PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| (51) International Patent Classification 6 : H02J 3/18, G05F 1/70 | A1 | (11) International Publication Number: WO 95/05697 <br> (43) International Publication Date: 23 February 1995 (23.02.95) |
|---|---|---|

(21) International Application Number: PCT/SE94/00341

(22) International Filing Date: 15 April 1994 (15.04.94)

(30) Priority Data:
9302632-6 13 August 1993 (13.08.93) SE

(71)(72) Applicant and Inventor: NYGREN, Peter [SE/ES]; Calle Andorra 3, 3C, E-28043 Madrid (ES).

(74) Agent: NYGREN, Börje; Doktor Allards gata 51, S-413 24 Göteborg (SE).

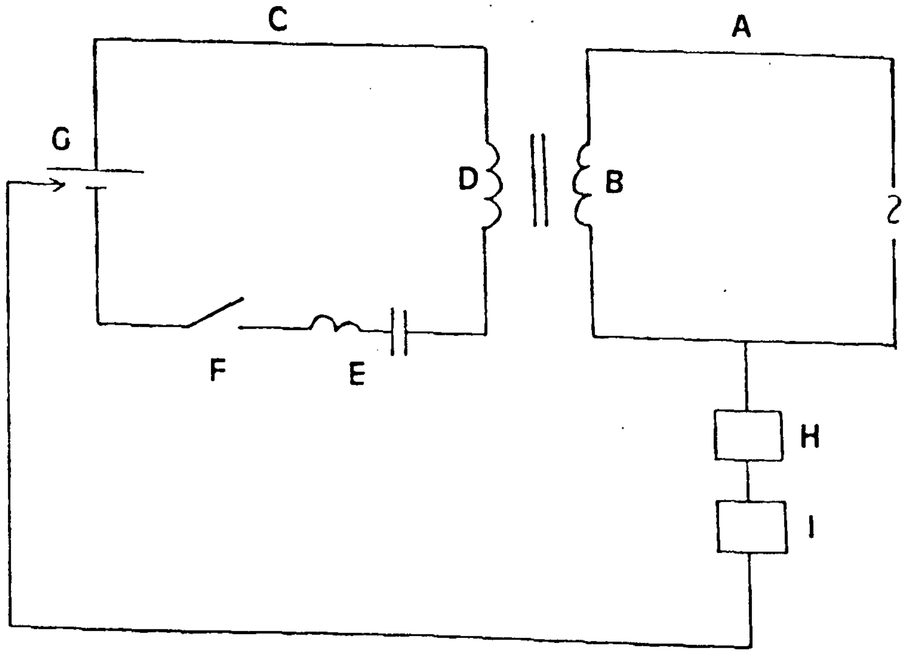
(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, US, VN.

**Published**
*With international search report.*
*With amended claims.*
*In English translation (filed in Swedish).*

(54) Title: DEVICE FOR COMPENSATION OF REACTIVE POWER IN ELECTRICAL SYSTEMS

(57) Abstract

The invention relates to a device for compensation of reactive (inductive) power in a.c. circuits. The inductive power, which is caused by autoinduction = an inertia when the electrons are accelerated, is a problem which limits the useful power that can be transmitted in a.c. networks. Normally the problem is solved by compensation with capacitors or idling rotating machines. The invention solves the problem by connecting a transformer to the primary circuit. The secondary winding of the transformer is fed with a d.c. voltage during the first half of every half cycle of the primary current. A resonance circuit controls the rise of the d.c. current which induces a magnetic energy in the primary circuit which compensates the autoinductance. The device is regulated automatically and infinitely variably by a regulator which is connected to a power factor (cos fi) meter. The interruption of the secondary circuit can be made by a mechanical breaker, by thyristors or by a static frequency converter. In an alternative design the secondary circuit consists of an extra winding in a normal power transformer.



*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | |
|---|---|---|---|---|---|
| AT | Austria | GB | United Kingdom | MR | Mauritania |
| AU | Australia | GE | Georgia | MW | Malawi |
| BB | Barbados | GN | Guinea | NE | Niger |
| BE | Belgium | GR | Greece | NL | Netherlands |
| BF | Burkina Faso | HU | Hungary | NO | Norway |
| BG | Bulgaria | IE | Ireland | NZ | New Zealand |
| BJ | Benin | IT | Italy | PL | Poland |
| BR | Brazil | JP | Japan | PT | Portugal |
| BY | Belarus | KE | Kenya | RO | Romania |
| CA | Canada | KG | Kyrgystan | RU | Russian Federation |
| CF | Central African Republic | KP | Democratic People's Republic of Korea | SD | Sudan |
| CG | Congo | | | SE | Sweden |
| CH | Switzerland | KR | Republic of Korea | SI | Slovenia |
| CI | Côte d'Ivoire | KZ | Kazakhstan | SK | Slovakia |
| CM | Cameroon | LI | Liechtenstein | SN | Senegal |
| CN | China | LK | Sri Lanka | TD | Chad |
| CS | Czechoslovakia | LU | Luxembourg | TG | Togo |
| CZ | Czech Republic | LV | Latvia | TJ | Tajikistan |
| DE | Germany | MC | Monaco | TT | Trinidad and Tobago |
| DK | Denmark | MD | Republic of Moldova | UA | Ukraine |
| ES | Spain | MG | Madagascar | US | United States of America |
| FI | Finland | ML | Mali | UZ | Uzbekistan |
| FR | France | MN | Mongolia | VN | Viet Nam |
| GA | Gabon | | | | |

