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Boards of Appeal

Chambres de recours

Case Number : T 592/91 - 3.5.2

D E C I S I O N
of the Technical Board of Appeal 3.5.2
of 20 October 1992

Appellant :
(Proprietor of the patent)

HITACHI, LTD.
6, Kanda Surugadai 4-chome
Chiyoda-ku
Tokyo 100 (JP)

Representative :

Patentanwälte
Beetz sen. - Beetz jun.
Timpe - Siegfried - Schmitt-Fumian
Steinsdorfstrasse 10
W - 8000 München 22 (DE)

Respondent :
(Opponent 01)

Robert Bosch GmbH
Postfach 10 60 50
W - 7000 Stuttgart 10 (DE)

Respondent :
(Opponent 02)

Siemens Aktiengesellschaft, Berlin und München
Postfach 22 16 34
W - 8000 München 22 (DE)

Decision under appeal :

Decision of Opposition Division of the European
Patent Office dated 10 June 1991 revoking
European patent No. 0 140 348 pursuant to
Article 102(1) EPC.

Composition of the Board :

Chairman : E. Persson
Members : W.J.L. Wheeler
J.A.H. van Voorthuizen

Summary of Facts and Submissions

- I. The Appellant contests the decision of the Opposition Division revoking European patent No. 0 140 348 on the ground that the independent Claims 1 and 6 did not involve an inventive step.
- II. Claim 1, as amended during the proceedings before the Opposition Division, is worded as follows:

"A method for generating a pulse width modulation (PWM) signal (E_u) to be used for operating a pulse width modulation (PWM) inverter comprising the steps of:

(I) generating interrupt signals (IRQ_1, IRQ_2) periodically after selected periodical time intervals (τ_C), determining sampling time points (A, C);

(II) generating a rectangular signal (E_s) which assumes alternately high and low levels after each time interval (τ_C);

(III) generating a modulating wave (U) whose level varies in the form of a sinusoidal waveform of a command frequency (f_R) and an amplitude (E_1) determined by a given command amplitude ratio (K_H) to thereby determine the levels of the modulating wave (U) at the sampling time points (A, C), and sampling the modulating wave (U) after every time interval (τ_C);

(IV) generating a virtual triangular wave (X) which has positive and negative peaks of a predetermined amplitude (H) corresponding in time to the sampling time points (A, C) and alternating at the sampling points (A, C)

and

(V) calculating time intervals of the pulse width modulation signal (Eu) based on the modulating wave (U) and the triangular wave (X)

characterized by the following steps:

(VI) calculating a first time interval (τ_-) between a first sampling time point (A) and a first point (B) of the virtual triangular wave (X) and a second time interval (τ_+) between a second sampling time point (C) and a second point (D) of said virtual triangular wave (X), wherein said first and second sampling time points (A) and (C) are corresponding to successive peaks of one and the opposite polarity of said virtual triangular wave, respectively, said first point (B) is positioned on each segment of said virtual triangular wave extending between its peak corresponding to said first sampling time point (A) and its succeeding peak of the opposite polarity and at the same level as that of said modulating waveform at said first sampling time point (A), and said second point (D) is positioned on each segment of said virtual triangular wave extending between its peak corresponding to said second sampling time point (C) and its succeeding peak of the opposite polarity and at the same level as that of said modulating waveform at said second sampling time point (C);

(VII) generating a pulse width reference signal (Tu) based on said first and second time intervals (τ_- , τ_+), said pulse width reference signal being indicative of time points which correspond to time lapses of said first and second time intervals (τ_- , τ_+) from said first and second sampling time points (A, C), respectively,

and

(VIII) generating the PWM signal (Eu) on the basis of said time points indicated by said pulse width reference signal (Tu) such that the level of said PWM signal is changed at each of said time points to a value corresponding to the level of said rectangular signal (Es) taken at that time point and held at said value until the next succeeding time point,

wherein said pulse width reference signal (Tu) and said PWM signal (Eu) are generated with a delay almost equal to the period (τ_C) of the interrupt signal (at IRQ₂), while the first time interval (τ_-) is calculated during a first interrupt period starting at the former interrupt signal (IRQ₁).

Claim 6, as amended during the proceedings before the Opposition Division, is worded as follows:

"A control apparatus for generating a pulse width modulation (PWM) signal (Eu) to be used for operating a pulse width modulation (PWM) inverter, comprising

means (13, 14) for generating interrupt signals (IRQ₁, IRQ₂) periodically after selected periodical time intervals (τ_C), determining sampling time points (A, C);

means (13, 611) for generating a rectangular signal (Es) which assumes alternately high and low levels after each time interval (τ_C);

means (13, 613, 615, 619) for generating a modulating wave (U) whose level varies in the form of a sinusoidal waveform of a command frequency (f_R) and an amplitude (E1) determined by a given command amplitude ratio (K_H) to thereby determine the levels of the modulating wave (U) at

the sampling time points (A, C), and sampling the modulating wave (U) after every time interval (τ_C);