1. Denomination: Device for compensation of reactive power in electrical systems.

2. The invention relates to a device according to the precharacterizing part of claim 1 and consists of an apparatus which is connected to an electrical system and which permits a simple and infinitely variable compensation of reactive power.

3. It is well known that reactive power is a problem which limits the transmission capacity in electrical a.c. systems and also creates harmonics.
Normally the reactive power is inductive and caused by autoinduction and induction in conductors and coils in for example motors and transformers.

Today three methods are used to compensate the reactive power:

I. Statically connected capacitor banks.
Advantages: Low costs and low losses.
Disadvantages: No possibility of control, dangerous (risk for discharge)

II. Thyristor controlled capacitor banks.
Advantages: As above + possibility of control
Disadvantages: Expensive and complicated

III. Idling over/under magnetized d.c. magnetized synchronous machines.
Advantage: Possibility of simple control
Disadvantages: Expensive, only economically justified for very high voltages, maintenance needed, and cannot be placed anywere.

Thus, there is a need for a simple, cheap and safe apparatus which can be regulated actively and placed anywhere.

THEORY
======
Let us look at how reactive power arises.

Symbols: R resistance, U voltage, I current, L inductance, Ul inductive voltage, Ur resistive voltage, Uc capacitive voltage, C capacitance, Ue total applied voltage, Z impedance, v phase angle, w angular frequency, acc acceleration, e- electron

I. Resistive circuit with voltage stiff source.

See figure 1

Ue = Ueo sin wt

Z = R => Io = Ueo/Z = Ueo/R
Current and voltage are in phase.

II. Inductive circuit.

See figure 2

Current and voltage are phase shifted with the angle v.

$Z = \sqrt{R^2 + w^2L^2}$ $\qquad Io = Ueo/\sqrt{R^2 + w^2L^2}$

III. Capacitive circuit.

See figure 3

Current and voltage are phase shifted with the angle v.

Transmitted power P = UeoIo

In the cases II and III the current amplitude Io decreases which gives a lower transmitted power P if the applied voltage Ueo is kept constant since the total countervoltage increases.

The objective is to compensate L and C so that the angle v is as close to zero as possible so that the current reaches its maximum value.
A normal goal is to achieve a power factor (cos v) of 0,9.

But what does ACTUALLY happen in the circuit? Why does the current decrease, i.e. the flow of the electrons?

To understand in depth what is happening in an electrical circuit, causes and effects in the movements of the electrons must be observed.
Inductance and capacitance are internal inertias in the system which affect the movements of the electrons.

Autoinductance:
===============

See figure 4

The generator pulls up and accelerates electrons from earth. The electron b is accelerated due to the repulsion from a but it is at the same time counteracted by the repulsion from c as well as by its own mass inertia. This chain of inertias is identical to the magnetism which is caused by the autoinducance.

All magnetism is caused by such relative movement and interaction between individual electrons.

In an electrical conductor: An a.c. current causes a variable magnetic field which is identical to the inertias above.

In a coil: The inertias, i.e. the magnetic field, is amplified since the electrons affect each other between the windings.
See figure 5

The inductive inertia (= the inductive voltage) has its maximum value 90 degrees phase shifted in relation to the current (which is parallel to the resistive voltage) since the acceleration reaches its maximum when the velocity reaches its minimum or: Acceleration = dI/dt and the acceleration reaches its maximum when the current curve reaches its maximum inclination which is in the point when the current curve passes zero.

Capacitance:
============

When a capacitor is exposed to an a.c. voltage the following inertia arises:

Step 1:

See figure 6

Step 2: The polarity is reversed

See figure 7

Precisely when the polarity is reversed, the electrons rush in/out from the plates.

Step 3: When the lower of the plates is filled with electrones, the electrostatic repulsion counteracts the current (like a spring that is tightened)

See figure 8

Finally, this repulsion hinders completely the current.

See figure 9.

We can here make two interesting observations:

1. When Uc and I have opposite directions, the capacitor gives an "extra pull" to the current (electrons rush in/out when the polarity is reversed).

Observe that voltage = inertia against the movements of the electrons. Current is, as is well known, defined in opposite direction to the real direction of movement of the electrons.

2. When the current peak is passed, Uc counteracts the current.

We also see that the inertia of the capacitor is in 180 degrees counterphase to the inductance.

See figure 10

The following example shows that the two inertias have opposite directions:

Step 1: At polarity reversion

See figure 11

The remaining excess charge in the capacitor plates gives an "extra pull", *, which counteracts the inductive inertia.

Step 2: Then, when the right plate begins to be filled with electrons, the inertia of the capacitor manifests itself and counteracts the current.

The phenomenon can be compared with building up potential energy in a cause-effect chain which limits the current amplitude. Observe that no energy is consumed!

In an inductive or capacitive system, the total countervoltage increases compared to a purely resistive system.
The extra pull and inertia cause the phase shift.

Compensated system i.e. Uc = Ul

See figure 12

1) Extra pull due to the discharge of the capacitor

2) Counteraction due to the inductive inertia

3) The inductive inertia gives an extra pull, counteracts the negative acceleration

4) The capacitor counteracts the current when it begins to be saturated.

We see that Uc and Ul compensate each other and the resulting voltage becomes purely resistive and in phase with the current.

Uncompensated systems: One of the inertias Uc or Ul prevails and the resulting voltage is phase shifted and the current amplitude decreases.

Conclusion: We see that the reactive power is equal to inertias which affect the electrons when they are accelerated and which limit the flow (= current) and that the inductance and capacitance counteract each other since they have opposite directions (they can therefore cause internal resonances in the system).

The actual location of coils and capacitors is of less importance since it is the resulting resonance mode of the system that is affected.

We can also state that the most common method to compensate an inductive circuit is to, in this way, introduce a capacitance.

Compare with idling overmagnetized synchronous machines which induce an EMF in counterphase to the inductive phase voltage.

4. The purpose of the invention is to compensate an inductive circuit, i.e. to eliminate the inductive inertia and thereby eliminate the reactive power and maximize the current amplitude but without using capacitors or idling rotating machines.

5. The invention constitutes a solution to this problem.

6. The solution is described in the characterizing part of claim 1.

7. One possible design of the invention is shown schematically in attached drawing.

Figure 13 shows the main components of the invention.

Legend of figure 13:

A = primary circuit which shall be compensated

B = coil connected in series with the primary circuit

C = secondary circuit which produces the compensation

D = coil connected in series with the secondary circuit, magnetically connected with coil B

E = resonance circuit

F = rotating breaker

G = d.c. voltage source

H = cos fi meter

I = regulator

The figure is repeated per phase!

8. According to figure 13, a coil is connected in series with the primary circuit. This coil is magnetically connected to another coil (through an iron core) which is connected in series with the secondary circuit (i.e. a transformer).

The secondary circuit is feeded by a d.c. voltage source (this is important - otherwise the reactive power would just be transferred from the primary circuit to the secondary circuit) which is regulated by the cos fi meter and the regulator.

The voltage of the secondary circuit is switched on and off in the right moment by the rotating breaker and the rise of the secondary current is controlled by the resonance circuit.

The interruption can also be made by thyristors or by a static frequency converter with a d.c. link (the frequency converter then replaces both the d.c. voltage source and the rotating breaker).

In another design the secondary circuit consists of an extra winding in a normal power transformer.

9. The device functions in the following way:
We assume that the primary circuit which shall be compensated is inductive. The purpose of the invention is to apply a force on the electrons in opposite direction to the inductive inertia and thereby achieve an extra pull precisely like from a capacitor.

The rotating breaker is designed in such a way that the secondary current is switched on when the primary current passes zero. Thanks to the resonance circuit a suitable rise is obtained for the secondary current which induces a magnetic field in the secondary coil. This magnetic field is transferred to the primary coil and through the chosen current direction in the secondary circuit, an EMF and a current are induced in the primary circuit which give the necessary extra pull on the electrons. This induced current avoids the autoinductance.

Let us consider the following dimensioning example:

We assume that the primary circuit has the following characteristics:

See figure 14

Assume that the phase angle is 52 degrees i.e. the power factor, cos fi, = 0,6

Ue = 5 kV = Ueo sin wt

I = Io sin (wt - fi)

See figure 15

tan fi = X/R => X = R tan fi = 50 * 1,3 = 65 ohm

$I = Ue/Z = Ue/\sqrt{X^2 + R^2} = 61$ A

L = X/w = 0,2 H

$P$ reactive $= XI^2 = 65 * 61^2 = 242$ kVar

Compare with a purely resistive load (without reactance X):

I = Ue/R = 5000/50 = 100 A

Thus, we have "lost" an electron flow of 100 - 61 = 39 A due to the autoinduction i.e. the inertia of the electrons.