a microcomputer (13) for generating a virtual triangular wave (X) which has positive and negative peaks of a predetermined amplitude (H) corresponding in time to the sampling time points (A, C) and alternating at the sampling points (A, C)

and

means (13) for calculating time intervals of the pulse width modulation signal (E_u) based on the modulating wave (U) and the triangular wave (X),

characterized in that

said microcomputer (13) calculates a first time interval (τ_-) between a first sampling time point (A) and a first point (B) of the virtual triangular wave (X) and a second time interval (τ_+) between a second sampling time point (C) and a second point (D) of said virtual triangular wave (X), wherein said first and second sampling time points (A) and (C) are corresponding to successive peaks of one and the opposite polarity of said virtual triangular wave, respectively, said first point (B) is positioned on each segment of said virtual triangular wave extending between its peak corresponding to said first sampling time point (A) and its succeeding peak of the opposite polarity and at the same level as that of said modulating waveform at said first sampling time point (A), and said second point (D) is positioned on each segment of said virtual triangular wave extending between its peak corresponding to said second sampling time point (C) and its succeeding peak of the opposite polarity and at the same level as

that of said modulating waveform at said second sampling time point (C);

a timer (15) is provided for generating a pulse width reference signal (T_u) based on said first and second time intervals (τ_- , τ_+), said pulse width reference signal being indicative of time points which correspond to time lapses of said first and second time intervals (τ_- , τ_+) from said first and second sampling time points (A, C), respectively; and

means (13-16) are provided for generating the PWM signal (E_u) on the basis of said time points indicated by said pulse width reference signal (T_u) such that the level of said PWM signal is changed at each of said time points to a value corresponding to the level of said rectangular signal (E_s) taken at that time point and held at said value until the next succeeding time point,

wherein said pulse width reference signal (T_u) and said PWM signal (E_u) are generated with a delay almost equal to the period (τ_c) of the interrupt signal (at IRQ_2), while the first time interval (τ_-) is calculated during a first interrupt period starting at the former interrupt signal (IRQ_1).

Claims 2 to 5 and 7 to 10 are dependent on Claims 1 and 6 respectively.

III. The following prior art documents were considered in the proceedings before the Opposition Division:

E1: S.R. Bowes and M.J. Mount: "Microprocessor control of PWM inverters", IEE Proceedings, Vol. 128, Part B, No. 6, November 1981, pages 293 to 305;

E2: M.G. Jayne, A.B. Williams and P.D. Davies: "A microprocessor-based control strategy for PWM inverters", Preprints of the Third IFAC Symposium, Lausanne, 12-14 September 1983, pages 453 to 459;

E3: B.K. Bose and H.A. Sutherland: "A High-Performance Pulsewidth Modulator for an Inverter-Fed Drive System Using a Microcomputer", IEEE Transactions on Industry Applications, Vol. IA-19, No. 2, March/April 1983, pages 235 to 243.

IV. The gist of the Opposition Division's reasoning was that a method and apparatus according to the prior art parts of Claims 1 and 6 was known from E2, in which the width of the PWM pulses was calculated using the same principle as was used in the present invention, except that the interrupts and calculations were performed only once per period of the triangular wave. It was obvious to increase the accuracy by doubling the frequency of the interrupts and calculations, in accordance with the present claims.

V. With the Statement of Grounds of Appeal the Appellant filed two sets of claims (main request and subsidiary request). The set relating to the main request consists of Claims 1 to 10 in the form they took in the oral proceedings before the Opposition Division.

VI. In reply to the statement of grounds of appeal, Opponent 2 (Siemens) referred to an additional prior art document:

E4: K. Heintze, H. Tappeiner and M. Weibelzahl:
"Pulswechselrichter zur Drehzahlsteuerung von Asynchronmaschinen", Siemens-Zeitschrift Vol. 45 (1971), No. 3, pages 154 to 161.

VII. Oral proceedings were held before the Board on 20 October 1992.

VIII. The Appellant argued in effect that documents E1, E2 and E3 all related to systems in which the triangular wave was synchronised with the sinusoidal modulation wave, the frequency ratio between the carrier and modulation waves being necessarily an integer, producing stepwise changes in the inverter output frequency at the ends of half periods of the modulation wave. The system according to the patent in suit involved more than just doubling the frequency of the interrupts and calculations: as a result of the steps VI to VIII of Claim 1, all frequency ratios were possible and the PWM output signal was adjustable after each time interval (τ_C), resulting in a quicker and smoother response to changes in the command frequency. The pulse width reference signal (T_u) used in the present invention was not known from any of the cited documents.

IX. The Respondents argued that the method and apparatus of Claims 1 and 6 of the patent in suit was equivalent to the prior art known from E2. In both cases the time lapse between sampling the amplitude of the sine wave at a peak of the triangular wave and the subsequent intersection of the triangular wave with the sampled amplitude of the sine wave was calculated and used to determine the width of a corresponding pulse in the PWM output signal. Given the same modulation and carrier waveforms, both systems would produce identical PWM output signals. The use of the pulse width reference signal (T_u) was obvious because the triangular wave was virtual. E4 disclosed the use of a constant frequency free running triangular carrier wave in the low frequency modulation region in combination with a synchronised triangular carrier wave in the high frequency modulation region where an asynchronous carrier would produce undesirable disturbances in the PWM output signal.