The magnetic energy which is "stored" in the primary circuit due to the autoinduction is:

$E = 0,5 * LI^2 = 0,5 * 0,2 * 61^2 = 372$ J

This means that we must add 372 Joule to the primary circuit from the secondary circuit during the first half of the first half cycle of the current through the induced current as extra pull to counteract the autoinduction.
On the other hand, we recover this energy during the second half of the first half cycle thanks to the extra pull of the inductance (see diagram above). The total energy change in the whole system is thus zero. The only extra energy that has to be added is to overcome resistive losses.
If we assume that the secondary circuit has the same autoinductance as the primary circuit, the same current of 61 A must be created in the secondary circuit which gives energy balance.

Losses in the secondary circuit: (Assume the resistance 1 ohm)

$P = RI^2/2 = 1860$ W = 0,8 % of the reactive power.

Thus, we apply 61 A in the secondary circuit during the first half of every half cycle of the current, but this energy is recovered during the second half of every half cycle in the primary circuit.

The resonance circuit creates a suitable rise of the current with a duration of one quarter of a cycle.

Unfortunately, a current I' is also induced in the secondary circuit (in the same direction as I2) due to the superposition principle, which has to be taken into consideration in the dimensioning (especially the losses).

See figure 16

10. Claims

1. Device for infinitely variable and self-regulating compensation of reactive (inductive) power in electrical a.c. circuits

c h a r a c t e r i z e d i n

that the apparatus consists of two circuits, the primary circuit which shall be compensated and a secondary circuit feeded by a d.c. voltage source

that the two circuits are magnetically connected in a transformer

that the d.c. voltage is regulated by a regulator connected to a power factor (cos fi) meter

that the d.c. voltage is switched on during the first half of every half cycle of the primary current

that the rise of the secondary current during the first half of every half cycle is controlled by a resonance circuit

that the secondary circuit induces a current in the primary circuit in the same direction as the primary current.

2. Device according to claim 1 c h a r a c t e r i z e d i n

that the secondary circuit is interrupted by a rotating mechanical breaker which is synchronized with the frequency of the net

3. Device according to claim 1 c h a r a c t e r i z e d i n

that the secondary circuit is interrupted by a static breaker (power electronics, eg a thyristor) which is synchronized with the frequency of the net

4. Device according to claim 1 c h a r a c t e r i z e d i n

that the d.c. voltage source and breaker of the secondary circuit consist of a static frequency converter with a d.c voltage link

5. Device according to claim 1 c h a r a c t e r i z e d i n

that the secondary circuit consists of an extra winding in a normal power transformer

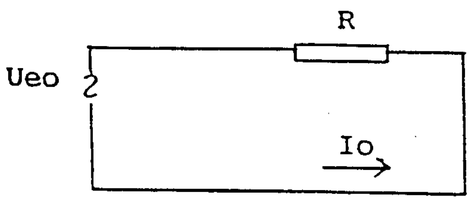
## AMENDED CLAIMS

[received by the International Bureau on 29 December 1994 (29.12.94); new claim 6 added; remaining claims unchanged (1 page)]

6. Device according to claim 1 characterized in

that the compensation is regulated by controlling the length of the dc current pulse (i.e. controlling the moments of switching on and off the dc current) instead of regulating the applied dc voltage.

Figure 1




Phase diagram:

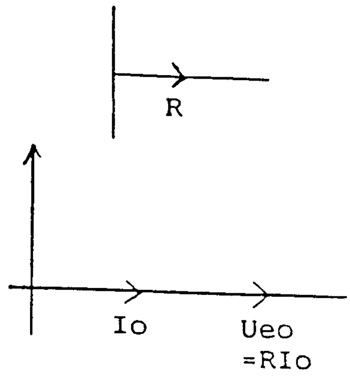
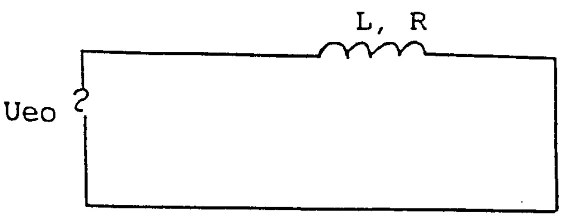
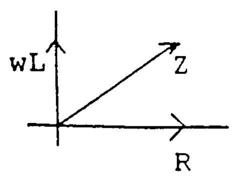



Figure 2



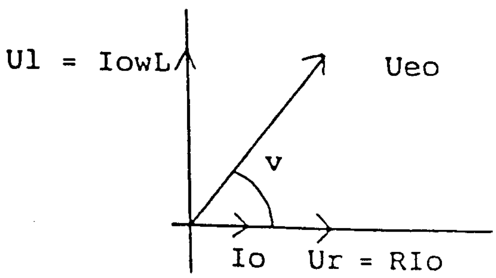
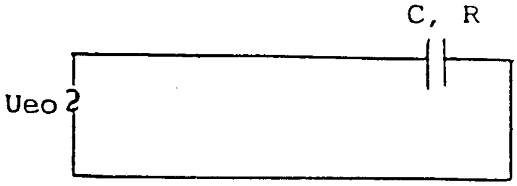
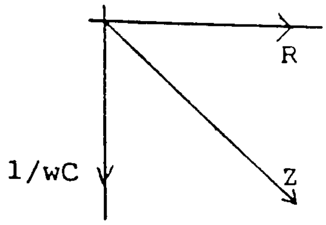



Figure 3




$$Z = \sqrt{R^2 + 1/w^2C^2} \qquad Io = Ueo/Z = Ueo/\sqrt{R^2 + 1/w^2C^2}$$

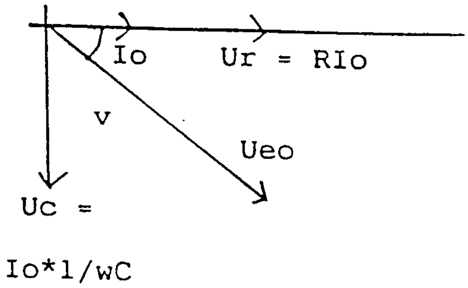



Figure 4

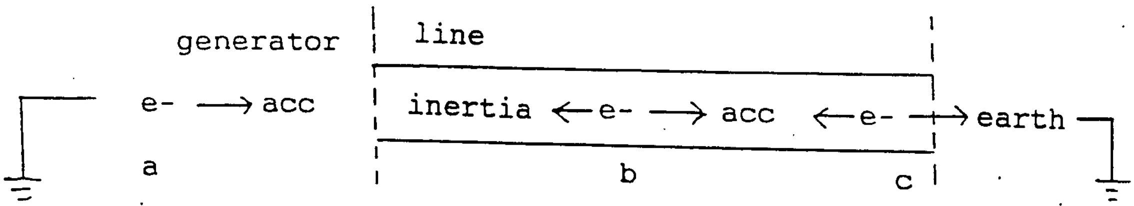



Figure 5

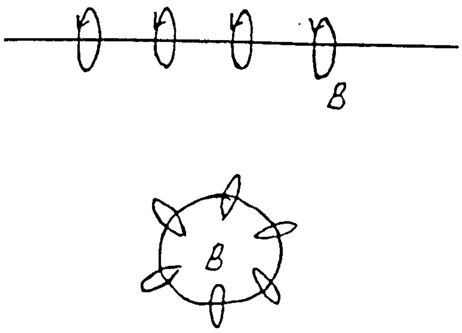


Figure 6