It was obvious that in a digitised asynchronous system the PWM output signal could be adjusted after each sample time point.

- X. The Appellant's main request is that the decision of the Opposition Division be set aside and that the patent be maintained in amended form on the basis of:

Claims 1 to 10 (main request) as filed with the statement of grounds of appeal on 21 October 1991;

Description: columns 1 and 2 as filed on 29 April 1991 with replacement of lines 41 to 45 of column 1 by the text submitted at the oral proceedings on 20 October 1992 and replacement of "steps C and D" in line 49 of column 1 by "steps VI to VIII", and columns 3 to 12 of description as printed in EP-B1-0 140 348 with replacement of "much simplified" in column 12, lines 42 and 43 by "simple";

Drawings: Figure 2 as filed on 29 April 1991 and Figures 1, 3, 4, 5, 6A and 6B as printed in EP-B1-0 140 348.

- XI. The Respondents request dismissal of the appeal.

Reasons for the Decision

1. The appeal is admissible.
2. The main question to be decided by the Board is whether the method and apparatus according to Claims 1 and 6 (see paragraph II above) involve an inventive step.
 - 2.1 Each of documents E1, E2 and E3 discloses a method and apparatus in accordance with the preambles of Claims 1 and

6 of the patent in suit. The Board notes that step (II) of Claim 1 is not explicitly mentioned in E1, E2 or E3, but it is considered to be implicit to a person skilled in the art.

- 2.2 As the Respondents have pointed out, it was already known from E4 to use an asynchronous triangular carrier wave in the low frequency modulation region, and it was already known to use asymmetrical sampling (E1 and E2) in a way which, given the same modulation and carrier waveforms, would produce PWM output signals identical with those produced by the present invention.
- 2.3 However, the PWM output signals are identical only when the modulation frequency and the modulation index are held constant. They are not identical when the command frequency (f_R) or the command amplitude ratio (K_H) is being changed, for, as pointed out by the Appellant, in E1 and E2 the PWM output signals are updated in response to changes in the command signals only at the end of a half period of the modulation wave whereas in the present invention they are updated after each time interval (τ_C), resulting in a quicker and smoother response to changes in the command signals.
- 2.4 The quicker and smoother response to changes in the command signals provided by the present invention is obtained by carrying out all the steps defined in the characterising part of Claim 1 of the patent in suit. These steps do not amount to a mere doubling of the frequency of the interrupts in Figure 1 of E2 as was assumed by the Opposition Division (see the last two paragraphs on page 6 of the decision under appeal). In particular, the generation of the pulse width reference

signal (Tu) as specified in step (VII) and the "wherein" clause at the end of Claim 1 and the generation of the PWM output signal (Eu) on the basis of the time points indicated by the pulse width reference signal (Tu) as specified in step (VIII) of Claim 1 make it possible to adjust each flank of the PWM output signal with a delay equal to the period of the interrupt signals without having to wait till the end of a half cycle of the modulation wave to update a table (as is done in E1 and E2).

- 2.5 There is not the slightest hint in any of the cited prior art documents of a signal comparable with the pulse width reference signal (Tu) used in the present invention. In view of the advantage of quicker and smoother response provided by the steps (VII) and (VIII) in combination with step (VI) and the conditions specified in the "wherein" clause at the end of Claim 1, they should not be lightly dismissed as mere "workshop equivalents" to the steps used in the prior art, as argued by the Respondents, let alone ignored entirely, as in the decision under appeal.
3. The Board therefore agrees with the Appellant that the method of Claim 1 involves an inventive step within the meaning of Article 56 EPC. The apparatus of independent Claim 6, which closely corresponds to Claim 1, involves an inventive step for similar reasons. Claims 2 to 5 and Claims 7 to 10 are properly dependent on Claims 1 and 6 respectively, so that their subject-matter also involves an inventive step and ground (a) in Article 100 EPC does not prejudice maintenance of the patent in suit on the basis of Claims 1 to 10 (main request).
4. In the opinion of the Board, the amended form of the patent (see paragraph X above) complies with

Article 123(2) and (3) EPC. The Respondents have not contended otherwise.

5. In the result, the Board is of the opinion that the patent may be maintained in the amended form in accordance with the Appellant's main request. The subsidiary request need not be considered.

Order

For these reasons, it is decided that:

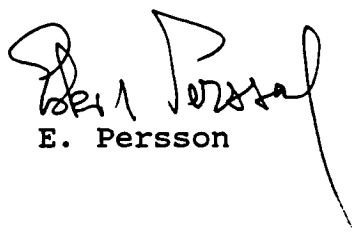
1. The decision under appeal is set aside.
2. The case is remitted to the first instance to maintain the patent in amended form in accordance with the Appellant's main request (see paragraph X above).

The Registrar:



M. Kiehl

The Chairman:



E. Persson