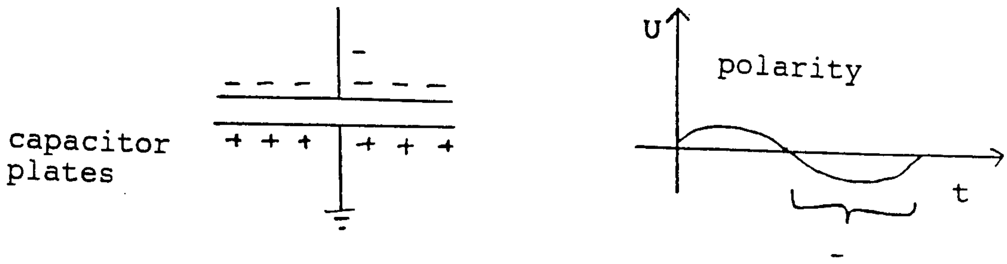



Figure 7

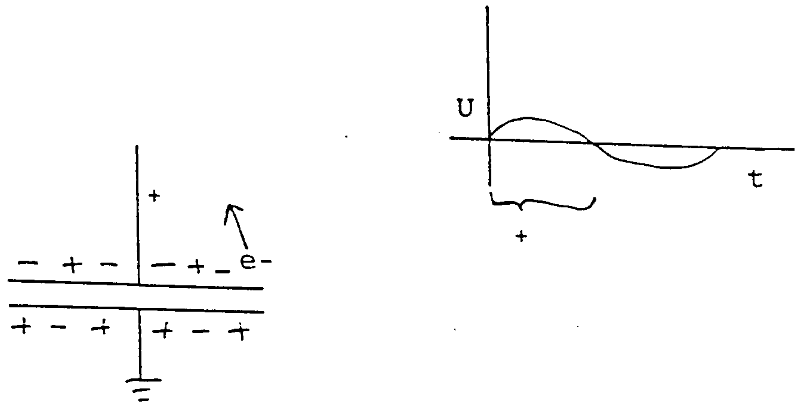



Figure 8

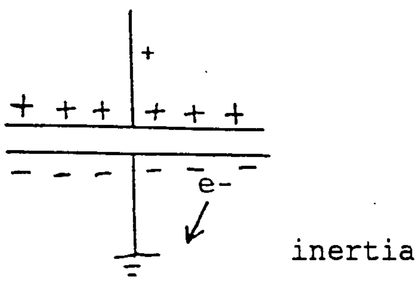
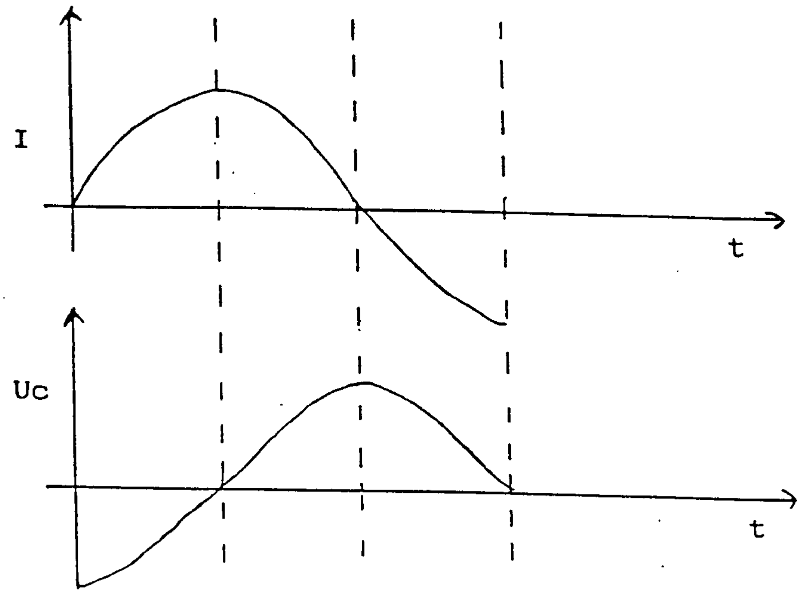
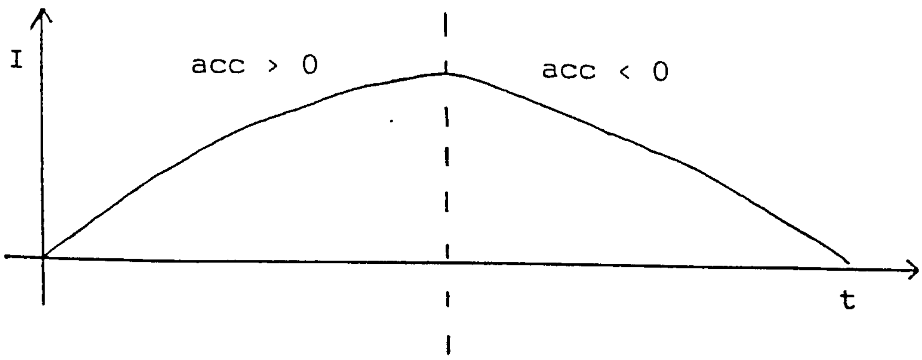


Figure 9




Uc = the inertia of the capacitor

Figure 10




the inductance counteracts ("takes energy from the net")

the inductance helps ("returns energy to the net")

the capacitance helps

the capacitance counteracts

Figure 11

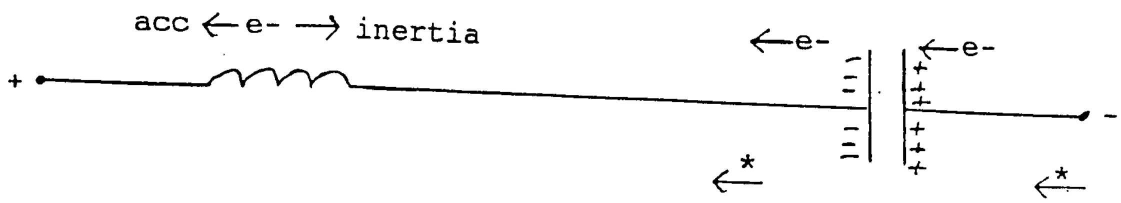



Figure 12

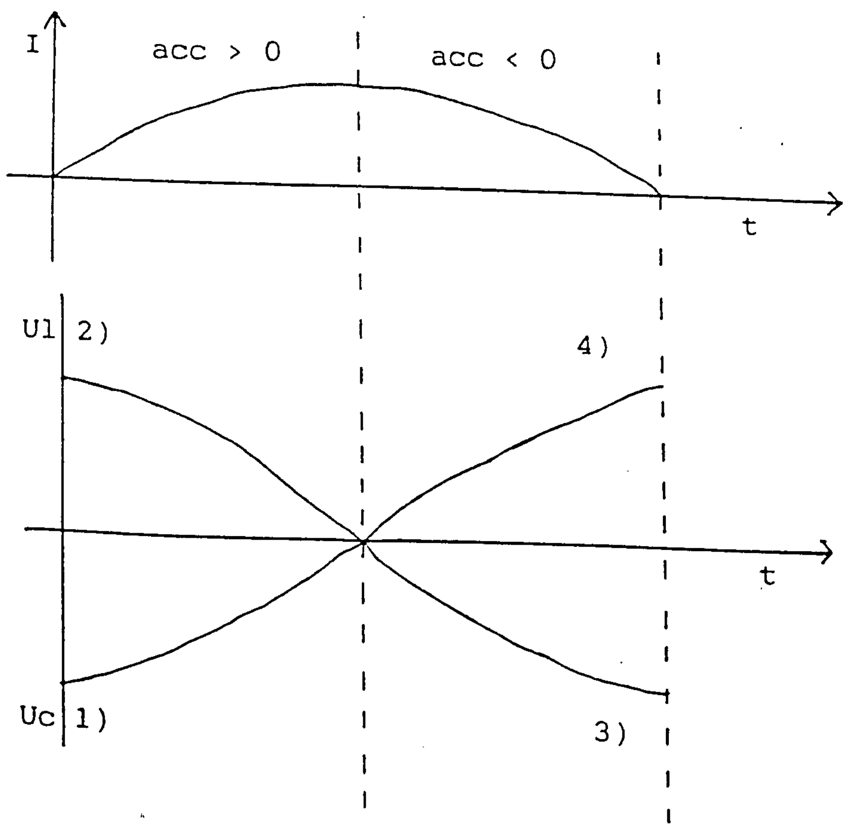


Figure 13

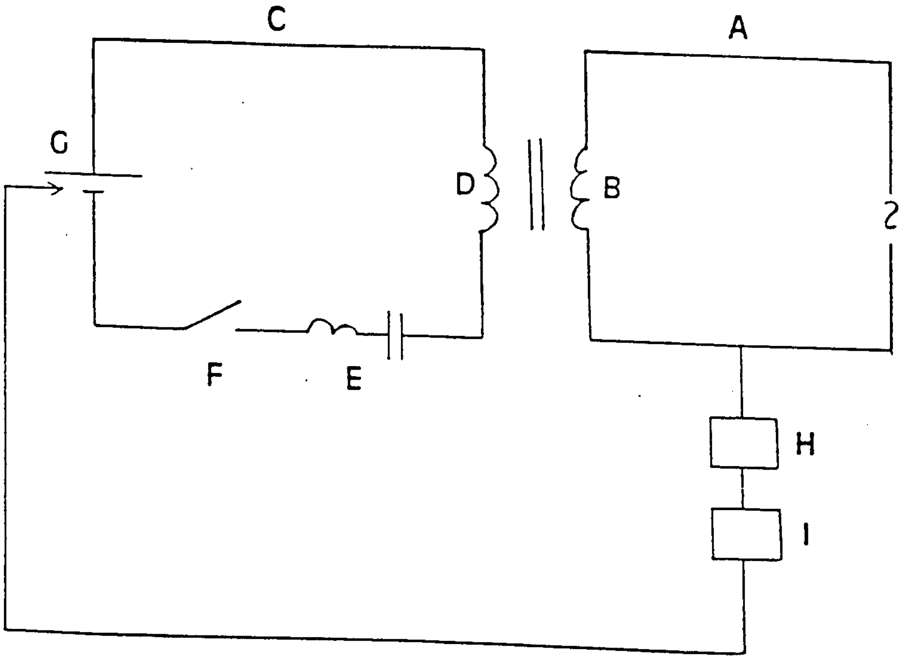


Figure 14

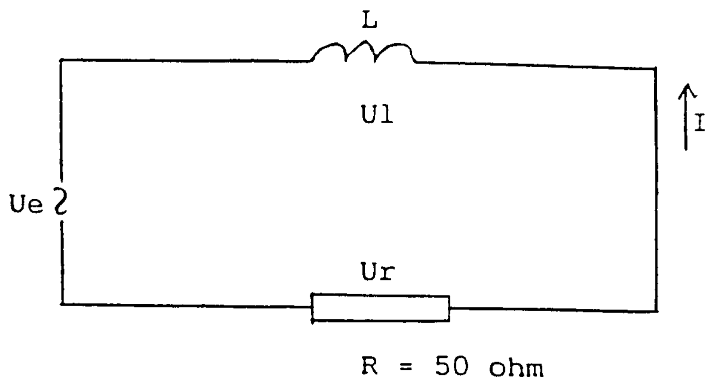



Figure 15

Phase diagram: (X = reactance)

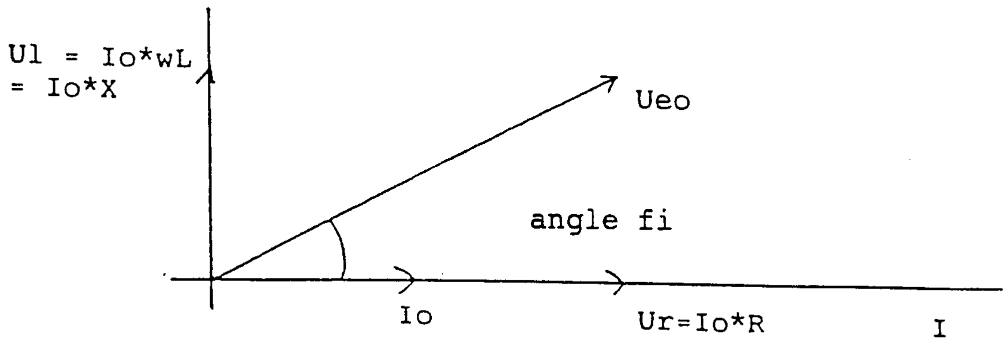
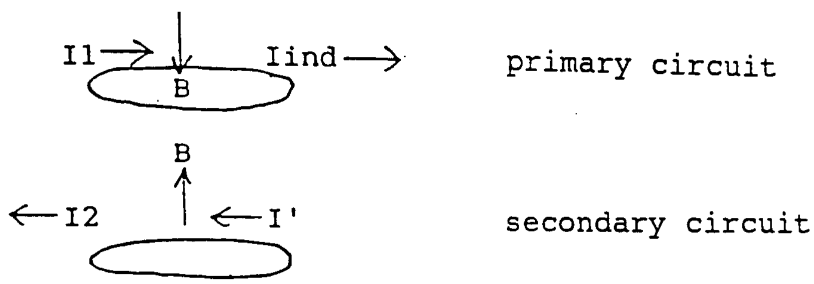



Figure 16



# INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 94/00341

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC6: H02J 3/18, G05F 1/70
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02J, G05F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US, A, 4914375 (T. HATANAKA), 3 April 1990 (03.04.90), column 1, line 60 - column 2, line 45<br>-- | 1 |
| A | EP, A1, 0440988 (ASEA BROWN BOVERI AB), 14 August 1991 (14.08.91), column 1, line 4 - line 22; column 4, line 13 - column 5, line 56<br>-- | 1 |
| A | US, A, 5032738 (JOHN J. VITHAYATHIL), 16 July 1991 (16.07.91), column 3, line 25 - column 4, line 36<br>-- | 1 |

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 17 November 1994 | 23 -11- 1994 |
| Name and mailing address of the ISA/<br>Swedish Patent Office<br>Box 5055, S-102 42 STOCKHOLM<br>Facsimile No. +46 8 666 02 86 | Authorized officer<br><br>Håkan Sandh<br>Telephone No. +46 8 782 25 00 |

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 94/00341

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | DE, A1, 4238892 (MOTTAGHIAN-MILANI, DARIUS-KARIM), 1 April 1993 (01.04.93), column 1, line 65 - column 3, line 30<br>-- | 1 |
| P,A | EP, A2, 0570839 (DELTRONIC IPARI ELEKTRONIKUS KESZÜLEK FEJLESZTÖ ES GYARTO KFT. ET AL.), 24 November 1993 (24.11.93), column 4, line 26 - column 5, line 47<br>--<br>-------- | 1 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

01/10/94

International application No.
PCT/SE 94/00341

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US-A- 4914375 | 03/04/90 | EP-A- 0401442 | 12/12/90 |
| | | JP-A- 1310418 | 14/12/89 |
| EP-A1- 0440988 | 14/08/91 | SE-B,C- 465342 | 26/08/91 |
| | | SE-A- 9000041 | 06/07/91 |
| | | US-A- 5051684 | 24/09/91 |
| US-A- 5032738 | 16/07/91 | AU-A- 7026987 | 14/08/87 |
| | | DE-D,T- 3787335 | 05/01/94 |
| | | EP-A,B- 0258314 | 09/03/88 |
| | | SE-T3- 0258314 | |
| | | WO-A- 8704538 | 30/07/87 |
| DE-A1- 4238892 | 01/04/93 | NONE | |
| EP-A2- 0570839 | 24/11/93 | NONE | |